To shock or not to shock: How big an issue is it? A study of the prevalence of defibrillators and associated incidents inside clinical hyperbaric chambers.

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1. Abstract

Hyperbaric oxygen therapy (HBOT) has been in use for over 150 years and is used to treat a range of clinical conditions including life threatening medical emergencies. It is the practice of providing oxygen and other breathing gases at higher than atmospheric pressure to a patient inside a sealed chamber. External defibrillation is the process of delivering an electrical shock to a patient's bare chest in order to convert a form of cardiac arrest known as ventricular fibrillation to a perfusing heart rhythm. The safety concerns of using a high energy electrical discharge within the confines of a hyperbaric chamber have been highlighted in previous literature as has the more strict safety procedures for hyperbaric oxygen chambers. The confined space nature and higher risk of catastrophic fire occurring inside a hyperbaric chamber have also been studied with electrical safety guidelines seemingly contraindicating the use of a defibrillator inside a chamber. This has caused a paradox as although the energy discharged and electrical energy required exceeds most guidance, literature has stated that defibrillation can be safely delivered within air filled chambers.

The research aimed to identify the incidents of in-chamber cardiac arrest, incidents involving defibrillators and the concerns and procedures that hyperbaric units have and use when dealing with in-chamber cardiac arrest and defibrillation.

51 hyperbaric units across the world responded to invitations to participate. The research took the form of an initial unit questionnaire with a follow up questionnaire sent to units that had experienced in-chamber cardiac arrest.

It was clear that in-chamber cardiac arrest was rare with only 10 cases of in-chamber cardiac arrest identified over a reference period of five years. Five of these arrests occurred in chambers that had the ability to defibrillate and three of these cases did receive in-chamber defibrillation without incident.

Data showed that the majority of units did not elect to carry out in-chamber defibrillation however did have procedures in place to deal with cardiac arrest. Overall patient survival rates for in-chamber cardiac arrest mirrored those of in-hospital cardiac arrest whether defibrillated inside the chamber or outside.

Units that could not defibrillate inside a hyperbaric chamber had greater concerns for fire and unintentional electrical shock than those units that did carry out in-chamber defibrillation. These two concerns where still prominent in both cohorts. Of those units that did permit in-chamber defibrillation, most had two forms of firefighting system inside their chambers. In-chamber cardiac arrest is a rare event and in-chamber defibrillation is even rarer. The small scale of the research did show some common traits and concerns however further research is required on a larger scale and possibly over a longer reference period.

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3. Contents

4. Abbreviations

A Ampere/ Amps
ac Alternating current
AED Automated external defibrillator
ASME American Society of Mechanical Engineers
ata Atmospheres absolute
atm Atmosphere
BHA British Hyperbaric Association
BIBS Built In breathing system
Cage Cerebral arterial gas embolism
CPR Cardio pulmonary resuscitation
dc Direct current
DCS Decompression sickness
EUBS European Undersea and Baromedical Society
EMT Emergency medical technician
HBO Hyperbaric oxygen
HBOT Hyperbaric oxygen therapy
ICU Intensive care unit
J Joules
MIE Minimum ignition energy
mJ Millijoule
MS Multiple sclerosis
NFPA National Fire Protection Association
OEA Oxygen Enriched Atmosphere
PAD Public access defibrillator
ppO_2 Partial pressure of oxygen
psi Pounds per square inch
PVHO Pressure vessel for human occupancy
SAUHMA South African Undersea and Hyperbaric Medicine Association
SCA Sudden Cardiac arrest
SPUMS South Pacific Undersea Medical Society
SurD Surface decompression
UHMS Undersea and Hyperbaric Medical Society
Vac Volts alternating current
Vdc Volts direct current
VF Ventricular fibrillation
VT Ventricular tachycardia
W Watts

5. Introduction

5.1 Hyperbaric oxygen

The modern use of hyperbaric oxygen (HBO) has become more widespread and commonplace world-wide treating both life-threatening acute illnesses, such as gas gangrene and arterial gas embolism, and chronic debilitating conditions such as non-healing wounds and sensorineural hearing loss. Currently the Undersea and Hyperbaric Medical Society (UHMS) identifies some 14 conditions that can be treated with hyperbaric oxygen therapy (table 1.0). This treatment has been in use for over 170 years and its medical uses over the last 50 years has evolved from its use in the treatment of decompression sickness in divers and caisson workers, known as the bends, to those 14 established conditions recognised by the UHMS. Its use in treating decompression sickness is often referred to as recompression and is still one of its most widespread uses. The commercial diving industry has used hyperbaric chambers as part of their standard equipment for many years, pre-dating its use in modern medicine. Indeed many clinical hyperbaric units began by purchasing and using equipment designed for the offshore diving industry and still do to this day.

Clinical indication	Treatment pressure
Air or gas embolism	**2.8-6.0 ata**
Carbon monoxide poisoning	**2.5-3.0 ata**
Clostridial myositis & myonecrosis	**3.0 ata**
Crush injury, compartment syndrome and other acute traumatic ischemias	**2.4-2.5 ata**
Decompression sickness	**2.8-6.0 ata**
Arterial insufficiencies	**2.4-2.5 ata**
Severe anaemia	**2.4-3.0 ata**
Intracranial abscess	**2.4-2.5 ata**
Necrotising soft tissue infections	**2.4-2.5 ata**
Osteomyelitis	**2.4-2.5 ata**
Delayed radiation injury	**2.4 ata**
Compromised grafts and flaps	**2.4-2.5 ata**
Acute thermal burns	**2.4 ata**
Idiopathic sudden sensorineural hearing loss	**2.5 ata**

Table 1.0: The current indications for hyperbaric oxygen therapy (HBOT) as listed by the UHMS and the most common pressures that are used to treat each condition.

This has proven an important issue as the accessibility of hyperbaric chambers to non-physicians using them to treat non-recognised conditions in unregulated or non-clinical environments is becoming more and more common. Even in the UK, the MS society (2008) lists some 50 centres throughout the UK that use hyperbaric chambers that do not require

regulation whereas the British Hyperbaric Association (2016) lists just 17 clinical hyperbaric units treating accepted conditions that are regulated by the Care Quality Commission.

The UHMS, (2016) defines hyperbaric oxygen as *'an intervention in which an individual breathes near 100% oxygen intermittently while inside a hyperbaric chamber that is pressurized to greater than sea level pressure (1 atmosphere absolute, or ata). For clinical purposes, the pressure must equal or exceed 1.4 ata while breathing near 100% oxygen'*.

BSEN 14931 2006: Pressure vessels for human occupancy (PVHO)- Multi-place pressure chambers for hyperbaric therapy- Performance, safety requirements and testing (2006:4) defines a hyperbaric chamber system as *'a pressure chamber and its supporting equipment'.*

The American Society of Mechanical Engineers, ASME, (2012:1) further defines a PVHO as *'a pressure vessel that encloses a human being within its pressure boundary while it is under internal or external pressure that exceeds a 2 psi differential pressure'.* Although these definitions clearly define HBOT and what is a hyperbaric chamber it is important to understand that hyperbaric chambers are generally classified by the number of people that can occupy the vessel. For this purpose the US National Fire Protection Association, NFPA, (2012) has categorised three types of chamber:

Class A: Multi-place for multiple occupancy

Class B: Mono-place for single occupancy

Class C: For animal use only

These chambers do not only differ by the number of occupants but also in their general construction, methods of operation and the gases used to pressurise them. In general, most multi-place chambers are divided into a series of interconnecting sub chambers known as main locks and entry locks or antechambers and main chambers (figure 1.0 and 1.1). These entry locks can be pressurised independently of the main lock for the purpose of allowing personnel to gain access to the main treatment chamber whilst it is under pressure without the need to depressurise it. These chambers are pressurised with medical or diving grade breathing air to pressures up to 6 ata with the patients breathing oxygen through an enclosed built in breathing system that supplies the breathing gas via masks or hoods or directly to patient ventilators. Attending medical personnel will breathe the air within the chamber without the need to use masks or hoods for the majority of the treatment but may use masks towards the end of the treatment to breathe oxygen as a means to accelerate decompression. This is done to prevent decompression sickness, also known as the bends, from occurring in the attending medical personnel who, during their time within a multi-place chamber, will be exposed to the same physiological decompression stresses that compressed air divers experience. Hyperbaric chambers should not be confused with hypobaric chambers or altitude chambers. Although very similar in design and look, hypobaric chambers are used by the military and aerospace industries to simulate high altitude hypoxic environments. This is done by decreasing the pressure inside the chamber to an equivalent altitude. This pressure can range from 0.9 ata to 0.0 ata (vacuum).

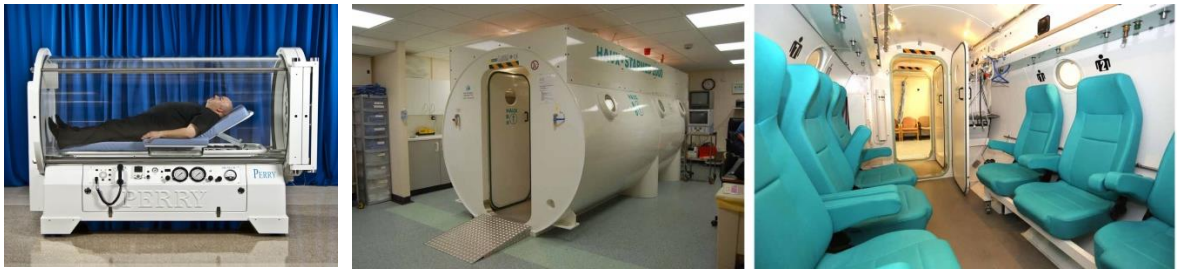

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Figure 1.0: L-R a typical mono-place chamber, external picture of a multi-place chamber, internal picture of a multi-place chamber.

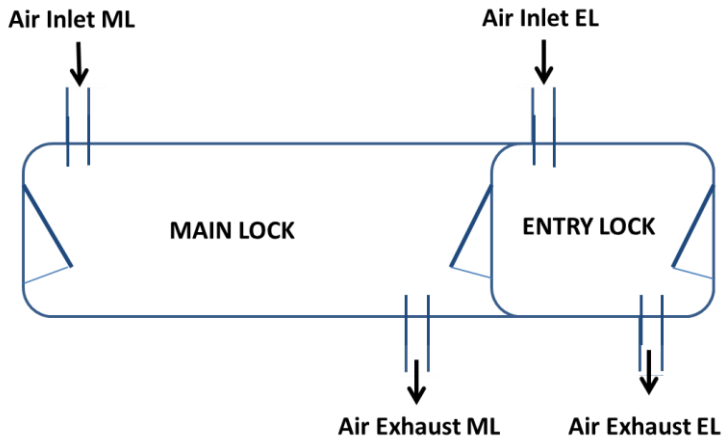

Figure 1.1: Shows a typical multi-place hyperbaric chamber. These chamber sizes range from small cylindrical chambers that can accommodate two people to large square pressure chambers that can accommodate 25 people.

Modern mono-place hyperbaric chambers (figure 1.0) are constructed largely around a single piece of acrylic that houses a removable bed or gurney capped off at both ends with metal stops with one end acting as the door. These chambers are pressurised with oxygen up to a pressure of 3 ata and the occupant simply breathes the gas within the vessel itself without the need for a mask or hood.

These oxygen enriched atmospheres (OEA) within mono-place chambers require very strict safety protocols in place as evidence suggests that fires within these chambers are almost always fatal (Sheffield, 1997).

Even in multi-place chambers that are pressurised with air, additional fire safety precautions are necessary due to the higher than normal partial pressure of oxygen (ppO_2) which in itself can act as an equivalent to an OEA.

5.2 Defibrillation

External cardiac defibrillators are portable medical devices that use a short burst of electrical energy directed at the heart in order to correct certain types of cardiac arrhythmias. Although used to correct or control certain types of non-immediately life threatening cardiac

arrhythmias; their primary use has been in the emergency setting to convert a life-threatening cardiac arrest conditions known as ventricular fibrillation (VF), and ventricular tachycardia (VT), to a perfusing cardiac rhythm. This is achieved by placing large two adhesive electrical pads or paddles onto the patient's bare chest and delivering a relatively large electrical shock, known as a countershock, to the heart that stops this fibrillation and allows the heart to restart itself with a perfusing cardiac rhythm.

The idea of using an electrical shock to correct these lethal cardiac arrhythmias was first demonstrated over 100 years ago; however their real use in converting these arrhythmias in humans did not occur until the 1930's with the modern use of them as an essential part of resuscitation becoming widespread by the 1970's.

These devices are universally regarded throughout the healthcare industry as an essential and irreplaceable part of any professional level resuscitation kit. Their use and availability in relatively recent times has also spread to other industries as part of their first aid provision to be used by laypersons and first aiders in a fully automatic mode; known as an AED (figure 1.2).

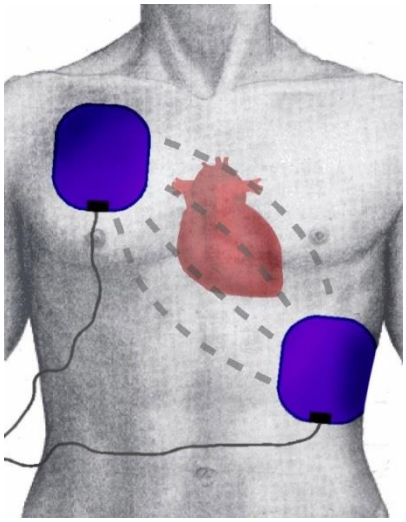

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Fig 1.2: A standard portable automated external defibrillator (AED) (L) and *common placement of electrode pads or paddles(R)*

The amount of energy discharged by defibrillators ranges between 150J and 360J (ILCOR, 2005) up to 35A and 5000 Vdc (Williams et al, 2003). There are two distinct types of defibrillator, monophasic and biphasic defibrillators. Monophasic defibrillators deliver an electrical current in one direction only from one pad or paddle to the other whereas biphasic defibrillators deliver current in one direction then, by reversing the polarity sending the shock back creating a cycle effect (fig 1.3).

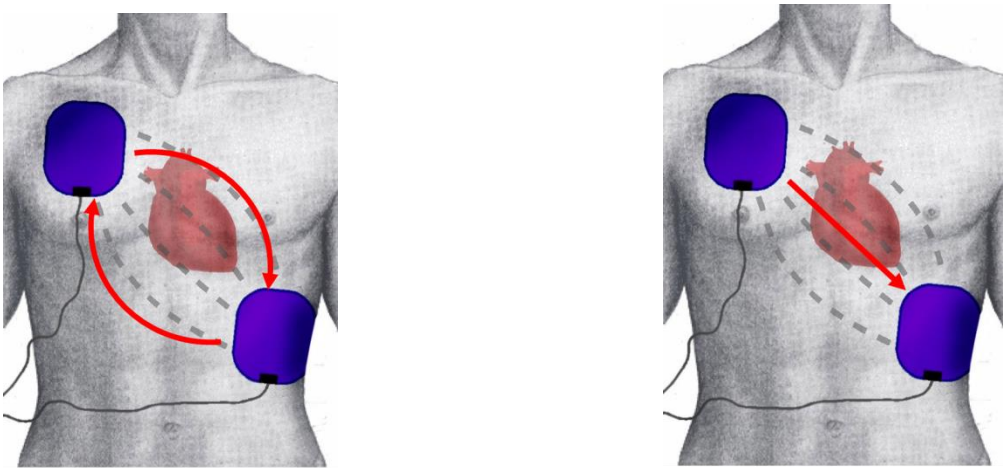

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Fig 1.3: A biphasic defibrillator (L) delivers a 'cycle' of electrical energy by travelling towards the positive pad then reversing and travelling back in the opposite direction. A Monophasic defibrillator by contrast sends the current in a single direction only (R).

