The incidence of cardiac arrest requiring defibrillation and defibrillation protocols in Australasian hyperbaric units

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Keywords
Cardiovascular; Diving medicine; Fire or explosion; Hyperbaric medicine; Hyperbaric facilities; Pressure chambers; Safety

Abstract
(Beilharz AG, Banham N, Gawthrope I. The incidence of cardiac arrest requiring defibrillation and defibrillation protocols in Australasian hyperbaric units. Diving and Hyperbaric Medicine. 2025 December 20;55(4):338–342. doi: 10.28920/dhm55.4.338-342. PMID: 41364857.)

Introduction: Cardiac arrest (CA) during hyperbaric oxygen treatment (HBOT) is exceedingly rare with only a few cases reported. It is unknown if in-chamber defibrillation of a patient has been performed in Australasia. In-chamber defibrillation is potentially dangerous with the risk of fire in an oxygen-rich environment. Australasian Standards prohibit the use of currently available defibrillators licensed for in-chamber use, as they contain lithium batteries. This study aimed to investigate how CA is managed in Australasian hyperbaric medicine units (HMUs) and to establish if there is a need to develop standardised protocols.

Methods: A 10-part SurveyMonkey® questionnaire sent to all 15 Australasian HMUs. Questions aimed to ascertain if there were cases where defibrillation during HBOT was indicated and if it was performed. We asked about emergency treatment protocols, defibrillation capabilities and if regular training drills were conducted. We asked if colleagues felt the need to have a uniform treatment protocol across Australasia and invited them to share their emergency protocols.

Results: Fourteen responses (93.3%) were received. No clinical cases of in-chamber CA or defibrillation were reported. Examples of emergency treatment protocols were provided by two respondents. Six respondents (43%) stated that regular emergency training drills for CA are performed in their HMU. Eleven respondents (79%) favoured standardised treatment protocols; however, comments suggested that this might be unachievable.

Conclusions: CA requiring defibrillation in the hyperbaric medicine context is rare and has not been performed in Australasia. Most HMUs have protocols in place, but they are not universally practiced regularly.

Introduction

Cardiac arrest (CA) in the context of hyperbaric oxygen treatment (HBOT) is a rare, yet critical event requiring special considerations. The incidence of defibrillation during HBOT in Australasia is unknown and there are only a few reported cases worldwide.[1–7] The purpose of this study was to ascertain the incidence of CA requiring defibrillation from all hyperbaric medicine units (HMUs) in Australasia.

Patient cohorts in HMUs are often elderly, at risk of coronary artery disease and its complications (including CA), and present with multiple co-morbidities.

When a cardiac arrest occurs during HBOT, the aetiology is of significance to determine the most suitable management option whilst aiming to minimise the risk of harm to other chamber occupants (other patients and medical attendants).

Hyperoxygenation during HBOT seems to confer a protective effect and may prevent cardiac insults to a certain degree, as well as providing a 'grace period' during which cardiopulmonary resuscitation (CPR) can be delayed. The high dissolved blood oxygen concentration is assumed to delay the onset of tissue hypoxia, buying time to decompress and provide out-of-chamber defibrillation.[4,6]

CA with ventricular fibrillation (VF) or pulseless ventricular tachycardia (VT) is best managed with early defibrillation. There is overwhelming evidence that the timely delivery of a direct current (DC) countershock in such cases is the most significant determinant of survival.[1,2] The Australian and New Zealand Committee on Resuscitation recommends that a shock is delivered as soon as a defibrillator is available and that pads are placed on the exposed chest in the antero-lateral or anterior-posterior position (in patients with an implantable cardioverter-defibrillator or a permanent pacemaker at least 8 cm from the generator position). Biphasic waveforms should be used with a default energy level of 200 joules (J) for all shocks; if not successful it is reasonable to increase the energy for subsequent shocks.[3] A single shock protocol should be followed with an emphasis on delivering

uninterrupted good quality chest compressions to create ideal conditions for successful shock delivery.[3]

Under 'Precautions' (9) and 'Oxygen and Fire Risk' (9.1), attention is drawn to electrical hazards in the presence of water, metal fixtures, oxygen (O_2) and flammable substances, but there is no specific mention of the special circumstance of defibrillation under hyperbaric conditions.[3] Four case reports involving adults and one involving a neonate have resulted in fires caused by sparks generated during defibrillation attempts when paddles were used in the vicinity of high flow O_2 (at ambient atmospheric pressure).[1] However, paddles have now become widely obsolete. There have been no reports of fires caused by sparking when shocks were delivered using adhesive pads.[2] The recommended technique advises taking precautions to minimise sparking by ensuring good pad contact with the chest wall, correct pad placement and that rescuers should try to ensure that defibrillation is not attempted in an O_2-rich environment (i.e., high-flow O_2 directed across the chest).