Monophasic defibrillators deliver a single shock at a much higher energy level at around 360J at 33A whereas biphasic defibrillators can deliver multiple cycles at lower levels and can adjust the amount of energy they deliver from between 150J to 360J at 14A to 33A (Adgey et al, 2005). The actual shocks last around 10 milliseconds however biphasic defibrillators will deliver several cycles each lasting 10 milliseconds during a single shock sequence (Osswald et al 1994). By and large biphasic defibrillators are the contemporary defibrillator of choice for most clinicians as the evidence suggests that they are more effective than monophasic defibrillators at converting VF and VT rhythms and because they can deliver a lower energy shock are less likely to cause burns or cardiac damage (Wanchun et al, 1999).

A key issue associated with the successful use of defibrillation is time. Larsen et al (1993) shows that for every minute that elapses without effective CPR and defibrillation survival rates drop by between seven and ten percent in cases of witnessed cardiac arrest. Many hospitals try to aim to give an initial shock within three minutes of the cardiac arrest (Gwinnutt et al, 2015).

5.3 Safety

The basic safety requirements around the use of electrical devices within clinical hyperbaric chambers are generally more conservative than is normally required in a standard clinical setting. This is due to two clear issues that when combined are somewhat unique to hyperbaric chambers.

1. The increase in the risk of fire starting and spreading rapidly or being explosive in nature.
2. The pressurised and sealed confined space that does not allow immediate access or egress in the event of an emergency.

The primary hazards associated with electricity are the same as in any other setting; that of fire and electrocution. These hazards are simply exacerbated by the environment within a hyperbaric chamber.

The methods used by many hyperbaric units to control these risks revolve around the removal of high energy electrical equipment and the use of low energy equipment in its place with safety procedures and requirements becoming stricter in oxygen filled mono-place chambers. In the US, portable electrical appliances related to patient care within class A chambers are required to be rated to no more than 120V and 2A with battery operated items limited to 12V and 48W or they must be purged with an inert gas. Within class B chambers all circuits are limited to 28V and 0.5W and can consist of only the intercom system and patient monitoring leads (NFPA, 2014). Any device that is to be used within a chamber must be suitable for use within high pressurised environments with any batteries being sealed to prevent off- gassing and must not be charged whilst inside the chamber (Wischhoeffer in Workman, 1999).

Guidance and recommendations in Europe and elsewhere mirror these recommendations by addressing the themes of lowered electrical energy within multi-place chambers and the prohibition of electrical devices within oxygen filled mono-place chambers whilst ensuring that devices are certified or recommended for use within hyperbaric chambers.

Although delivered over a very short period of time, measured in milliseconds, the amount of electrical energy discharged by a defibrillator is more than enough to cause severe electric shock (Lipman, 2007) or ignite a fire. As an example, the lowest end of this discharge range (150J) is still around 80 times greater than the minimum ignition energy (MIE) requirements for cotton fibres, a common material found in healthcare, which has an MIE of 1950mJ (Babrauskak, 2003). When an OEA is added the MIE requirements drop dramatically. Murphy in Kent (2012) shows that certain flammable substances contained within 100 percent oxygen require around one percent of the spark energy that is needed to cause ignition in air.

With the addition of pressure, the MIE for certain flammables in air can reduce by a factor of five without the need for additional oxygen (Murphy in Kent, 2012).

This creates somewhat of a dilemma for clinicians and safety officers as these guidelines and requirements would mean that the use of standard defibrillators of any kind cannot be used within a hyperbaric chamber as the amount of current delivered is way above the limits imposed by these requirements.

These risks to general safety and the strict limits on the use of such electrical devices may be viewed as being in conflict with the needs of a patient who requires defibrillation within a few minutes in the event of a cardiac arrest; whether they are inside a hyperbaric chamber or not. This is very clear, as evidence from Cappuci et al (2002) shows a positive correlation between early defibrillation and patient survival in cases of sudden cardiac arrest.

Patients treated within clinical hyperbaric chambers are unwell to various degrees by default. This can range from a generally young and healthy individual with minor symptoms of decompression sickness to very unstable patients of various ages suffering from a range of complex conditions that require intensive care or are at risk of becoming acutely unwell. In many healthcare settings, if a patient becomes acutely unwell and requires resuscitation, clinics

and hospitals will often have specific cardiac arrest response teams or 'crash teams' who are responsible for rapidly responding to and providing resuscitation and advanced life support to patients in cardiac arrest within their hospital or clinic. These teams, on average, consist of five people (Lauridsen et al, 2015) and will often comprise a mix of medical staff that includes physicians and nursing staff, all trained to the highest levels of resuscitation practice. In the event of a cardiac arrest within a chamber these people will be required to wait until the chamber has been decompressed and the patient has been removed or members of the team would need to be placed into the chamber via an entry lock prior to beginning or continuing with any resuscitation efforts. The latter option may not be viable for several reasons:

1. The patient is in a mono-place chamber that is not designed for attending medical personnel to be inside with them.
2. The team may not have been trained or may not be medically fit to work in compressed air chambers.
3. The size of the chamber may not be big enough to accommodate that many extra people.
4. It may take too long to place all the members of the team into the chamber and pressurise them so that they can deal with the patient.

It is clear that in the event of a cardiac arrest inside a mono-place chamber that the chamber would need to be decompressed prior to carrying out any form or resuscitation. However, whether or not to decompress a multi-place chamber rapidly to allow defibrillation and resuscitation to be carried out will depend on certain variables:

1. The decompression stress upon any attending medical personnel may require them to undergo staged decompression that would significantly delay any decompression, in certain circumstances this could be over an hours delay.
2. The clinical condition of the patient may be such that being under pressure is deemed a lifesaving necessity at the time; as could be the case with severe cerebral arterial gas embolism (CAGE).
3. The skill and knowledge of attending personnel inside the chamber and the equipment they have to deal with cardiac arrest.

This third variable is of utmost importance if in chamber defibrillation is to be considered along with the hyperbaric unit's general risk appetite.

An individual hyperbaric unit's risk appetite will vary and will often take into consideration legal requirements, policies, current best practice and risk assessments as well as the clinical lead's personal view on patient risk benefit versus the risks to staff and others. Another key factor that is needed is the individual unit's ability to deal with an untoward event such as a fire inside the chamber or unintended electric shock to staff. Multi-place chambers will often have a comprehensive firefighting sprinkler type system installed by the manufacturer or specialist engineers that can be activated from outside the hyperbaric chamber by the operator or the inside attending personnel. Specific guidance on the capabilities of these firefighting systems has been developed in both the US and EU. In the EU, BS EN 16081:2011 Hyperbaric chambers. Specific requirements for fire extinguishing systems. Performance, installation and testing (2011) gives specific guidance aimed at manufacturers and end users for the firefighting

requirements inside multi-place air filled chambers. In the US, NFPA 99: Healthcare facilities code, chapter 19, hyperbaric chambers (2015) gives similar guidance. Mono-place chambers do not have firefighting systems due to the fact that they have limited internal space and that these systems would probably not be effective in the event of a fire or explosion inside an oxygen filled chamber.

The issue of whether or not to defibrillate inside a hyperbaric chamber is a complex one that must balance the needs of the patient against the safety of the attendants and others.

6. Aim of the project

The complexities of working within the confined space under higher than atmospheric pressures clearly compound many standard risks that are associated with the use of defibrillators. The literature review (section 7) shows that safety issues around defibrillators and hyperbaric chambers overlap but there is a clear gap in the actual evidence to quantify or qualify the level of risk on the specifics of defibrillation within a hyperbaric chamber. The literature does not identify the extent of use of defibrillators and associated incidents or identify common practice within hyperbaric units. This may make difficult for individual units to carry out their own risk assessments on the issue and make decisions and develop procedures for in-chamber cardiac arrest that balance patient need with staff safety. If individual hyperbaric units have better data on both the perceived and actual risks associated with in-chamber defibrillation it is hoped that the unit specific risk assessment and decision making processes can be made easier. Therefore a simple research aim has been identified.

The aim of this research:

Improve the principles of safe use for defibrillators in hyperbaric chambers.

6.1 Objectives

To achieve this aim, the key question of; 'How safe is it to use defibrillators inside hyperbaric chambers?' needs to be addressed. This will ultimately be answered by reviewing the variables in three key areas:

A. Prevalence of defibrillators within hyperbaric chambers
B. Safety concerns and controls commonly in use
C. Prevalence of incidents involving defibrillators within hyperbaric chambers

These three areas can be categorised around two themes; that of prevalence vs incidents and key control strategies currently in use. From this first theme, prevalence and incidents, four objectives have been identified.

The first objective:

Quantify the prevalence of defibrillators available to use inside a hyperbaric chamber during a treatment.

This objective is clearly necessary to identify the scale of one of the most important variables that of identifying how many units do have the hardware capability to defibrillate inside a hyperbaric chamber.

The second objective:

Identify how often does cardiac arrest occur and how often defibrillators are used within hyperbaric chambers.

This objective will be necessary to identify what the chances of actually carrying out defibrillation inside a chamber are and the ratio of defibrillator capable units to actual cases of cardiac arrest and defibrillation.

The third objective:

Identify how many safety related incidents involving the use of a defibrillator occur during hyperbaric treatments.

This is a key research question and a fundamental quantitative number will need to be established so that the scale of the issue can be identified and contextualised.

The fourth objective:

Compare and contrast the effectiveness of in chamber versus outside the chamber defibrillation and resuscitation.

This objective will enable a quantifiable evaluation of the risks vs benefits of both strategies from the perspective of patient outcome. This has required the research to give a basic operational definition of successful resuscitation:

Definition of a successfully resuscitated person: *One that left the unit with spontaneous circulation or regained spontaneous circulation later.*

This important variable may assist hyperbaric units when balancing the risks versus the benefits of in chamber defibrillation and developing effective hierarchies of control and risk management strategies.

The second theme of key control strategies also has four clear objectives

The fifth objective:

Identify the type of units that are prepared to defibrillate inside their chambers.

This will identify the general setting of the various hyperbaric units and the basic risk appetite for defibrillation inside chambers.

The sixth objective:

Identify the types of chambers and safety related equipment used in conjunction with defibrillators.

This objective will aim to identify the 'hardware' that units use to offset any risks associated with defibrillation.

The seventh objective:

Identify the key concerns that units have with the concept of in-chamber defibrillation.

By understanding these concerns that individual units have, a better understanding of the perceived risk benefit balance can be gained.

The eighth objective:

Identify the key common safety strategies used during in-chamber cardiac arrest and defibrillation.

This objective will aim to identify the 'software' that units use by reviewing the tactics and procedures commonly used.

With the two themes having had suitable objectives assigned to them a final objective is needed so that these themes and objectives can be linked and a true relationship to the final aim established.

The ninth objective:

Analyse the quantifiable data so that relationships between variables can be identified.

This will identify trends and patterns which will allow sound conclusions and recommendations to be defined.

7. Literature review

7.1 History of defibrillation

The deliberate use of electricity as a clinical intervention for people in cardiac arrest can be traced back to the 1930's when Hooker et al (1933) published their data on the effects of alternating current on the heart in the American Journal of Physiology. Hooker et al cite the works of Prevost and Battelli (1899) that showed that a large countershock could be used to stop ventricular fibrillation in dogs. Indeed, Hooker et al also experimented on dogs and showed that an external application of ac current in the range of six to seven amperes at voltages between 180 and 190 Vac was needed to stop ventricular fibrillation (VF) in anaesthetised dogs. These experiments demonstrated that electrical current could be effectively applied to the heart via the external thoracic wall without the need for any form of invasive surgery.

It was not until the late forties that a human heart in VF was restored to normal rhythm by the use of electricity (Beck et al, 1947). This however was completed using ac current during surgery and the current was supplied directly to the heart via paddles. It was nearly ten years later that Zoll et al (1956) demonstrated that an ac electrical countershock could be successfully applied externally without the need for surgery. However it is clear that by 1961 safety issues for the use of the ac defibrillator that Zoll used were starting to be considered. A case study by Lown (1961) indicates that, having never used a defibrillator before, questions over its safety were being asked including the possibility of an explosion when used near oxygen.

Working in parallel with the west, the Soviet Union and other communist eastern bloc countries were also progressing in the field of defibrillation. By the mid-forties evidence from the Institute of Physiology in Moscow showed that not only was defibrillation by the use of a single dc electrical discharge more effective than ac current but it was also safer (Gurvich & Yuniev, 1946). Gurvich went on to develop the first commercially available dc current defibrillator in 1952.

The work by Gurvich and Yuniev was verified independently in the west in by experimentation on dogs (West and McKay, 1953).

By the late sixties Pantridge and Geddes (1967) advocated the use of mobile cardiac care units so that defibrillation could be given in the prehospital setting, indeed their work over a 15 month period showed that this was not only possible but safe and noted that no patient involved in the study died in transit to hospital. Cakulev et al (2010) cite Pantridge and Geddes (1967) and credit Pantridge with advocating prehospital use of portable defibrillators by

firefighters and ambulance personnel during the early seventies. Rho and Page (2007) published a review of the efficacy and use of Automated External defibrillators (AED) by lay persons that demonstrated early on scene defibrillation using public access defibrillators (PAD) by members of the public with limited training in basic CPR and AED use improved the survival rates of cardiac arrest victims.

7.2 History of hyperbaric medicine

Haux and Workman (2000) cites Simpson (1857) who mentions a seventeenth century English clergyman named Henshaw who first developed a pressurised room to treat chronic diseases which he called a 'domicillium'. Indeed Henshaw is mentioned in many published articles and books on hyperbaric medicine and its history. This domicillium was little more than a sealed room with a bellows used to increase the pressure inside (Neuman & Thom, 2008).

Priestley (1775) describes a 'pure air' which he discovered and immediately noted that it caused flames to burn out faster and hotter. This 'pure air' was oxygen and even at this early stage Priestley notes that it may indeed be a useful adjunct in medicine.

Mathieu (2006) further identifies Junod who in 1834 identified that high pressure oxygen could have medicinal benefits for man. It is of interest to note that the initial uses of hyperbaric oxygen were not used for the treatment of divers with decompression sickness (DCS) and indeed the first real studies on treating and preventing decompression sickness come from work completed by physicians working on the construction of bridges which used pressurised caissons that kept water out and allowed men to work on the foundations of bridge piers (Neuman & Thom, 2008). The work of Bert (1878) is cited in many publications as an important historical milestone in the evolution of hyperbaric oxygen therapy and is recognised and cited as one of the foundations of modern hyperbaric medicine (Mathieu, 2006). Bert's pioneering work on the effects of HBO led to the identification of the toxic nature of oxygen when breathed at high pressures. By the turn of the century work by the noted physiologist J.S Haldane et al (1908) led to the improved prevention of decompression sickness in divers by the use of strict time and depth limits based on mathematical models. By 1928 the largest hyperbaric chamber yet constructed was built by Ohio based anaesthesiologist Dr Orville Cunningham who built an entire six storey steel ball hospital that could be pressurised to 3 ata. By the late thirties work by Behnke and Yarborough (1937) had identified that breathing pure oxygen under pressure would be superior to breathing just air under pressure for the treatment of decompression sickness.

By the late fifties research led by the Dutch physician Ite Boerama et al (1958) used modern evidence based methods to show the benefits of hyperbaric oxygen for a range of ailments and is often referred to as the father of modern hyperbaric medicine (Kindwall & Whelan, 2009). This was later followed by work on clostridial infections such as gas gangrene by means of 'drenching' the body with oxygen to fight the bacterial infection. This involved treating people at the highest concentration of oxygen possible at the highest pressure identified as 3 ata (Boerama & Brummelkamp, 1963).

Today there are fourteen clinical conditions that are routinely treated with hyperbaric oxygen world-wide (Table 1.0).

7.3 Safety issues identified with defibrillation and hyperbaric oxygen

The issues surrounding the safety of electricity have been known since its practical use was first demonstrated in the early nineteenth century. Thomas Edison famously electrocuted an elephant in 1903 to demonstrate the dangers of ac current which at the time was in direct competition with his patented dc current electrical system. Little in the way of literature could be identified that specifically dealt with the issue of user safety. Manufacturer guidance and user manuals have short safety guidance indicating a fire or explosion hazard if used in the presence of flammable or anaesthetic gases as well as in the presence of oxygen (Physio-control, 2010). This same publication notes 16 hazards, including three specific warnings regarding fire and three regarding the risk of unintentional electrical shock. The other ten warnings relate to damage to equipment or specific clinical patient safety issues. Defibrillators on average discharge around 2,000 volts of direct current (Vdc) at around 5 amps (A) in less than a one hundredth of a second (Parbrook et al, 1993) this is not the highest amount of energy they can discharge simply an average. A 5 amp current is a large enough discharge to potentially cause severe harm or even death to those who come into contact with the discharge. However evidence from Gibbs (1990) identifies an injury rate among emergency medical technicians (EMT) involved in defibrillation of 1 per 1000 shocks delivered. The vast majority of those injuries were very minor and there were no reported fatalities.

The issue around defibrillation causing a fire is of a higher concern and several publications note the caution needed when using defibrillators in the presence of oxygen or in oxygen enriched atmosphere. Bruley et al (1989) mention the phenomenon of surface fibre flame propagation in OEA that can potentially occur from any electrical surgical instrument that produces heat and make note of the potential of electrical arcing across a patient's chest from defibrillation being enough to cause a fire in this way. Mehta et al (2013) cites a single case of fire in an operating theatre caused by a defibrillator and a safety action notice from Scotland (NHS Scotland, 1995) also cites an incident of fire caused by defibrillation resulting in severe burns to a patient.

The most prominent safety concern highlighted in HBOT literature is fire. Indeed fires in chambers continue to occur globally and have a high propensity for fatalities as identified by Sheffield (1997). Sheffield's retrospective study, which analysed fires in hyperbaric and hypobaric chambers over a period of 73 years, noted that the only survivors in these fires were those where the chamber was pressurised with air and that fatality rates were far higher in chambers with an OEA.

Ross et al (1996) recommends that defibrillators are not routinely used in hyperbaric chambers and cites the risk of sparking from defibrillator paddles with poor contact with the skin or repeated countershocks when contact gels with high initial impedance are used. However these guidelines only mention the use of paddles and not adhesive pads. Kot (2004) has stated that defibrillation can be carried out safely in HBOT however clearly rules out its use in OEA

chambers such as single person mono-place chambers that are routinely pressurised with 100% oxygen. This is similarly mentioned by Weaver (2011) who states that defibrillation can be safely carried out inside a hyperbaric chamber as long as oxygen tension levels are maintained to NFPA guidelines. Gough-Allen (1995, ed Workman) notes that even in non OEA air filled chambers the risk of fire is still enhanced due to the increased partial pressure of oxygen. To countenance the risk of fire inside hyperbaric chambers Burman (2013) recommends that no electrical equipment that exceeds 24-28vdc and 4w should be used inside a hyperbaric chamber. This is similar to the recommendations of Gough-Allen et al (1996) who recommend a maximum of 24 vdc. Two specific experimental studies into in-chamber defibrillation were identified. Swanson et al (2009) safely carried out defibrillation on six pigs at pressures of up to 6 ata inside a 60 inch double lock chamber as part of a pilot study into the efficacy of in-chamber defibrillation. Kronlund et al (2011) carried out electrical testing on modified lifepak 1000 defibrillators at pressures up to 3 ata. This led to this specific type of modified defibrillator being certified for use inside a hyperbaric chamber by Germanischer Lloyd.

7.4 Themes and analysis

Pitkin (1999) carried out an in-depth literature review of defibrillation inside hyperbaric chambers and this review highlights themes common to both hyperbaric safety and general defibrillator safety. This notes the need to balance the increased risks of the use of defibrillators inside a hyperbaric chamber with the lifesaving capabilities of the device for the patient. Early research into both hyperbaric medicine and defibrillation focuses on the purely clinical benefits of both types of therapy and as knowledge and use of both have developed so have questions on the limits and safety issues surrounding their uses. Oxygen enrichment is a theme identified as a risk for both hyperbaric oxygen and defibrillation. Indeed focus on oxygen safety became a major issue for the US space program when in 1967 the crew of Apollo one were killed in an oxygen fire during testing on the launch pad at Cape Canaveral, Florida. It is primarily from this time that the focus on electrical safety, and hence the use of defibrillators, combined with enriched oxygen atmospheres becomes more intense with more publications and research on the subject being carried out.

The literature regarding the safe use of defibrillators has limited evidence to suggest that electrocution of attending medical personnel is as big an issue as would initially be imagined when looking at the current and voltage levels discharged by these devices. This, in all likelihood, is due to the extremely short duration of discharge combined with the large amount of electrical resistance that a human undergoing defibrillation presents. Indeed in recent times suggestion that medical personnel could continue with CPR chest compressions during defibrillation indicates that the risk of electrocution is low enough to accept the risk of being in direct contact with a patient during defibrillation, albeit with the use of standard medical rubber gloves (Lloyd et al, 2008). It should be noted that the limitations of the study by Lloyd failed to address the possible issue of the breakdown of the materials in the glove leading to a direct contact with the patient during shocking. However the research by Hoke et al (2009)

identified 29 incidents of unintentional electric shock to bystanders during defibrillation all minor in nature and supports the earlier work of Gibbs (1990).

Fires caused by electrical arcing during defibrillation are clearly an issue as guidance from the UK Resuscitation Council on the safe use of defibrillators puts emphasis on the issue of oxygen use during defibrillation (Soar et al, 2015). From a medical perspective, the issue around defibrillation and oxygen safety is encompassed into a wider theme of electrical safety and oxygen. The evidence identified in much of the literature involves anecdotal accounts of single case studies identifying defibrillation as a cause of fire. The theme of fire prevention combined with oxygen and electrical safety is most focused in the operating theatre were meta-analysis of data shows that these areas are at a high risk of oxygen fires due to the high concentrations of oxygen in use combined with high energy pieces of equipment such as lasers, cauterising tools and defibrillators.

Evidence from Sheffield (1997) also identifies electric arc/spark as the main cause of fires inside both diving and clinical hyperbaric chambers. However there is little evidence of actual incidents involving defibrillators within hyperbaric chambers. Strict recommendations are cited in several publications that could potentially complicate the use of these devices inside hyperbaric chambers, such as ensuring that the defibrillator monitor is outside the chamber and that only the pads are inside the chamber connected via an electrical penetrator (Kot, 2004). This would mean the actual defibrillator operator would not be in direct contact with the other members of the resuscitation team. It should be noted however that very recently a specific defibrillator certified for use inside a hyperbaric chamber has been developed by a private company, GS Elektromedizinische Geräte GmbH (2012).

8. Methodology

The research was aimed at clinical hyperbaric units only and excluded units not commonly defined as a clinical unit. For this purpose a clinical unit has been defined as one that is supervised by a medical doctor and its primary role is as a healthcare facility designed to treat illness. Due to the relatively small number of clinical hyperbaric units, the research has been on a global scale to ensure an adequate amount of samples can be collected. Due to the varied nature of global standards, to ensure that appropriate clinics were used as samples certain eligibility requirements had to be met. The use of hyperbaric chambers by those that are not under the direction of a licensed physician or appropriate healthcare professionals were excluded. These unregulated centres will treat different conditions often under the control of non-licensed or unqualified persons. With such high numbers of these types of units using vastly different methods their inclusion in any study may significantly alter the raw data leading to misleading ratios or irrelevant conclusions.

The global setting required a restrictive inclusion criterion that accepted and defined only clinical hyperbaric units that met the following criteria:

1. Have an appointed and qualified physician as medical director.
2. Treat at least one condition listed on the UHMS indications list (2015).
3. Regulated as a clinical facility under local regulations where appropriate.

Units that are used primarily by the diving industry for diving operations or as part of their emergency plans were excluded.

The general study design was that of a cross sectional retrospective cohort study employing a mixed methods approach using random cluster sampling with replacement. The decision to use sampling with replacement was to ensure a large enough number of samples could be collected. The retrospective element was needed so that data on incidents could be gathered.

Initial cohorts were based on several global regions.

- United States and Canada
- Europe
- Australasia and Asia
- Rest of the world

The research involved splitting samples into specific cohort groups from those hyperbaric units that met the previously mentioned criteria. The two main cohort groups were identified as those that are prepared to defibrillate inside a chamber and those that are not.

The main method of data collection was the use of unit questionnaires sent via email using a two stepped approach to encourage as many hyperbaric units to respond as possible and to assist in the processing of data by quickly allocating respondents into one of the two distinct cohorts.

This was completed by the use of a single internet based questionnaire (appendix 1) comprising of mainly closed questions of a basic nature with the aim of quickly identifying those hyperbaric units that:

1. Have the capability and intent to defibrillate inside the chamber during treatment
2. Do not have the capability or intent to defibrillate inside the chamber during treatment.

From this point the initial pre-set questionnaire (appendix 1) sent out to all referred respondents to specific questions dependent on the answers they initially gave to key questions that investigated whether units:

1. Do not have the ability to defibrillate inside a chamber.
2. Have the ability to defibrillate inside a chamber.
3. Have had incidents of cardiac arrest during treatment.
4. Concerns and procedures chambers that don't defibrillate have.
5. Concerns and procedures chambers that do defibrillate have.

Those units that indicated incidents of cardiac arrest inside a chamber, whether they are capable of in chamber defibrillation or not, received a follow up questionnaire regarding details of the incidents themselves (appendix 2).

It was considered from an early point that many of the respondents would not speak English as a first language or would speak limited English. Due to limited funding, translation of the questionnaire was not an option and thus simple English was used to encourage as many respondents to reply as possible. All questions were reviewed prior to completion of the research instruments to ensure that they were not:

1. Leading questions.
2. Double barrelled questions.
3. Misleading or difficult to understand.
4. Biased.

9. Results and discussion

9.1 Context and general settings

530 hyperbaric units world-wide were invited to participate and sent questionnaires. Out of a total of 1233 identified hyperbaric units this number equates to 42.9% of the sample population. A total of 51 responses, equating to 9.6% of those invited, were received back. However not all were completed with 7.8% of respondents (n=4) only partially completing the questionnaire. This is clarified in the data with all percentages stated relating to the number of respondents that answered the specific question being discussed.

The geographical distribution of respondents was from regions identified as the USA and Canada, Europe (including Turkey) and Australasia and Asia. There were no respondents from other regions of the world (figure 2.0).

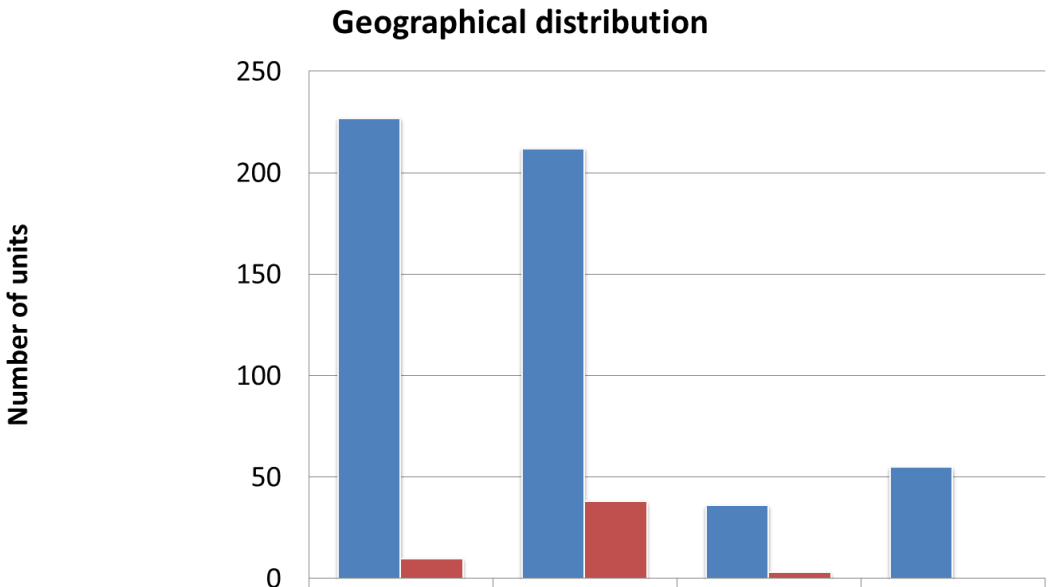

Fig 2.0: Geographical distribution of invites and respondents

The first question identified whether units where either hospital based or standalone clinics (figure 2.1). The results show that the majority of units that responded where indeed hospital based units (n= 38). The majority of responses also indicated that most units (n=34) could accept and treat intensive care patients (figure 2.2).

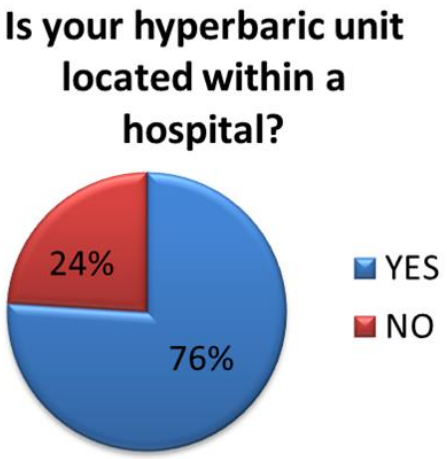

Fig 2.1: n=51

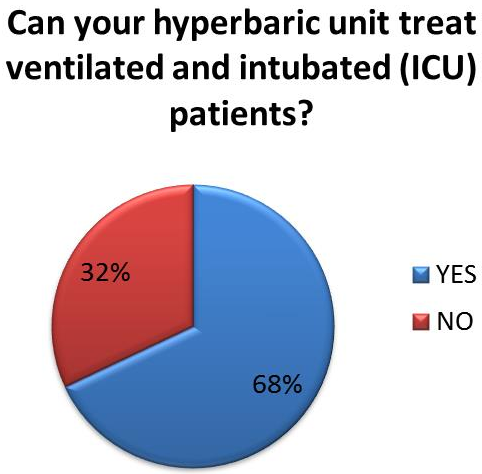

Fig 2.2: n= 50

Of those units that responded that they could treat intensive care unit (ICU) patients, 91.17% (n=31) indicated that they were hospital based units.

Of the total study population, 23.5% (n=12) indicated the ability to defibrillate patients inside a hyperbaric chamber whilst it is under pressure (figure 2.3).

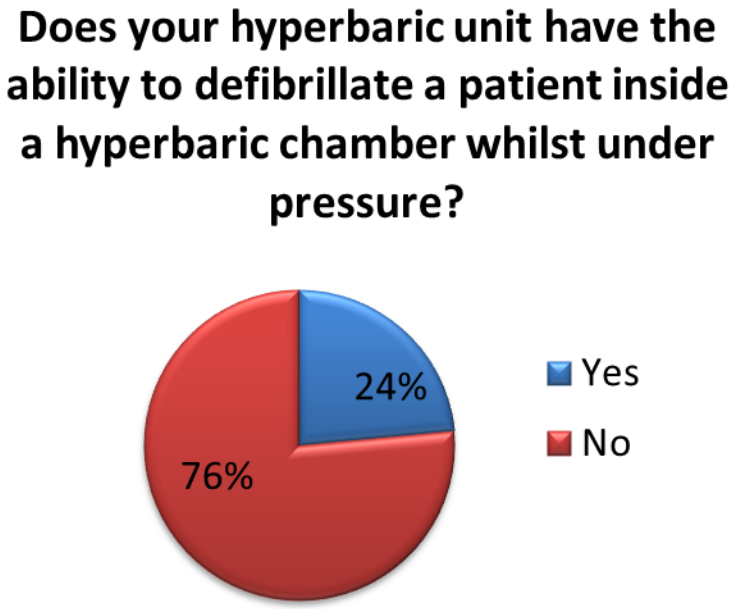

Fig 2.3: n=51

Of those units that indicated they had the ability to defibrillate inside a hyperbaric chamber under pressure only two were non-hospital based. One of those units indicated that they did have ICU capabilities and the other did not.