The Fiona Stanley Hospital HMU has emergency procedures to follow in case of CA requiring defibrillation in monoplace and multiplace chambers (*Appendix 1). All include decompressing the chamber to surface pressure and shock delivery outside the chamber. We aimed to establish the incidence of cardiac arrest requiring defibrillation in Australasian HMUs and to survey their related emergency procedures.

Methods

Written approval was obtained for data review and extraction from Governance, Evidence, Knowledge and Outcomes (GEKO) at Fiona Stanley Hospital, Perth, Western Australia (Approval Number 52502).

A questionnaire was sent to all HMUs in Australasia via SurveyMonkey (SurveyMonkey Inc.) to ascertain the incidence of in-chamber CA requiring defibrillation. The survey was anonymous, with the option to self-identify and provide further details if deemed appropriate. The survey questionnaire (*Appendix 2) also aimed to establish if HMUs had related emergency procedures in place should a CA occur and if they differed with respect to monoplace or multiplace chambers and between different treatment tables. If a HMU had such cases occur, they were invited to provide more detail on how these were managed.

Results

The survey questionnaire and respondents' replies can be viewed in *Appendix 2.

The response rate to the survey was 93.3% (14/15 HMUs). There were no clinical cases of CA, but one historical experiment of multiple in-chamber defibrillations of a large piece of meat while under pressure was reported.

Two respondents provided examples of emergency procedures and 11 (79%) favoured these to be standardised across all HMUs. However, comments suggest that this might be impractical or unachievable.

Discussion

Defibrillation forms an essential part of modern resuscitation algorithms by delivering an electric shock to a patient's chest with the aim of converting a shockable rhythm (ventricular fibrillation or tachycardia) causing cardiac arrest to sinus rhythm.[1–3] This is achieved by storing an electrical charge in a capacitor and then subsequent discharging it to the patient's chest via electrodes (pads or paddles).

Most defibrillators currently in use are biphasic, delivering lower energy shocks via adhesive pads with supposedly less risk of sparking and arcing compared to monophasic shocks delivered with paddles.[1] However, several reports to the US Food and Drug Administration (FDA) database MAUDE (Manufacturer and User Facility Device Experience) indicate sparking even with adhesive pads and there is one report of a patient receiving burns during defibrillation in an ambulance.[4] Sparking, arcing and risk of burns can be minimised by applying a meticulous technique with either paddles or pads. The Australia and New Zealand Committee on Resuscitation recommends to avoid charging paddles unless on the patient's chest, ensuring good contact and no gap between paddles/pads and the chest wall, avoiding placement over ECG electrodes, leads, medication patches, implanted devices or central line insertion sites. The patient should not be in contact with metal fixtures or in a high O_2 environment.[3]

In-chamber defibrillation is potentially dangerous with the most significant risk being fire from elevated partial pressures of O_2 and voltaic arcing providing an ignition source. Performing in-chamber defibrillation with cables being fed out of the chamber via a penetrator and the defibrillator and operator placed outside the chamber may reduce the risk of fire. This system is currently mostly applied in HMUs in Europe and less commonly in North America, Asia and Australasia. None of the Australia-New Zealand respondents were using this capability at the time of our survey.

The results of our survey revealed that there is no actual clinical experience with CA in the diving and hyperbaric medicine context in Australasia. The only reported experience with defibrillation under pressure in a

*** Footnote:** Supplementary Appendix 1 and 2 are available to view at https://www.dhmjournal.com/index.php/journals?id=374

Figure 1
Simulation model for informal in-chamber defibrillation trial Fremantle Hospital 1994

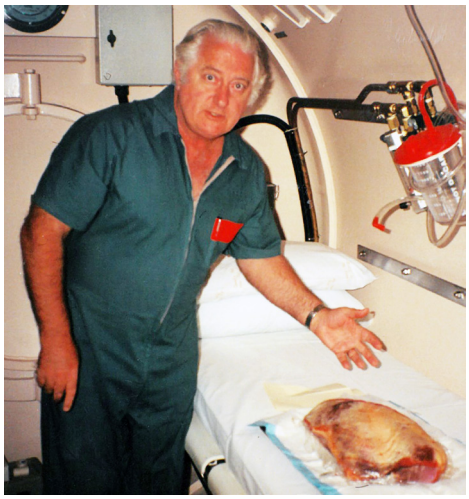
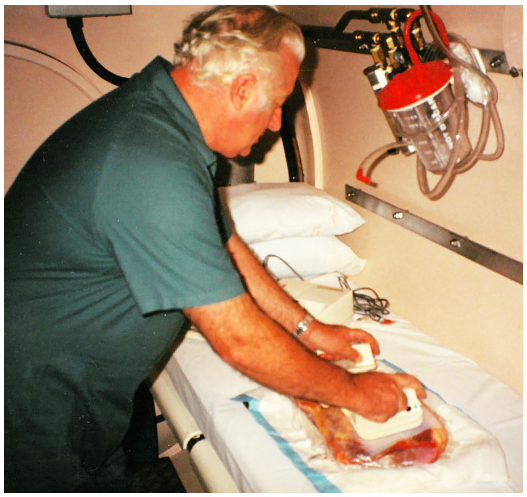