With a large proportion of respondents indicating that they are hospital based or can accept intensive care patients it was expected that there would be a high number of respondents that would have immediate access to a defibrillator. This was, by and large, shown to be correct

with 84.3% of respondents (n=43) indicating that they have direct access to a defibrillator with the defibrillator being held either within the unit itself or close by (figure 2.4).

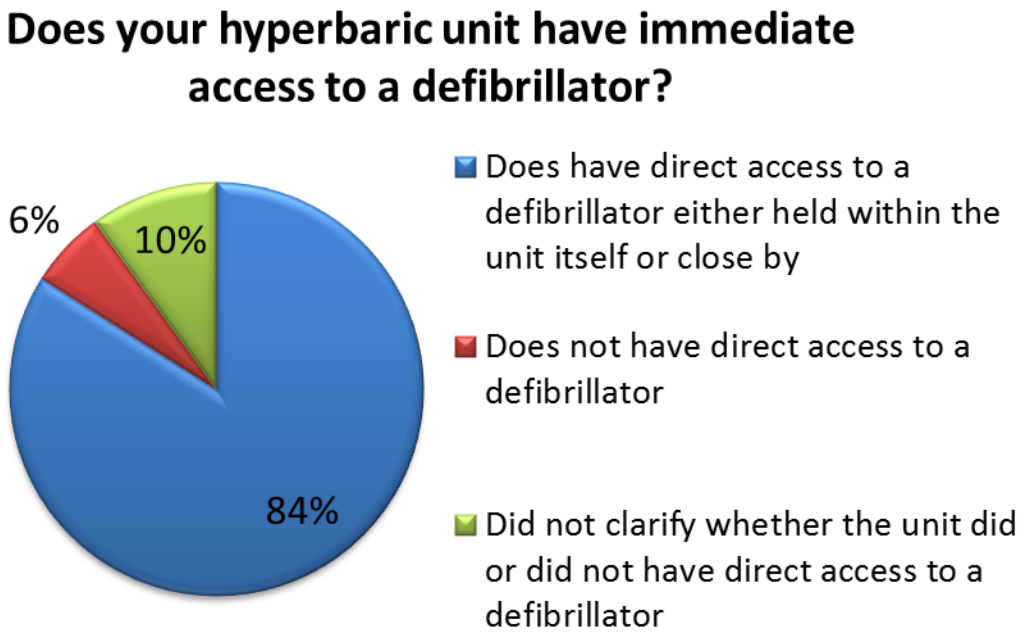

Fig 2.4: n=51

The majority of respondents stated that they operated only multi-place air filled hyperbaric chambers, with 18% and 16% of respondents indicating that they operated only mono-place hyperbaric chambers or both mono-place and multi-place chambers respectively (figure 2.5).

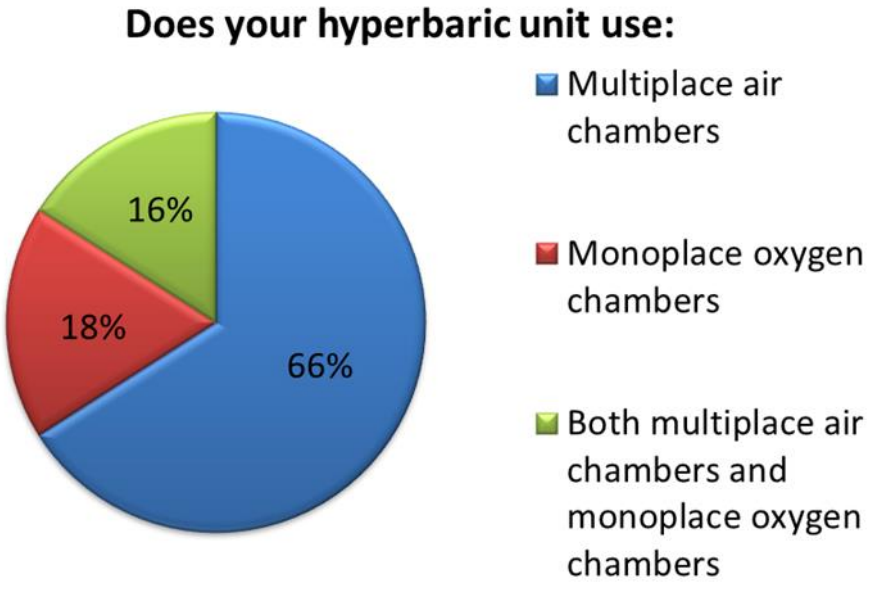

Fig 2.5: n=50

9.2 Data from units that cannot defibrillate inside chambers under pressure

Of those hyperbaric units that indicated that they did not have the capability to defibrillate inside a pressurised hyperbaric chamber 41% of respondents indicated that they had a

defibrillator held within the unit itself (n=15) with 51.35% (n=19) indicating that the defibrillator was held close by but not within the confines of the unit itself (figure 2.6).

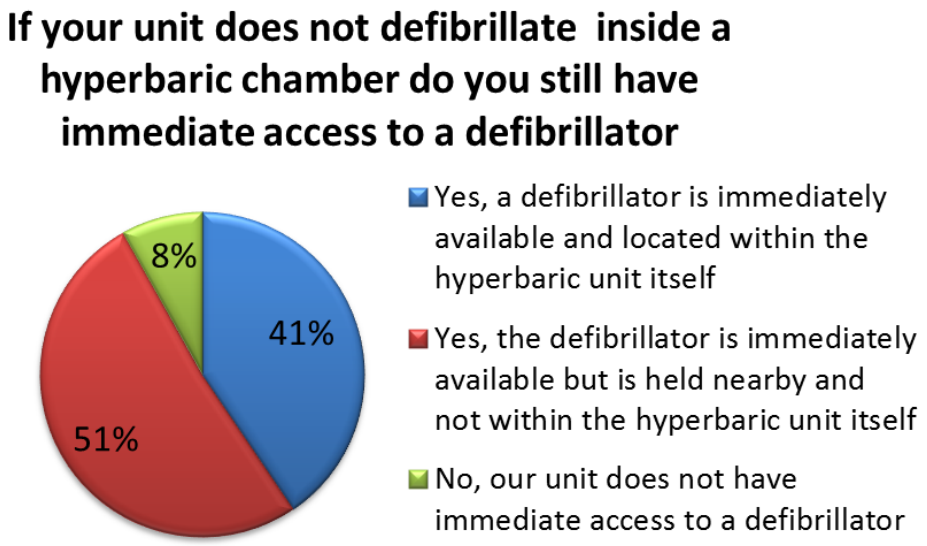

Fig 2.6: n=37

Of those respondents that did not allow defibrillation inside a hyperbaric chamber five cases of sudden cardiac arrest (SCA) were identified, all were patients, i.e. no cases of SCA in staff or consultants. Of this cohort, four of these cases were identified as having non-shockable rhythms with two of those patients surviving. The single case of SCA with a shockable rhythm received defibrillation outside the chamber and survived as per the definition of effectiveness (section 6.1).

The next series of questions examined procedures and strategies used by these units. When reviewing the number of respondents that have established procedures in place to deal with an SCA inside a hyperbaric chamber the majority (69.4%) indicated that they did have procedures in place (figure 2.7).

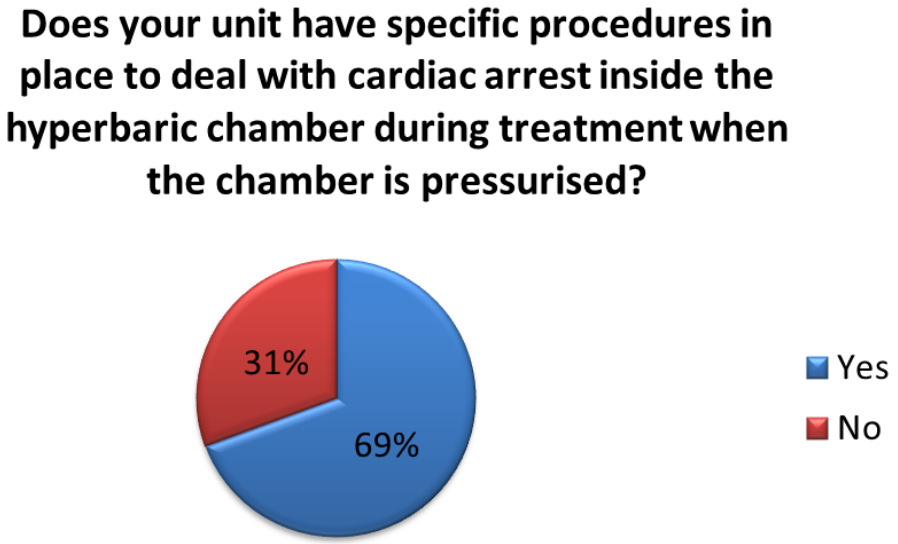

Fig 2.7: n=36

It was assumed that procedures for mono-place chambers versus multi-place chambers would differ vastly so specific questions were aimed at those that operate multi-place chambers and those that operate mono-place chambers.
12 units that operate mono-place hyperbaric chambers indicated that they had emergency actions and procedures that are used during an in-chamber SCA (figure 2.8).

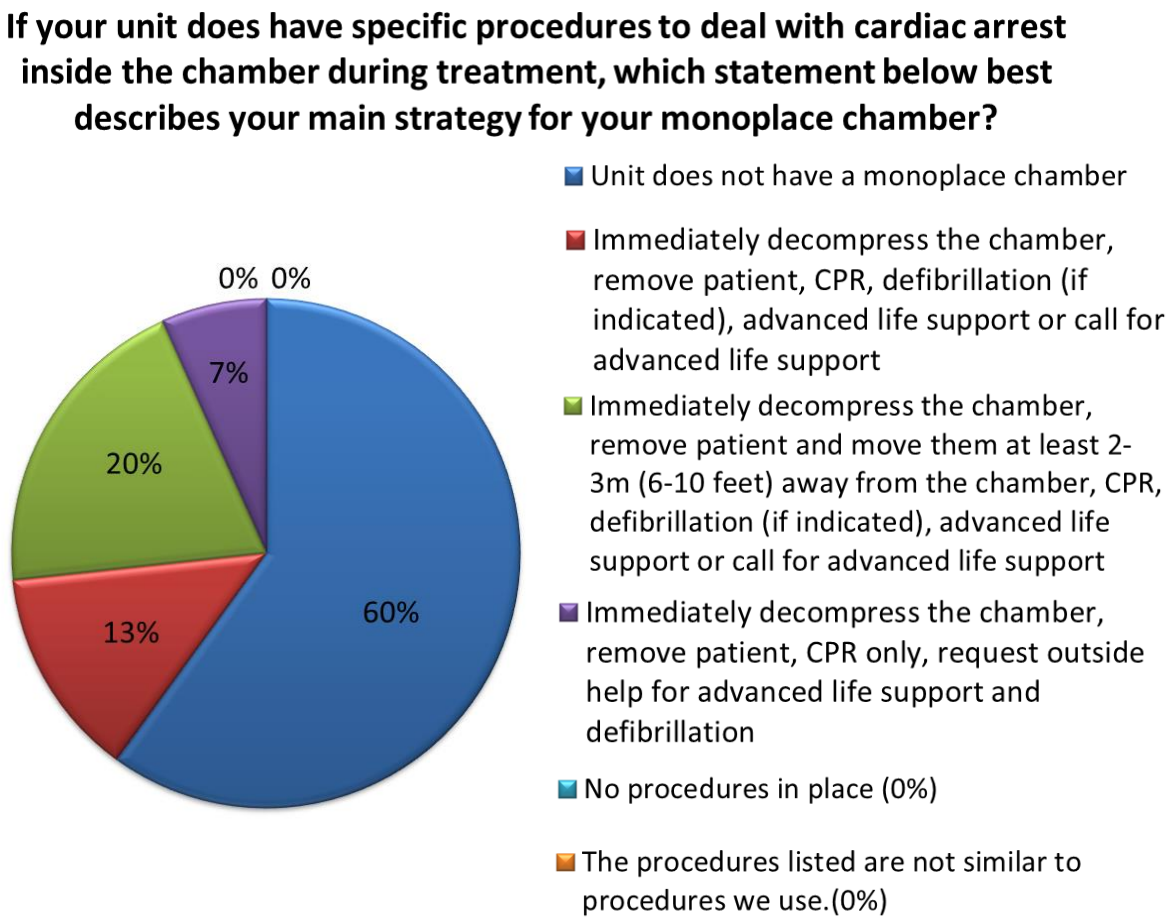

Fig 2.8: n=30. Only 30 respondents replied to this question with 40% (n=12) indicating they had procedures in place for their mono-place chambers.

The procedures listed in the question were based on potential unit scenarios and a specified best practice procedure of removing a patient a set distance from the mono-place chamber before attempting defibrilation (Johnson in Weaver & Strass, 1991). Half of those who indicated using mono-place chambers and answered this question stated that they use this particular strategy.
With more options and differing concerns for air filled multi-place chambers, a larger selection of procedures was included. Some 26 units identifed that they used multi-place hyperbaric chambers. The questionnaire offered ten different procedcures as options for respondents to choose from (table 2.0) There was no clear prefered procedure identified however the most popular choice was procedure A with 25.9% (n=7) identifing that this is the procedure they use.

However 18.5% (n=5) identified that the procedures they use are not similar to those options given. It is worth noting that no respondents stated that they used procedure C.

If your unit does have specific procedures to deal with cardiac arrest inside the chamber during treatment, which statement below best describes your main strategy for your multi-place chamber?

Procedure code	Chart colour code	Description
A		***Chamber with attendant:*** CPR, immediately decompress chamber to surface, remove patient, defibrillation (if indicated) advanced life support (ALS) or call for ALS, treat attendant for omitted decompression or DCS
B		***Chamber with attendant:*** CPR, immediately decompress chamber to surface, remove patient, defibrillation (if indicated), ALS or call for ALS, treat attendant only if symptoms of DCS occur
C		***Chamber with attendant:*** CPR, decompress chamber to surface using standard decompression tables, remove patient, defibrillation (if indicated), ALS or call for ALS.
D		***Chamber with attendant:*** CPR, immediately decompress chamber using surface decompression tables (SurD), remove patient, defibrillation (if indicated) ALS or call for ALS, recompress attendant as per SurD tables.
E		***Chamber with attendant:*** CPR, doctor to enter the chamber and make further decisions after patient evaluation.
F		***Chamber with attendant:*** CPR, only doctor to make further decisions and give instructions
G		***Chamber without attendant:*** Doctor or member of staff to enter the chamber and make further decisions after patient evaluation
H		***Chamber without attendant:*** CPR, immediately decompress chamber to surface, remove patient, defibrillation if indicated, ALS or call for ALS.
I		***Procedures listed above are not similar to those used by the unit***

Table 2.0: List of procedure options with corresponding pie and bar chart colour codes (figs 2.9 and 3.0) given to respondents who stated they use multi-place chambers.

The following charts show the breakdown of the responses as a percentage (figure 2.9) with figure 3.0 showing the numbers of respondents grouped into three cohorts identifed as:

i. Those units who clearly stated they use inside chamber attendants.

ii. Those units who clearly identifed that they do no use inside attendants.

iii. Those that the stated the procedures listed where not similar to the procedures they use..

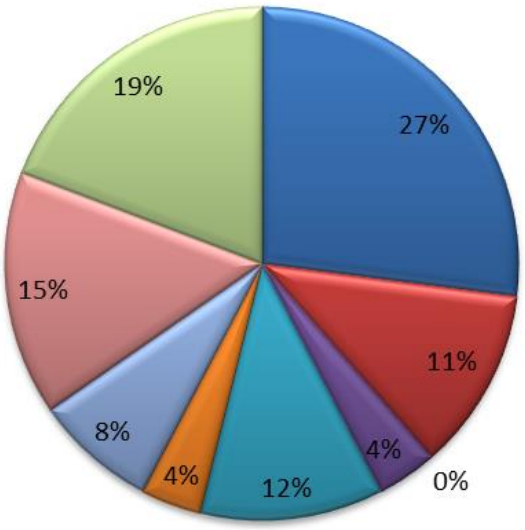

Fig 2.9: n=26: percentage breakdown of the procedures listed in table 2.0 by respondents who stated they use multi-place chambers. Note that no respondents (0%) identified with procedure C.

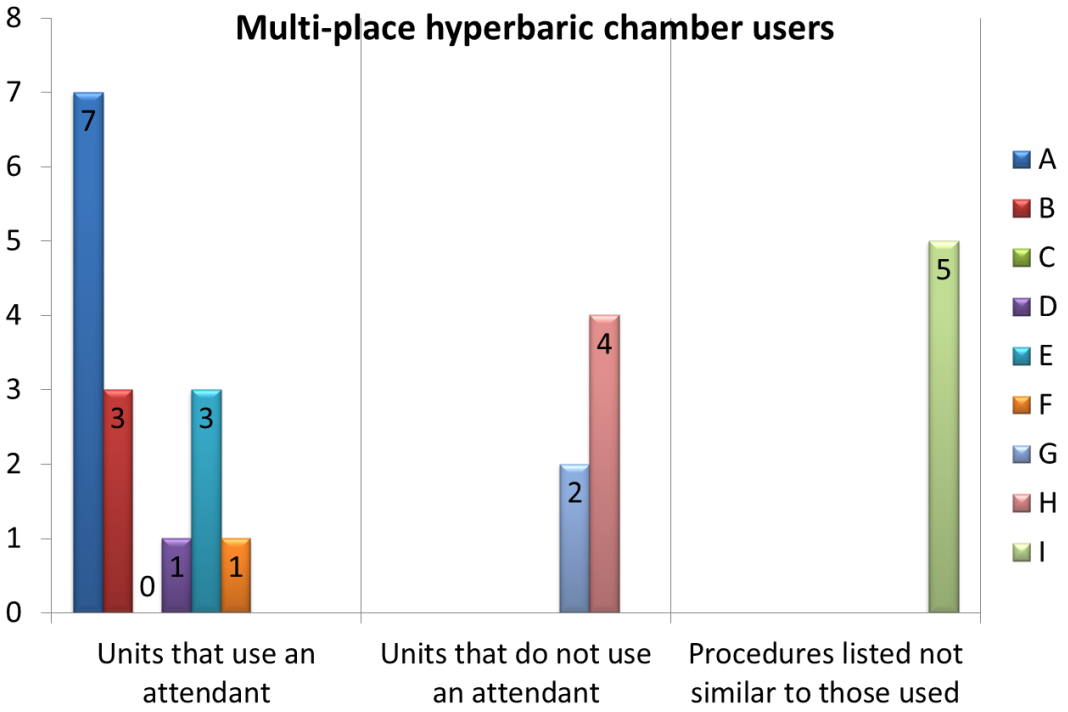

Fig 3.0: n=26: Chart shows the breakdown of responses (in numbers) to procedures listed by cohort groups.

Note that the numbers of units that stated the procedures they used were not similar to those options given does not identify whether the unit does or does not use inside attendants. Of those five units that gave this response, two units indicated through other answers that they did use inside attendants.

Units that do not have the capability to defibrillate inside the chamber when it is under pressure were asked what the reasons were for not allowing in-chamber defibrillation. The question gave six possible reasons and respondents were asked to rank each reason in order of priority (one highest, six lowest). 36 respondents answered this question either partially or fully with half the respondents indicating that safety (n=18) had a priority of one out of six (figure 3.1).

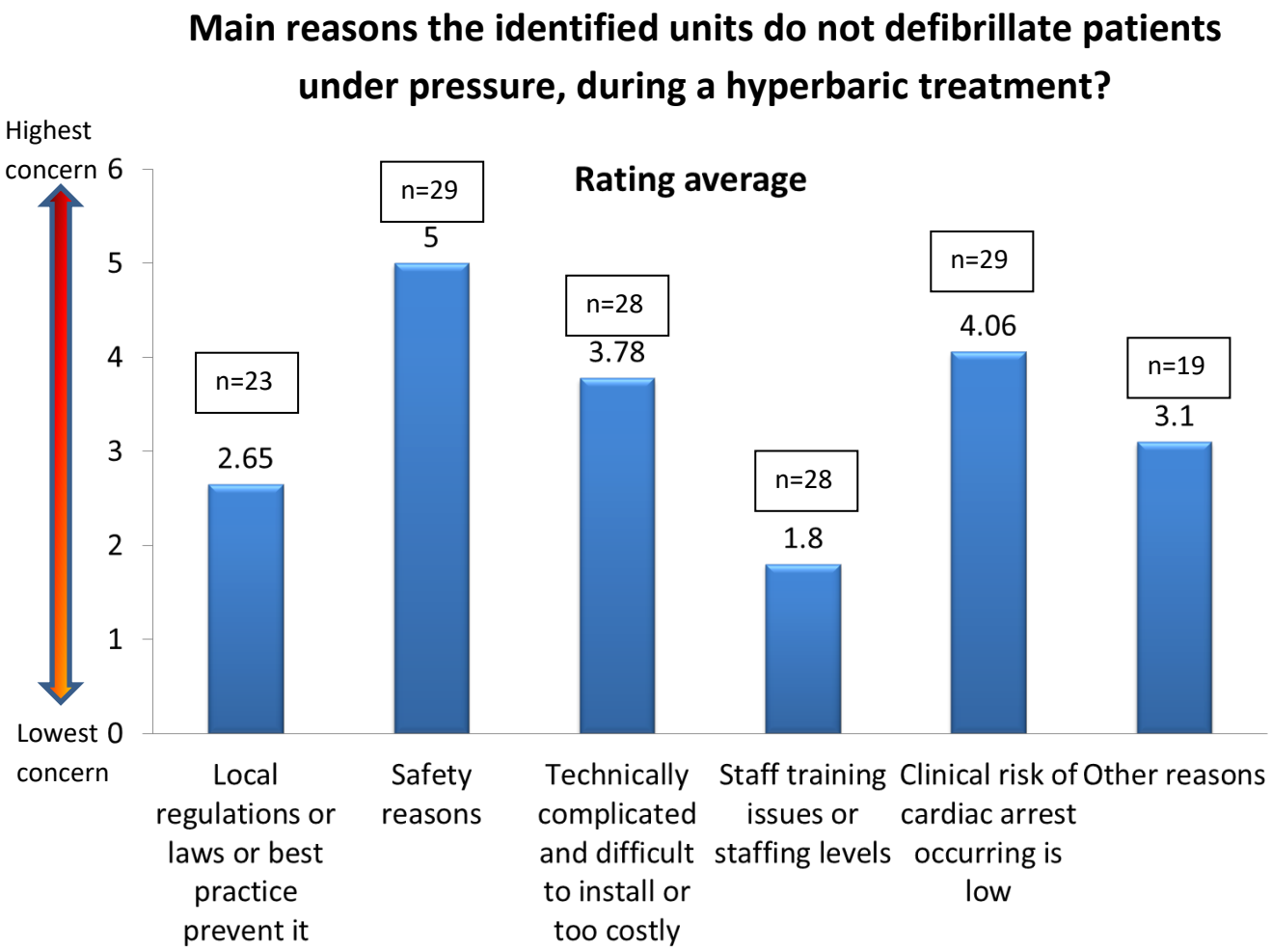

Fig 3.1: n=36.

The second most stated reason with a priority rating of one (n=6) was that it would be technically complicated or difficult to install or too costly (table 2.1). However this was the third highest priority as a rating average.

In order of priority (1=highest priority 6= lowest priority), what are the main reasons why your unit does not defibrillate patients under pressure during a hyperbaric treatment?

Answer Options	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6
Local regulations or laws or best practice prevent it	1	4	2	1	9	6
Safety reasons	18	4	2	2	0	3
Technically complicated and difficult to install or too costly	6	6	3	5	5	3
Staff training issues or staffing levels	1	1	8	9	5	4
Clinical risk of cardiac arrest occurring is low	2	12	7	4	2	2
Other reasons	5	1	2	2	1	8

Table 2.1: n=36. Note that not all respondents gave ratings to every option given.

These units were also asked what main safety concerns they would have if they were to consider in-chamber defibrillation and asked to prioritise them in order. The highest overall concern was that of fire with a clear majority of 70% of those who responded indicating this as an issue with 57% indicating this was the main priority. 33 respondents answered this question either partially or fully with unintentional electric shock and patient clinical safety issues being the second and third highest concerns respectively (figure 3.2) when taking into consideration ratings averages. Although patient clinical safety issues rated on average the second highest concern, slightly more units identified that unintentional electric shock was their highest priority (n=4) than those that identified patient clinical safety (n=3). Table 2.2 shows the breakdown of responses to the question.

Main concerns those units that do not have the capability to defibrillate inside a chamber, would have if they were to consider in-chamber defibrillation

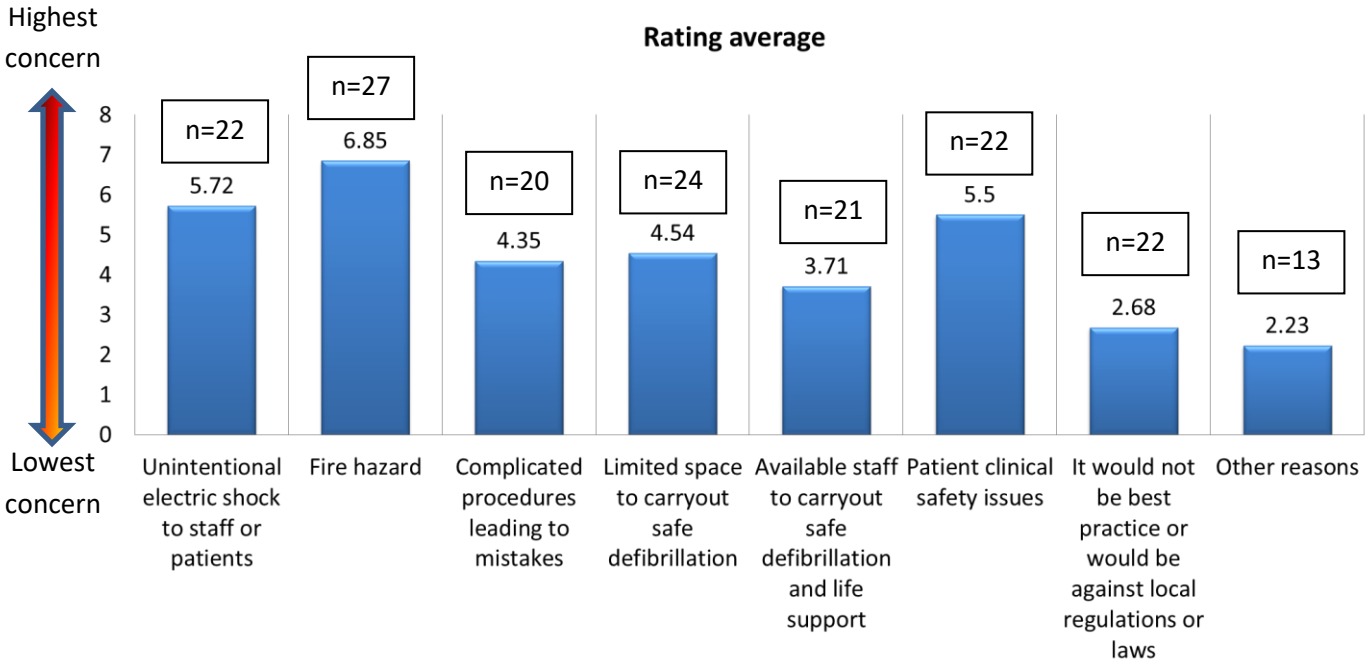

Fig 3.2: n=33.

As a unit, in order of priority (1= highest priority 8= lowest priority) when considering the use of a defibrillator inside your chamber(s) what would be your main safety concerns?

(Number of responses to each priority)

Answer Options	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Priority 7	Priority 8
Unintentional electric shock to staff or patients	4	5	4	3	4	1	0	1
Fire hazard	19	1	3	1	0	0	0	3
Complicated procedures leading to mistakes	0	4	2	2	5	4	2	1
Limited space to carryout safe defibrillation	1	5	4	3	1	4	5	1
Available staff to carryout safe defibrillation and life support	1	0	2	2	5	7	3	1
Patient clinical safety issues	3	7	2	4	0	5	1	0
It would not be best practice or would be against local regulations or laws	1	0	2	2	2	1	6	8
Other reasons	1	1	0	0	0	0	3	8

Table 2.2: n=33. Note not all respondents gave ratings to every option.

Of the five cases of SCA that occurred in chambers that do not have the capability to defibrillate, four cases had non-shockable rhythms of which two survived. The single case of SCA with a shockable rhythm also survived and was defibrillated outside the chamber. The total survival rate for SCA in these chambers was 60% however it would be difficult to extrapolate this number due to the low numbers involved. All five cases of SCA occurred in hospital based units with ICU capability. Follow up data using a second questionnaire (appendix 2) was received on four of these cases. Of those cases, three were intensive care patients; one being treated for gas embolism the other two for necrotising soft tissue infections. There was a single case of SCA in a non-ICU patient being treated for arterial insufficiencies. In all four cases the treatment was fully aborted and all four cases occurred within multi-place air filled chambers. All five cases of cardiac arrest occurred in European hyperbaric units, with the four cases identified on the follow up occurring in multi-place chambers. The mean average number of patients inside the chamber at time of arrest was 2.5, with the largest number of patients inside a chamber at time of arrest for a single event being four (table 2.3).

Follow up data from hyperbaric units that have experienced cases of in-chamber SCA but do not have the capability to defibrillate inside the chamber whilst under pressure.

SCA case#	Condition being treated	Type of multi-place chamber	# of patients in chamber at time of arrest	# of attendants inside chamber	Attendant highest qualification	Defib used (outside chamber)	Time to deco (from arrest to surface)	Point of arrest
1	CAGE	3 person square chamber	1	1	ICU nurse	Yes	1-3 minutes	At therapy pressure
2	Arterial insufficiencies	5-6 person cylindrical chamber	4	2	Other healthcare professional (non nurse or Dr)	No	3-5 minutes	Towards end of treatment after deco stop
3	Necrotising fasciitis	3 person cylindrical chamber	3	2	ICU nurse	No	1-3 minutes	At therapy pressure
4	Necrotising fasciitis	3 person square chamber	2	2	ICU nurse	No	1-3 minutes	At therapy pressure

Table 2.3: Shows additional data from the follow up questionnaire sent to those units that identified that they have had cases of SCA (appendix 2).

All four cases were incident free with no issues identified during any of the procedures used. One SCA occurred at a hyperbaric unit that uses procedure E (Chamber with attendant: CPR, doctor to enter the chamber and make further decisions after patient evaluation), however this procedure was not followed.

The three other cases of SCA occurred in units that used procedure A (Chamber with attendant: CPR, immediately decompress chamber to surface, remove patient, defibrillation (if indicated) advanced life support (ALS) or call for ALS, treat attendant for omitted decompression or DCS). This procedure was followed in all three cases. A single case occurred in a cylindrical chamber system that utilised three chambers that could accommodate two ICU patients each that was connected together by a single common entry lock which enabled attendants from the other chambers to enter and provide mutual assistance.