Figure 2
In-chamber defibrillation model in use Fremantle Hospital 1994



hyperbaric chamber was from the Fremantle Hospital HMU, Western Australia, where experiments of defibrillation of a large piece of meat were conducted in 1994 (Figures 1 and 2). Defibrillation was performed with a LifePak 5® defibrillator using paddles (pre-adhesive pad era) with an energy of 360 J, monophasic shock energy delivery, at ambient pressure and at 203, 284, 304 kPa (2.0, 2.8 and 3.0 atmospheres absolute) in a six atmospheres capable cylindrical multiplace chamber. No sparking or other adverse effects were observed. (Personal Communication H Oxer, N Banham, A Waring 2023). The LifePak 5® defibrillator functioned normally at pressure and subsequently.

Griffiths found in his 2007 survey of HMUs worldwide that in-chamber CA was rare.[8] Ten cases were reported by 51 facilities over a five-year period. Three out of the 10 cases received in-chamber defibrillation without adverse effects or reported safety incidents.

Of the five cases of CA that occurred in facilities without the capability to defibrillate at pressure, only one had a shockable rhythm. The condition treated was cerebral arterial gas embolism, the patient and inside attendant the only occupants in a three-person square chamber. CA occurred at treatment pressure (not further detailed), with the time for decompression from arrest to surface reported as 1–3 minutes (mins). Defibrillation was performed outside the chamber and the patient survived.

Of the 12 HMUs with the capability for in chamber defibrillation under pressure, eight were in Europe, one each in the US and Canada and the remainder in Asia and Australasia. Interestingly, two of these units indicated that, despite the capability being present, in-chamber defibrillation was not permitted. The reasoning behind this was not specifically mentioned, though safety concerns (such as unintentional electric shock to staff or patients, fire hazard, complicated procedures leading to mistakes, limited space to carry out safe defibrillation and patient clinical safety issues) amongst the questionnaire respondents were mentioned. These were reported as percentages of responses, not the concerns of the individual facilities.

Patient survival rates for in-chamber cardiac arrest mirrored those of in-hospital cardiac arrest, regardless of being defibrillated inside or outside the chamber.

Griffiths identified the need for more research and covering a longer observation period.[8]

Schmitz et al., reviewed cardiopulmonary resuscitation (CPR) during HBOT in 2023, making recommendations for practice.[7] The extensive literature review concluded that CPR in the context of HBOT is a rare, but a critical event requiring special considerations. The review re-visited known safety issues, including the risks that the presence and use of a defibrillator in the hyperbaric environment poses, i.e., fire risk, implosion of vacuum filled cathode ray tube monitors, device malfunction under pressure and operator error from nitrogen narcosis. Recommendations were that the defibrillator should be stored outside the chamber and, if the capability is present, adhesive pads attached to the patient and fed through a penetrator in the chamber hull connecting to the defibrillator outside. With this setup, unexpected cases requiring defibrillation could have a first shock delivered within a reasonable two-minute period after recognition of CA. If defibrillation is necessary at pressure, an FiO_2 of 21.5% should not be exceeded at the moment of shock delivery. This is even stricter than the 23.5% maximal allowable concentration in the Australasian Standard.[9] In the absence of a defibrillator, some authors recommend a precordial thump in case of witnessed VT or VF, but this remains controversial.[7]

Stricter safety requirements are necessary in clinical hyperbaric chambers for two reasons. There is an increased risk of a fire starting due to the O_2-rich environment and this spreading rapidly or being explosive, and the chamber environment represents a pressurised and sealed space which does not allow immediate access or exit in the event of an emergency, therefore posing a safety risk to both patients and attendants.

The amount of electrical energy discharged by a defibrillator is more than enough to start a fire. For example, an energy of 150 J is still approximately 80 times greater than the minimum ignition energy (MIE) requirement for cotton, a common material used in the hyperbaric setting (MIE 1,950 mJ).[8]

Sustaining a CA during HBOT potentially puts the patient at a distinct disadvantage. Delay to diagnosis, the requirement to decompress, space constraints, limitations to staff access and other measures to reduce fire risk conflict with the patient's need for timely diagnosis and effective resuscitation. All commonly used treatment tables used in Australasia allow rapid depressurisation of a chamber to surface pressure, although the decompression obligation of the inside attendant may need managing. Rapid depressurisation and moving out of the chamber can offset most of the above- mentioned disadvantages. Doing so will facilitate easier management of CA and, given the overall low incidence of shockable ryhthms, not impact on overall survival from CA.