Team debriefings were held after all four cases to identify any issues that arose during the arrest procedures.

9.3 Data from units that could defibrillate inside chambers under pressure

Of the 51 respondents, 12 identified that they did have the capability to defibrillate inside chambers under pressure. Eight of those units were from the EU region with a single unit from the US and Canada region and two from the Asia and Australasia region. Of those 12 units, two units clearly indicated that although they had the capability they did not permit in-chamber defibrillation. Further data was obtained from nine out of the 12 units. All nine of these units indicated that they used multi-place chambers and had very rapid access to a defibrillator (figure 3.3) with some 55.5% of respondents (n=5) indicating that they also allow the defibrillator to go into the chamber and be used with one of those units locating it inside the chamber itself. One unit had a defibrillator approved for use inside a hyperbaric chamber but did not permit in chamber defibrillation. The two other units indicated that they do not allow the defibrillator itself to go into the chamber but the pads or paddles are inside the chamber via and electrical penetrator with the defibrillator connected to them and operated from outside the hyperbaric chamber.

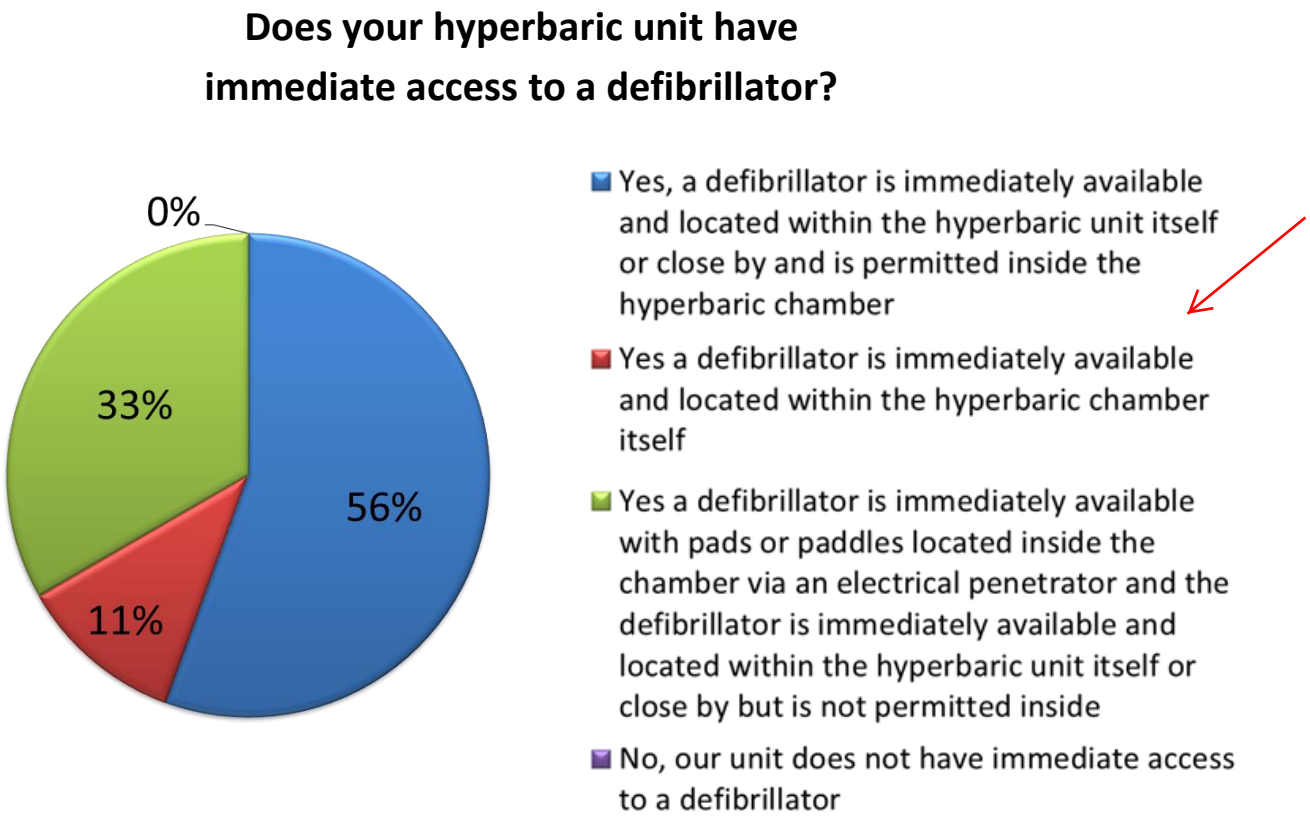

Fig 3.3: n=9. All respondents indicated that they had immediate access to a defibrillator

Of those 12 units, nine clearly indicated that they have the capacity and willingness to permit in-chamber defibrillation. Of these nine units, seven were hospital based and seven were capable of treating ICU patients

Of those units that allow a defibrillator to go into the hyperbaric chamber, four stated that the defibrillator they use is certified by the manufacturer for use inside a hyperbaric chamber with a single unit stating that it is not certified but that they do permit it to be used inside the chamber.

When the similar questions regarding safety concerns around the use of defibrillation inside a hyperbaric chamber were answered; similar concerns emerged as a rating average (figure 3.4).

Main concerns of those units that do permit defibrillation inside a chamber

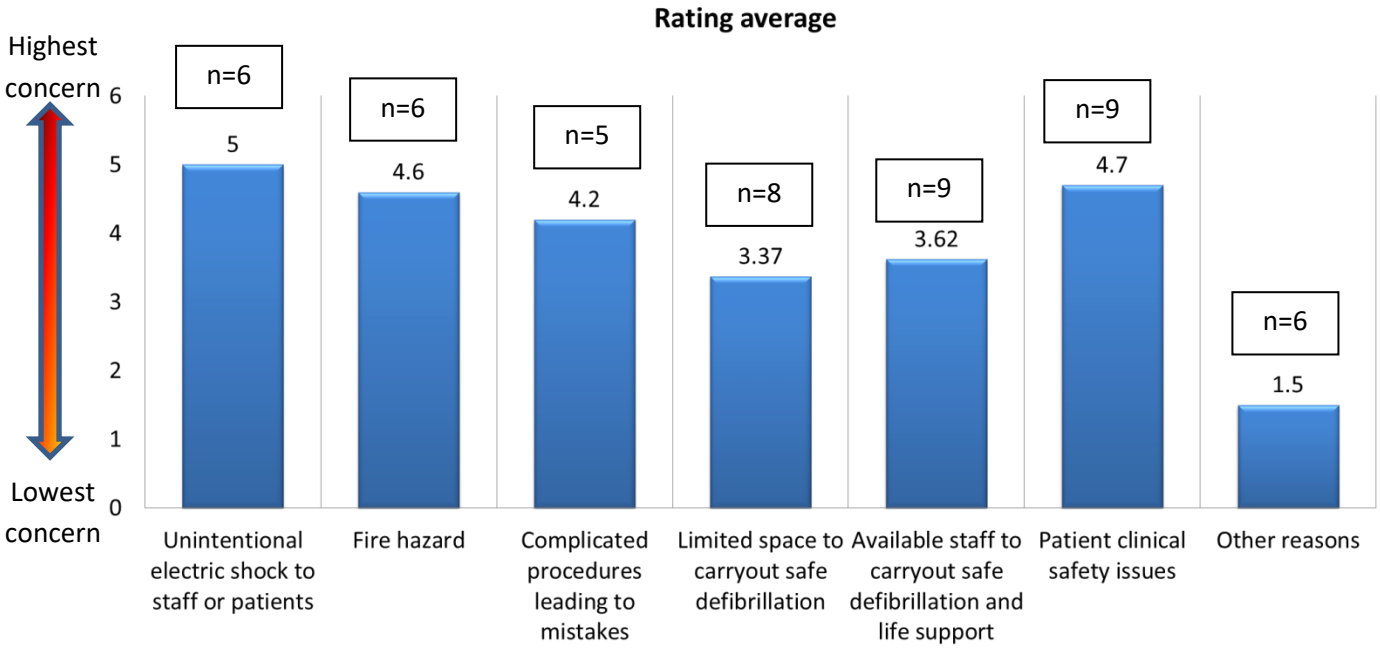

Fig 3.4: n=9.

When averaged, the main concern for these units is not fire hazard, which is the main concern for hyperbaric units that could not defibrillate inside their chambers; in point of fact fire hazard averages as the third highest concern behind unintentional electric shock and patient clinical safety issues.

However fire hazard did have the largest number of respondents identify it as the highest possible priority in both cohorts (fig 3.5)

Comparison of highest safety priority for in-chamber defibrillation by percentage

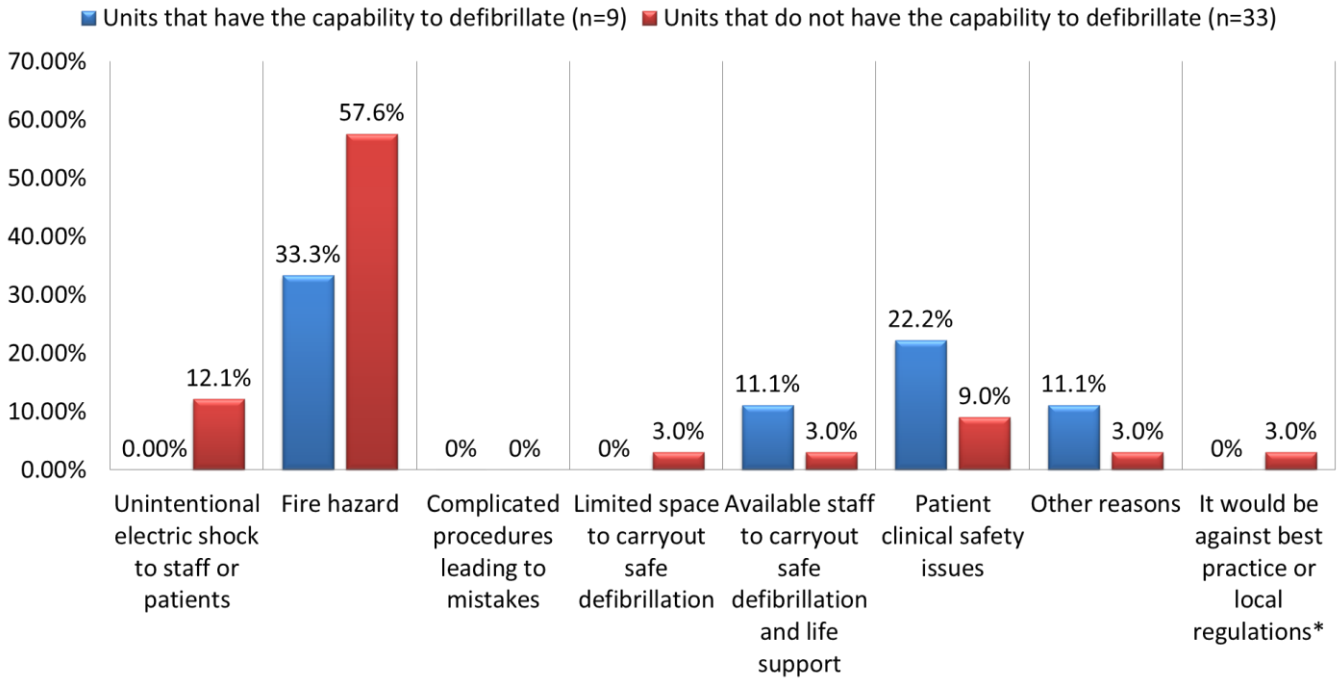

*Fig 3.5: Percentage of units that indicated which available option had the highest safety priority (priority rating of 1). *This question was not put to units that indicated they could defibrillate inside a chamber.*

Although concern over the potential fire hazard was evident, not all respondents identified this as a hazard at all and only three respondents identified this as their main concern (table 2.4). When evaluating whether respondents viewed these options shown in fig 3.5 as issues at all there was again a clear difference in level of concern (figure 3.6).

As a unit, in order of priority (1= highest priority, 7= lowest priority) what are your main safety concerns when using a defibrillator inside a chamber whilst at pressure?

(*Number of responses to each priority)*

Answer Options	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5	Priority 6	Priority 7
Unintentional electric shock to staff or patients	0	4	0	1	0	1	0
Fire hazard	3	0	0	1	0	1	1
Complicated procedures leading to mistakes	0	0	3	0	1	1	0
Limited space to carryout safe defibrillation	0	1	1	1	3	1	1
Available staff to carryout safe defibrillation and life support	1	3	2	0	2	0	1
Patient clinical safety issues	2	0	2	4	1	0	0
Other reasons	1	0	0	0	0	3	2

Table 2.4: n=9. Note not all respondents gave ratings to every option.

Comparison of whether available options were given any priority between 1 and 7 (units that can defibrillate) or 1 and 8 (units that cannot defibrillate)

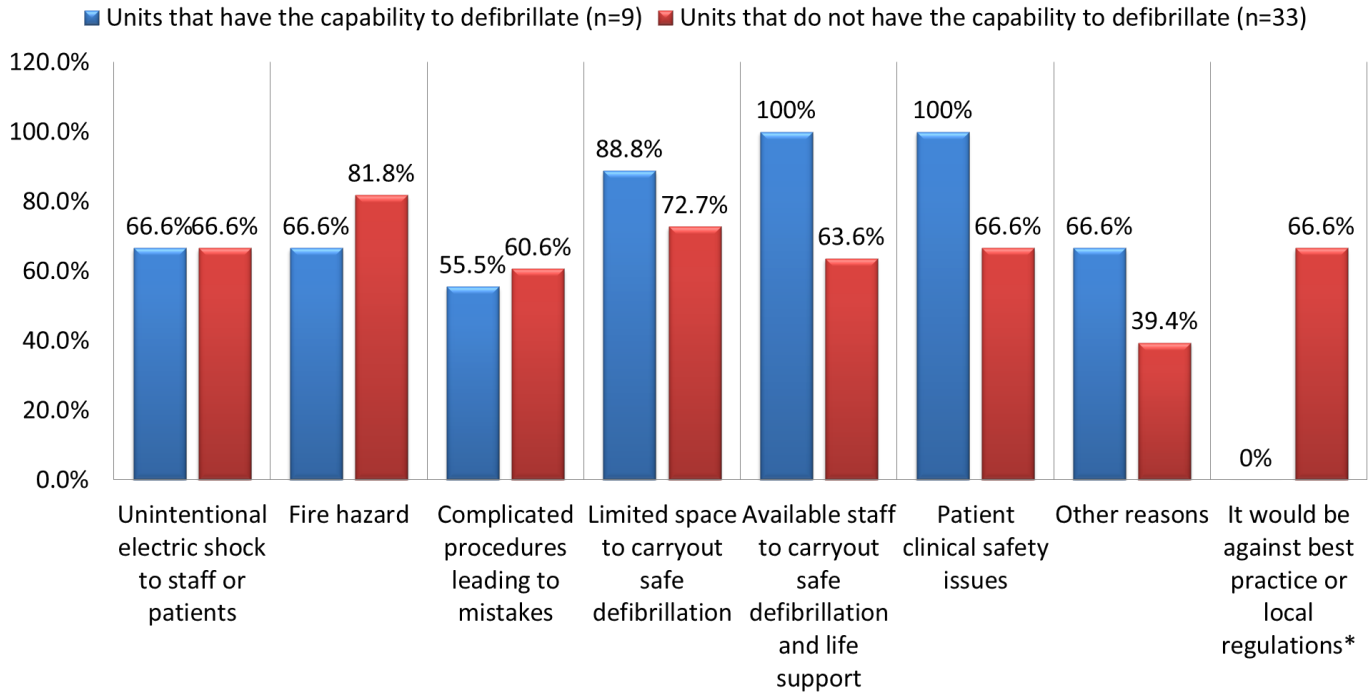

*Fig 3.6: Chart shows the comparison of respondents that identified whether the listed concerns were given any priority at all. *This question was not put to units that indicated they could defibrillate inside a chamber.*

Of those nine respondents that further data was received from, 77.7% (n=7) stated that they did have a set procedure for its use. One unit did not have a specific procedure for in chamber defibrillation but did permit it by using pads or paddles inside the chamber via an electrical penetrator with the defibrillator located outside. Further questions centred on the specific safety procedures that these units used.