In Australasia, the use of defibrillators licensed for in-chamber use in Europe (Physio-Control LifePak 1000® and GS Elektromed Corpuls3®) has not been permitted according to Standards (AS/NZS 4774.2), as they contain lithium-ion batteries.[9]

In case of cardiac arrest in any HMU in Australasia, because the defibrillator cannot be present inside the chamber when pressurised, chamber decompression must occur if the decision is made to defibrillate. Only one of the responding HMUs in Australasia has the capability for the defibrillator leads to be fed through the chamber hull via a penetrator and is currently evaluating its use with the Corpuls3 defibrillator.

Twelve out of 14 responding HMUs surveyed have emergency procedures in place, and all of these mandate that defibrillation is performed only after the chamber is depressurised. The emergency procedures at Fiona Stanley Hospital states that in case of CA, a monoplace chamber is to be depressurised immediately, the patient slid onto the gurney, and CPR commenced as directed by medical staff. In case of CA in multiplace chambers, there is a distinction between treatment pressure and duration at that pressure which determines if the inside attendant can bring the patient to surface whilst performing chest compressions or if the attendant has to surface in a separate lock to complete their required decompression obligation and a doctor locked into the chamber to surface with the patient, performing chest compressions. This time limit is 60 mins at 140 kPa gauge pressure (14 metres of seawater (msw) equivalent / ~243 kPa absolute pressure), or 45 mins at 180 kPa gauge pressure (18 msw / ~284 kPa absolute pressure), respectively. These emergency procedures are clear, simple, very easy to follow and are on one printed page each. (* Appendix 1). These points are also depicted on the respective treatment tables used.

The emergency procedures at Christchurch Hyperbaric Medicine Unit in New Zealand are much more complex and detailed. The nine-page document distinguishes between multiple treatment tables and incorporates in-hospital adult life support algorithms.

Neither the Fiona Stanley nor Christchurch emergency procedures stipulate the exact timing and location of defibrillation, but the Fiona Stanley procedure does state that the patient is to be removed from the chamber immediately after emergency decompression. An important component of the Fiona Stanley procedure is immediate activation of the hospital's 'Code Blue' resuscitation team by the outside attendant.

Preparedness of all staff in hyperbaric facilities to respond rapidly to an emergency can be maintained and improved by performing regular emergency drills, where emergency procedures and their performance by staff are tested. However, less than half of respondents to our survey reported such drills occur regularly. Incorporating simulation training methods into the environment of HMUs is increasingly being encouraged to improve fidelity and quality of emergency response training. The Master's degree in Hyperbaric and Diving Medicine of the University of Padova in Italy, implemented by Paganini, is an example of how in-situ simulation can be used in this context.[10] A recent Delphi study identified cardiac arrest as one of five scenarios that merit simulation training in HMUs.[11]

Meunier et al., looked at the optimal timing and positioning for safe defibrillation after emergency decompression and opening of an O_2-filled monoplace chamber.[12] They found that it took two to four mins for the O_2-concentration to fall below 23.5% after emergency decompression. The position at which < 23.5% was achieved fastest was on the gurney, outside the chamber.

There appears to be no great desire to change the current response to an in-chamber CA in the Australasian facilities surveyed. The opinion of some practitioners that a uniform approach across all units might be beneficial in managing this rare event is questioned by more experienced colleagues, who advise that this might be difficult, as it does not take individual operational circumstances into account and might in fact be unachievable. The consensus was to keep with current regimes and emergency procedures as per individual units.

Recent technical developments, such as defibrillators with non-lithium-ion batteries or penetrators for defibrillator leads should encourage the hyperbaric community in Australasia to consider moving to an in-chamber defibrillation policy. New technology and understanding would benefit the patients and might lead to progressive risk reduction.[13] The reluctance to change the status quo might have to do with the rarity of the event and the fact that equipment upgrades in hyperbaric facilities are expensive, might lag behind new technological developments and are subject to extensive regulatory processes. A literature review of this issue in the current issue of Diving and Hyperbaric Medicine Journal drew conclusions that are thematically aligned with those arising from this survey.[14]

Conclusions

Defibrillation under hyperbaric conditions is a very rare event, with no clinical cases reported in Australasia and the only in-chamber defibrillation having taken place in an experimental setting. The consensus from this survey is to continue with current protocols and defibrillate only after decompression of the hyperbaric chamber and applying emergency procedures as per individual facilities. Improving preparedness may be improved by performing regular emergency drills, with the addition of *in-situ* simulation techniques to improve fidelity.

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Conflicts of interest and funding: nil

Submitted: 2 April 2025
Accepted after revision: 5 September 2025