Units that indicated that they did have a specific procedure were given a list of 10 safety related actions that could be used as part of a procedure (table 2.5) and asked which of these they have included in their procedures.

Answer options	Hyperbaric unit 1	Hyperbaric unit 2	Hyperbaric unit 3	Hyperbaric unit 4	Hyperbaric unit 5	Hyperbaric unit 6	Hyperbaric unit 7
Check chamber oxygen content	✓	✓	✓	✓		✓	✓
Only adhesive defibrillator pads to be used (no paddles)		✓	✓	✓	✓	✓	✓
Paddles or pads placed on the patient's front and back (Anterior and posterior placement)			✓				✓
Paddles or pads placed on the patient's chest (anterior lateral placement)	✓	✓	✓	✓	✓	✓	
Chamber breathing system switched to air during shocking		✓		✓			
All staff inside the chamber to visually check that no one is touching the patient or gurney/trolley		✓	✓	✓	✓		✓
All staff inside the chamber to give a visual signal to the defibrillator operator that they are not touching the patient or gurney/trolley	✓			✓	✓		
All staff inside the chamber to tell the defibrillator operator that they are not touching the patient or gurney/trolley			✓	✓	✓		✓
All staff inside the chamber required not to touch metallic parts of the chamber during the shock	✓	✓		✓			
Operator confirms that shock is delivered and it is safe to touch the patient or continue CPR.	✓	✓	✓	✓	✓	✓	✓

Table 2.5: Identified actions that form part of formal procedures for defibrillation inside their hyperbaric chamber for those units that indicated that they had the capability and would defibrillate inside their chamber (n=7).

These units that could defibrillate inside a chamber where then given a list of nine pieces of safety related and communication equipment that are common to many chambers and asked which of these items they use. Response to this question was also low with only seven respondents answering (table 2.6).

Does the chamber you allow defibrillation in have any of the following:	Hyperbaric unit 1	Hyperbaric unit 2	Hyperbaric unit 3	Hyperbaric unit 4	Hyperbaric unit 5	Hyperbaric unit 6	Hyperbaric unit 7
Externally operated fire fighting system (deluge or sprinkler system)	✓		✓	✓		✓	✓
Internally operated fire fighting system (deluge or sprinkler system)		✓	✓	✓		✓	✓
Automatic fire fighting system (deluge or sprinkler system)	✓					✓	
Fire fighting hoses/ hand lines inside the chamber	✓	✓		✓		✓	
Hyperbaric fire extinguisher inside the chamber			✓	✓	✓	✓	✓
Standard fire extinguisher inside the chamber		✓					
Two way speaker system (bullhorn) that allows hands free communication between staff inside and outside chamber operator	✓	✓	✓	✓	✓	✓	✓
Two way headset that allows hands free communication between inside attendant and outside chamber operator		✓					✓
CCTV system		✓	✓	✓	✓	✓	✓

Table 2.6: Items of safety related equipment found in the chambers that respondents identified as the hyperbaric chambers they permit defibrillation in (n=7).

Of the nine units that gave further data, five incidents of in chamber SCA within the last five years were identified; three of which received defibrillation inside the chamber whilst under pressure one of which was successfully resuscitated. The other two cases of in chamber SCA did not have shockable rhythms and neither patient survived. All five cases occurred in hospital based ICU capable units. No responses were received from the follow up questionnaire sent out to the units that had experienced in chamber SCA and had the capability to defibrillate inside the chamber.

No safety related incidents involving in chamber defibrillation were identified in any responses from any of the samples surveyed. When comparing the available data on SCA's from respondents that do permit in-chamber defibrillation and those that do not, a total of 10 cases of in-chamber SCA were identified (table 2.6) with an overall resuscitation success rate of 40.% (n=4).

in-chamber vs outside chamber defibrillation	Total number of in-chamber SCA (in the last 5 years)	Number of in-chamber SCA with shockable rhythms defibrillated	Number of in-chamber SCA patients who received defibrillation and were successfully resuscitated	Number of in-chamber SCA with non shockable rhythms	Number of in-chamber SCA with non shockable rhythms and were successfully resuscitated
Units that do permit in-chamber defibrillation	5	3*	1	2	0
Units that do not permit in-chamber defibrillation	5	1	1	4	2

*Table 2.6: Comparison of in-chamber SCA data (*All three cases defibrillated in-chamber). A total of 10 cases of in-chamber cardiac arrest where identified over a five year reference period. Five cases occurred in hyperbaric units that did permit in-chamber defibrillation and five cases occurred in chambers that did not. All 10 cases occurred in hospital based, ICU capable units. Only six units had experienced in-chamber cardiac arrest which equates to 11.7% of the sample. These statistics show an immediate survival rate of 40% for all 10 cases. When viewed over the reference period (5 years) and including all 51 respondents the probability rate for any single unit experiencing a cardiac arrest is 0.196 or 1 every 25.5 years. The probability of one of these ICU capable units experiencing an in-chamber cardiac arrest is 0.29 or 1 every 17 years.*

These results change drastically when examining only the units that clearly permit in-chamber defibrillation (n=9) with a probability rate of 0.55 or 1 every 9 years. The probability of any of these units having to carry out defibrillation due to in chamber SCA is 0.078 or 1 every 64.1 years. The same probability for an ITU capable unit is 0.117 or 1 every 42.7 years. When examining those units that do permit in-chamber defibrillation, and using variables specific to those units, the probability of any one of the identified units having to carryout defibrillation in a hyperbaric chamber is 0.333 or 1 every 15 years.

9.4 Qualitative data

All respondents were given the opportunity to give further comments on the subject of in-chamber defibrillation. Those that did make comments ranged from simple unambiguous statements such as *"Too dangerous"* to more pragmatic approaches. The theme of defibrillation being deemed too dangerous to attempt inside the chamber was a noted one, one respondent stated:

"After losing a patient from cardiac arrest in 1974, I supervised installation of defibrillator inside the military multi-place chamber. We used it successfully in 1984. In 1990 new physicians on the staff felt it was too dangerous so the paddles were removed and a policy was established to defibrillate outside the chamber"

Other views examined the clinical risk of cardiac arrest occurring, even in a critically ill patient. One respondent stated:

"I have done HBO2 (sic) and CCM for 30 years. Although we have a Fink large multi-place chamber in the hospital that supports critical care all of our critically ill patients are treated in mono-place chambers. More than 5 years ago I have had to do such cardioversion twice and defibrillation after removal of the patient three times. In the last 5 years such events have not happened. Personally I think doing defibrillation in a chamber while at pressure is much ado about little and should not be done. However the critical patient needs to be intubated and have central lines and arterial lines with pressure already running when necessary so cardiac arrest becomes very unlikely anyway."

Many of the qualitative answers were from units that used mono-place chambers which revolved around the theme that defibrillation is never carried out inside one and therefore is not an issue.

Another common theme was to further explain the procedures that units use. The need to immediately decompress a chamber so that defibrillation can take place outside vs the decompression obligations of any inside attendant was mentioned. In this case, the possibility of compressing extra staff into the chamber to take over resuscitation allowing any attendant to be relieved and decompressed in a separate adjoining chamber or lock was one noted theme.

Staffing levels and training was the final theme noted. With respondents expressing the need for regular staff and regular training to cover standardised procedures.

10. Conclusions

Cardiac arrest during hyperbaric treatment is clearly a rare event. Few hyperbaric units are prepared to allow in chamber defibrillation as part of their procedures to deal with cardiac arrest. Although small in size, the research has been able to identify some key issues and has achieved its aim of improving the principles of safe defibrillator use inside hyperbaric chambers by identifying key factors that may assist individual hyperbaric units when carrying out their own risk assessment.

Objective one looked at the prevalence of defibrillators available for use inside a hyperbaric chamber.

It is clear that having the ability to defibrillate inside a hyperbaric chamber does not mean that units would automatically choose to do this as some of the respondents have clearly identified. Of the 51 respondents to the initial questionnaire only 23.5% stated that they had the ability to defibrillate inside a hyperbaric chamber however only 17.6% clearly indicated that they would defibrillate inside a hyperbaric chamber. This shows that the prevalence of defibrillators available to use inside a hyperbaric chamber, whether the entire unit goes into the chamber or just the pads or paddles via an electrical penetrator, is low.

Objective two examined the prevalence of in-chamber cardiac arrest and in-chamber defibrillation.

Of the 10 cases of in-chamber cardiac arrest identified, only four cases received defibrillation (whether in-chamber or not). Based on the overall study sample size, this is an individual unit's

probability rate of 0.196 or one arrest every 25.5 years for all classes and types of hyperbaric unit and a probability rate of 0.078 or one defibrillation every 64.1 years. This shows that in-chamber cardiac arrest is a very rare event with the potential for the use of in-chamber defibrillation by default even rarer. However, when evaluating cardiac arrest rates in hyperbaric units that are prepared to defibrillate inside a hyperbaric chamber the probabilities change drastically. For these units the probability rate is much higher at 0.55 or one arrest every nine years and a probability rate of 0.333 or one every 15 years for in-chamber defibrillation.

Objective three involved identifying how many safety related incidents involving the use of a defibrillator during a hyperbaric treatment.

There were no incidents involving defibrillators identified and this was not wholly unexpected due to the low numbers of in-chamber cardiac arrest and defibrillation identified. Of the small number that responded to the follow up questionnaire no safety related incidents at all were identified.

Objective four looked to compare and contrast the effectiveness of in-chamber versus outside chamber resuscitation and defibrillation.

Table 2.6 compared the available data on successful resuscitation including defibrillation between units that could and would defibrillate patients inside a hyperbaric chamber to those units that would not. Even though the apparent overall success rate for units that do not permit in-chamber defibrillation was higher the general sample size is very small and may not be representative of the whole study population. However, when the overall immediate survival rate of 40% is compared with a general in-hospital immediate survival rate of resuscitation of 48.9% (NCAA, 2016) the difference is relatively significant.

Objective five aimed to identify the type of unit that was prepared to defibrillate inside a hyperbaric chamber.

Although a small number of samples indicated a willingness to defibrillate inside a hyperbaric chamber it was clear that the majority of these chambers tend to be hospital based and capable of treating intensive care patients.

Objective six aimed to identify the types of chambers and safety related equipment used in conjunction with defibrillators.

All those respondents that indicated that they would defibrillate inside a chamber used multi-place hyperbaric chambers which is in line with current best practice and not unexpected, however it is worthy of note that one of these chambers was identified as a duo-place chamber (capable of taking only two occupants). All of those respondents used a two way hands free communication systems. With all those units having some form of firefighting equipment available inside the hyperbaric chamber, indeed most had some form of redundant or back-up system of firefighting. Most units relied on some form of sprinkler/ deluge system with either a fire extinguisher or firefighting hand lines as a secondary firefighting system.

Objective seven examined key concerns that all respondents had with the concept of in-chamber defibrillation.

Units of all types had a high concern for fire and unintentional electric shock; however these concerns were lower in those units that did have the capability to defibrillate. Those units that

did have the capability to defibrillate also indicated that not having enough staff to carryout safe in-chamber defibrillation was a high concern. It is clear that safety is the main reason that chambers that do not have the ability to defibrillate choose not to do so.

Objective eight sought to identify key common safety strategies used during in-chamber cardiac arrest and defibrillation.

Three case scenarios were identified, cardiac arrest in a mono-place hyperbaric chamber, cardiac arrest in an air filled multi-place chamber and cardiac arrest in a multi-place air filled chamber where defibrillation was permitted. The majority of units have procedures in place to deal with in-chamber cardiac arrest however 30% of units that could not defibrillate inside a hyperbaric chamber had no such procedures in place. Of the small sample size of units that operated mono-place chambers 50% used the procedure that called for immediate decompression of the chamber then removal of the patient 2-3 metres away prior to attempting defibrillation. For those units that used multi-place chambers but could not carry out in-chamber defibrillation the results were more mixed with no clear preferred method. However it was clear that this group was divided into two sub-groups; those that did use in-chamber attendants and those that did not. The majority did use attendants and the most popular procedure for them was to immediately decompress the chamber to the surface and if necessary treat the attendant for omitted decompression or decompression sickness. For those units that had the capability and would defibrillate inside a chamber the emphasis was placed on specific actions that operators would perform prior to delivery of a shock. Most respondents agreed that pads or paddles could be placed on the chest laterally as normal and all stated that the operator was to confirm that a shock has been delivered and this it is safe to touch the patient. The majority of these units (85.7%) also checked the oxygen content within the chamber prior to delivery of the shock with the same numbers also requiring staff to check that no one is touching the patient or gurney prior to delivery of the shock. A same number also stated that they would only use self-adhesive pads as opposed to paddles.

The final objective aimed to analyse the quantifiable data to establish and links between variables.

As previously mentioned, cardiac arrest inside a hyperbaric chamber is rare and that defibrillation inside a chamber would be rarer. With no evidence to suggest that there had been any safety related incidents involving in-chamber defibrillation relationships centred on capabilities, concerns and cases of in-chamber cardiac arrest. Although the chances of any single unit experiencing an in-chamber cardiac arrest was low it was clear that those units that where capable and prepared to carry out in-chamber defibrillation were more likely to experience this. Similarly chambers that have an intensive care capability were also at a higher risk of experiencing an in-chamber cardiac arrest. What is also clear is that although safety concerns regarding in-chamber defibrillation are given similar priorities, those units that are do have the capability to carry out in chamber defibrillation are less concerned with the possibility of fire occurring when compared to those units that do not have the capability. Overall concerns regarding available staff and clinical safety issues are more prominent among respondents that did have the capability to defibrillate.

The data shows that defibrillation inside a hyperbaric chamber has been effective and carried out safely; however the sample size is very small. Although testing has been previously carried out in swine, further holistic scenario research is required. Opinions on whether defibrillation is safe or should be carried out also vary, with the majority of respondents not opting to carry out in chamber defibrillation with safety concerns clearly being the main reason.

Although it could cause a delay in delivering defibrillation, electing to decompress the chamber and defibrillate outside the chamber has also been effective. This does not seem to have a major impact on initial survival rates for resuscitation when compared to in hospital cardiac arrest statistics as long as the decompression is immediate and relatively quick. There is no evidence that this rapid decompression has harmed any inside attendant as those units indicated that they treat the attendant for omitted decompression or decompression sickness as part of their procedures anyway. However the sample size of this cohort is small and further research is required.

It is would be advisable for those units that wish to consider in-chamber defibrillation to carry out a thorough risk assessment based on the units capabilities and outside support that is available. Consideration should be given to the space needed to carry out safe defibrillation as well as the type of defibrillator to be used with a better option of having a chamber compatible defibrillator that can be placed into the chamber in an emergency. A key concern would be identifying the training needs of staff that may be required to carry out in chamber defibrillation as well as ensuring adequate numbers of trained staff. A further consideration should be given to the type of patients being treated and the level of general care that a unit can supply as only units that have an intensive care capability and support should consider in-chamber defibrillation. A primary firefighting system should be installed with access to a redundant back up firefighting system also being available. Non-conductive matting should cover the entire floor space of the chamber and staff should wear non-conductive footwear.

For those units that would not carry out in-chamber defibrillation; it would be necessary to carry out a risk assessment with emphasis on the effect of rapid decompression on any attendant or other patients. If these units cannot decompress the chamber so that a shock can be delivered within Three minutes, or cannot gain access to advanced life support capabilities within a similar timeframe to that of any parent hospital that would be expected, it would be advisable that this is stated during the consent phase of any patient consultation. This would be more relevant to hospital based units and should include an explanation of why there would be a delay. Attendants should be recompressed inside a chamber as soon as possible if they have omitted decompression. Units should not wait for symptoms to occur and surface decompression using oxygen should be considered as a means to prevent decompression sickness in attendants during and after an in-chamber cardiac arrest. If units choose to treat attendants for omitted decompression or decompression illness as part of their cardiac arrest procedures the extra risks to the attendant should be explained prior to employment and should be included in any training or, at the very least, prior the start of the treatment.

All units will need to recognise the unique risks to any option they use and should carry out regular training on the specific scenario of in-chamber cardiac arrest and abort procedures.

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13. Appendices

Appendix 1.

Initial questionnaire

Defibrillation safety inside hyperbaric chambers
(P1 General)

Is your hyperbaric unit located within a hospital?	
Answer Options	
YES	
NO	

Does your hyperbaric unit use:	
Answer Options	
Multiplace air chambers	
Monoplace oxygen chambers	
Both multiplace air chambers and monoplace oxygen chambers	
Other	

Can your hyperbaric unit treat ventilated and intubated (ICU) patients?	
Answer Options	
YES	
NO	

Does your hyperbaric unit have the ability to defibrillate a patient inside a hyperbaric chamber whilst under pressure?	
Answer Options	
YES	
NO	

Defibrillation safety inside hyperbaric chambers
(P2 Hyperbaric units that do not defibrillate inside a chamber during treatment)

Does your hyperbaric unit have immediate access to a defibrillator?	
Answer Options	
Yes, a defibrillator is immediately available and located within the hyperbaric unit itself	
Yes, the defibrillator is immediately available but is held nearby and not within the hyperbaric unit itself	
No, our unit does not have immediate access to a defibrillator	

In the last 5 years, to the best of your knowledge, how many cases of cardiac arrest have occurred within your hyperbaric chamber(s) during a hyperbaric treatment?	
Answer Options	
Open question	

In the last 5 years, if you have had cases of cardiac arrest within your chamber(s) during a hyperbaric treatment how many had a shockable rhythm that was defibrillated?	
Answer Options	
Open question	

In the last 5 years, how many patients who arrested during treatment and received defibrillation were successfully resuscitated? For the purposes of this study a successfully resuscitated patient is one that left the unit with spontaneous circulation or regained spontaneous circulation later.	
Answer Options	
Open question	

In the last 5 years, how many patients who arrested during treatment and defibrillation was not indicated or used were successfully resuscitated? For the purposes of this study a successfully resuscitated patient is one that left the unit with spontaneous circulation or regained spontaneous circulation later.

Answer Options
Open question

Does your unit have specific procedures in place to deal with cardiac arrest inside the hyperbaric chamber during treatment when the chamber is pressurised?

Answer Options
YES
NO

If your unit does have specific procedures to deal with cardiac arrest inside the chamber during treatment, which statement below best describes your main strategy for your monoplace chamber?

Answer Options
Unit does not have a monoplace chamber
Immediately decompress the chamber, remove patient, CPR, defibrillation (if indicated), advanced life support or call for advanced life support
Immediately decompress the chamber, remove patient and move them at least 2- 3m (6-10 feet) away from the chamber, CPR, defibrillation (if indicated), advanced life support or call for advanced life support
Immediately decompress the chamber, remove patient, CPR only, request outside help for advanced life support and defibrillation
No procedures in place
The procedures listed are not similar to procedures we use.

If your unit does have specific procedures to deal with cardiac arrest inside the chamber during treatment, which statement below best describes your main strategy for your multiplace chamber?

Answer Options
Unit does not have a multiplace chamber
Chamber with attendant: CPR, immediately decompress chamber to surface, remove patient, defibrillation (if indicated) advanced life support or call for advanced life support, treat attendant for omitted decompression or decompression sickness
Chamber with attendant: CPR, immediately decompress chamber to surface, remove patient, defibrillation (if indicated) advanced life support or call for advanced life support, treat attendant only if symptoms of decompression sickness occur.
Chamber with attendant: CPR, decompress chamber to using standard decompression tables, remove patient, defibrillation (if indicated) advanced life support or call for advanced life support,
Chamber with attendant: CPR, immediately decompress chamber using surface decompression tables, remove patient, defibrillation (if indicated) advanced life support or call for advanced life support, recompress the attendant as per the surface decompression tables
Chamber with attendant: CPR, doctor to enter the chamber and make further decisions after patient evaluation,
Chamber with attendant: CPR, only doctor to make further decisions and give instructions.
Chamber without attendant: Doctor or member of staff to enter the chamber and make further decisions after patient evaluation
Chamber without attendant: CPR, immediately decompress chamber to surface, remove patient, defibrillation (if indicated) advanced life support or call for advanced life support.
No procedures in place
The procedures listed are not similar to procedures we use

In order of priority (1=highest priority 6= lowest priority), what are the main reasons why your unit does not defibrillate patients under pressure during a hyperbaric treatment?

Answer Options	1	2	3	4	5	6
Local regulations or laws or best practice prevent it						
Safety reasons						
Technically complicated and difficult to install or too costly						
Staff training issues or staffing levels						
Clinical risk of cardiac arrest occurring is low						
Other reasons						

As a unit, in order of priority (1= highest priority 8= lowest priority) when considering the use of a defibrillator inside your chamber(s) what would be your main safety concerns?

Answer Options	1	2	3	4	5	6	7	8
Unintentional electric shock to staff or patients								
Fire hazard								
Complicated procedures leading to mistakes								
Limited space to carryout safe defibrillation								
Available staff to carryout safe defibrillation and life support								
Patient clinical safety issues								
It would not be best practice or would be against local regulations or laws								
Other reasons								

Defibrillation safety inside hyperbaric chambers
(P3 Hyperbaric units that can defibrillate inside a chamber during treatment)

Does your hyperbaric unit have immediate access to a defibrillator?

Answer Options
Yes, a defibrillator is immediately available and located within the hyperbaric unit itself or close by and is permitted inside the hyperbaric chamber
Yes a defibrillator is immediately available and located within the hyperbaric chamber itself
Yes a defibrillator is immediately available with pads or paddles located inside the chamber via an electrical penetrator and the defibrillator is immediately available and located within the hyperbaric unit itself or close by but is not permitted inside the chamber
No, our unit does not have immediate access to a defibrillator

If the defibrillator you use is allowed inside the hyperbaric chamber during treatment whilst the chamber is under pressure, is the defibrillator certified and approved by the manufacturer for use inside a hyperbaric chamber?

Answer Options
We do not allow a defibrillator inside the chamber whilst it is under pressure
Yes it is approved and certified by the manufacturer for use inside a hyperbaric chamber
No it is not approved and certified for use by the manufacturer for use inside a hyperbaric chamber, but we do allow its use inside the chamber whilst under pressure

As a unit, in order of priority (1= highest priority, 7= lowest priority) what are your main safety concerns when using a defibrillator inside a chamber whilst at pressure?

Answer Options	1	2	3	4	5	6	7
Unintentional electric shock to staff or patients							
Fire hazard							
Complicated procedures leading to mistakes							
Limited space to carryout safe defibrillation							
Amount of staff available to carryout safe defibrillation and life support							
Patient clinical safety issues							
Other reasons							

In the last 5 years, to the best of your knowledge, how many cases of cardiac arrest have occurred within your hyperbaric chamber(s) during a hyperbaric treatment?	
Answer Options	
Open question	

In the last 5 years, if you have had cases of cardiac arrest within your chamber(s) during a hyperbaric treatment how many had a shockable rhythm that was defibrillated inside the chamber whilst under pressure?	
Answer Options	
Open question	

In the last 5 years how many patients who arrested during treatment and received defibrillation inside the chamber whilst under pressure were successfully resuscitated? For the purposes of this study a successfully resuscitated patient is one that left the unit with spontaneous circulation or regained spontaneous circulation later.	
Answer Options	
Open question	

In the last 5 years how many patients who arrested during treatment and defibrillation was not indicated or used were successfully resuscitated? For the purposes of this study a successfully resuscitated patient is one that left the unit with spontaneous circulation or regained spontaneous circulation later.	
Answer Options	
Open question	

Does your hyperbaric unit have a specific procedure for the use of a defibrillator inside the hyperbaric chamber during pressurisation?

Answer Options
YES
NO

If your unit does have a procedure are operators required to carry out any of the following prior to delivering a shock? (check/tick all that apply)

Answer Options
Check chamber oxygen content
Only adhesive defibrillator pads to be used (no paddles)
Paddles or pads placed on the patient's front and back (Anterior and posterior placement)
Paddles or pads placed on the patient's chest (anterior lateral placement)
Chamber breathing system switched to air during shocking
All staff inside the chamber to visually check that no one is touching the patient or gurney/trolley
All staff inside the chamber to give a visual signal to the defibrillator operator that they are not touching the patient or gurney/trolley
All staff inside the chamber to tell the defibrillator operator that they are not touching the patient or gurney/trolley
All staff inside the chamber required not to touch metallic parts of the chamber during the shock
Operator confirms that shock is delivered and it is safe to touch the patient or continue CPR.

Does the chamber that you allow defibrillation in have any of the following? (check/tick all that apply)

Answer Options
Externally operated firefighting system (deluge or sprinkler system)
Internally operated firefighting system (deluge or sprinkler system)
Automatic fire fighting system (deluge or sprinkler system)
Firefighting hoses/ hand lines inside the chamber
Hyperbaric fire extinguisher inside the chamber
Standard fire extinguisher inside the chamber
Two way speaker system (bullhorn) that allows hands free communication between staff inside and outside chamber operator
Two way headset that allows hands free communication between inside attendant and outside chamber operator
CCTV system

In the last 5 years, have you had any safety incidents involving defibrillation inside the chamber whilst it is at pressure?	
Answer Options	
YES	
NO	

Defibrillation safety inside hyperbaric chambers
(P4 Defibrillator safety incidents in hyperbaric chambers)

How many general safety related incidents involving the use of defibrillators inside a chamber under pressure have you had in the last 5 years	
Answer Options	
Open question	

How many of these incidents' primary safety issue was:	
Answer Options	
Fire or risk of fire	
Electrocution of staff or bystanders	
Defibrillator or defibrillator pads/paddles failure or defect (No risk of fire or electrocution of staff)	
Clinical patient safety issue only	
Other issue	

How many people have been injured as a result of these incidents?	
Answer Options	
Open question	

If anyone was injured, how many of these injuries were:	
Answer Options	
Minor injuries	
Moderate injuries	
Major injuries	
Death	

Defibrillation safety inside hyperbaric chambers (P5 Additional comments)

Additional comments on defibrillation inside a hyperbaric chamber during treatment.	
Answer Options	
Open question	

Appendix 2.

Follow up questionnaire
(To those units that have had in-chamber cardiac arrest)

What condition was the person who had a cardiac arrest being treated for? (Check /tick all that apply).				
In-chamber cardiac arrest in the last five years				
Answer Options	Case 1	Case 2	Case 3	Case 4
Air or gas embolism				
Carbon monoxide poisoning				
Clostridial myositis and myonecrosis (gas gangrene)				
Crush injury, compartment syndrome or other acute traumatic ischemias				
Decompression sickness				
Arterial insufficiencies				
Severe anaemia				
Intracranial abscess				
Necrotising soft tissue infections				
Osteomyelitis (refractory)				
Delayed radiation injury (soft tissue and bone necrosis)				
Compromised grafts and flaps				
Acute thermal burns				
Idiopathic sudden sensorineural hearing loss				
Other condition				
The cardiac arrest was not in a patient				

At what point in the treatment did the arrest occur?				
In-chamber cardiac arrest in the last five years				
Answer Options	Case 1	Case 2	Case 3	Case 4
Before any pressurisation but still inside the chamber				
During the pressurisation (compression) phase				
During the treatment phase at a fixed pressure				
During the decompression phase of the treatment				
After the treatment but still inside the chamber				

Was the patient an intensive care patient?

In-chamber cardiac arrest in the last five years

Answer Options	YES	NO
Case 1		
Case 2		
Case 3		
Case 4		

How many patients were being treated in the chamber at the time of the arrest? (including any patient that arrested).

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
0				
1				
2				
3				
4				
5-6				
7-10				
11-12				
13-15				
16-20				
More than 20				

How many members of staff were inside the chamber during the resuscitation (including any hospital or other clinical staff compressed into the chamber to assist)?

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
0				
1 member of staff				
2 members of staff				
3 members of staff				
4 members of staff				
5 members of staff				
More than 5 members of staff				

What was the medical qualification of the first responder to the arrest? (first person to gain 'hands on' access to the patient and begin resuscitation. If more than one person was present please state the person with the highest qualification)

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Consultant anaesthetist or intensivist (medical doctor)				
Other medical consultant (medical doctor)				
Physician (medical doctor)				
Registered (Licensed) Intensive care nurse				
Registered (Licensed) nurse				
Other registered (Licensed) healthcare professional				
Non healthcare professional				

Was the treatment aborted due to the arrest? (this includes any decompression for an attendant that had to be used that was not part of the treatment table's standard decompression)

In-chamber cardiac arrest in the last five years

Answer Options	YES	NO
Case 1		
Case 2		
Case 3		
Case 4		

If the treatment was not aborted what was the reason? (please only answer if a treatment was not aborted)

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Clinical reasons				
Attendant decompression obligations as per the treatment protocol				
Other reasons				

What best describes the type of chamber the arrest occurred in?

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Mono-place hyperbaric chamber				
Cylindrical (round) multi-place chamber				
Square multi-place chamber				
Other type of chamber				

How many people can the main chamber that the arrest occurred in accommodate? (This is best identified by the number of individual BIBS masks or hoods that can be used in the main chamber compartment)

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Mono-place chamber (single occupant)				
2 persons				
3 persons				
4 persons				
5-6 persons				
7-10 persons				
11-12 persons				
13-15 persons				
16-20 persons				
More than 20 persons				

How much time passed from point of arrest to end of decompression? (including any staged decompression stops for any attendants).

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
The treatment and decompression continued as normal				
Less than 1 minute				
Between 1 and 3 minutes				
Between 3 and 5 minutes				
Between 5 and 10 minutes				
Between 10 and 20 minutes				
Between 20 and 40 minutes				
Between 40 and 60 minutes				
Over 60 minutes				

Was a defibrillator used on the patient whilst the chamber was under pressure?

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Yes				
No defibrillation was not indicated (but it is permitted in the chamber if necessary)				
No Defibrillation is not permitted in the chamber (but defibrillation was indicated)				
No Defibrillation is not permitted in the chamber (and defibrillation was not indicated)				

How closely were your in-chamber cardiac arrest procedures followed? (this question is qualitative in nature and we understand that it is based on personal belief and recollection)

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Followed completely with no issues identified				
Followed completely with some minor to moderate safety or procedural issues identified				
Followed completely with some serious safety or procedural issues identified				
Followed partially with no issues identified				
Followed partially with some minor to moderate safety or procedural issues identified				
Followed partially with some serious safety or procedural issues identified				
No specific in-chamber procedures followed with no issues identified				
No specific in-chamber procedures followed with minor to moderate safety or procedural issues identified				
No specific in-chamber procedures followed with serious safety or procedural issues identified				
No comment as the answers supplied do not accurately describe what happened				

Was a team debriefing held after the arrest to identify any issues or raise concerns?

In-chamber cardiac arrest in the last five years

Answer Options	Case 1	Case 2	Case 3	Case 4
Yes				
No				
Partially or informally				

Do you have any further information that you would like to add about these cases of cardiac arrest during hyperbaric treatment?

Answer Options
Open question