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NAVAL SCUBA-DIVING INJURIES AND ASSOCIATED UNDERWATER HAZARDS IN MALAYSIA

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ABSTRACT

Naval scuba-diving is part of military training and follows the standard military diving manuals and protocols. Advances in diving technology has allowing divers to safely descend to greater depths that were previously impossible. This may expose the divers to underwater hazards and barotrauma injuries causing a significant morbidity and even death. Barotrauma is physical damage to body tissues caused by a difference in pressure between a gas space inside, or in contact with, the body, and the surrounding gas or fluid. Barotrauma generally manifests as sinus or middle ear effects, decompression sickness (DCS), lung overpressure injuries and injuries from external squeezes. Other potential hazards namely oxygen toxicity, nitrogen narcosis, immersion pulmonary oedema and effects of hydrostatic pressure. Hence, this review discusses pathophysiology and presentation of barotrauma along with its associated hazards as well as medical management of the divers including roles of compression chamber for treatment and post-mortem purpose.

Introduction

Scuba diving is a specialised activity that is utilised for various purposes in military forces. The term ‘scuba’ is an acronym derived from the term Self-Contained Underwater Breathing Apparatus. These purposes range from combat roles, combat support and logistical support functions. In many instances, scuba diving is also utilised by military special force for specific tactical purposes. Military divers may be involved in specialised diving roles such as those requiring multiple breathing gas mixtures and deep-sea high-pressure work environments.

Scuba diving is not the exclusive domain of naval personnel as scuba apparatus were initially developed for commercial purposes and as the different architectures for these underwater breathing devices matured, the scuba apparatus was adapted for military usages. Scuba technology has since been driven by requirements both of commercial and military need into the various systems that are in use currently. Scuba diving is practised either on a recreational, military or commercial basis such as when doing reef recreational diving, working as a naval clearance diver or as a commercial diver engaged in underwater logging or engineering works.

Nonetheless, all forms of scuba diving require training before any individual can be allowed to dive independently. This is because different diving roles and breathing equipment are needed. In recreational and commercial diving activities, techniques and breathing equipment are used to fit into working diving environment such as surface supplied diving or deep and saturation diving. In contrast, the military divers are trained to follow the standard military diving manuals and protocols [1]. Advances in diving technology allows divers to descend to greater depths and places which previously have been impossible to reach [2]. As a disadvantage, it may expose the divers to underwater hazards and barotrauma injuries causing a significant morbidity and even death. For safety reasons, proper acclimatization is important for those who descend deeper as injurious pressure effects can occur as the result of a difference in atmospheric pressure. A diver is at risk to decompression injuries, when the diver ascending to the surface ie; from high pressure to normal atmospheric pressure. In diving, each 10 metre depth of water increases the pressure by one atmosphere – 101 kilo Pascals (kPa) so that, in a non-rigid diving suit, the air supply has to be provided at the appropriate pressure relative to the working depth [3].

According to the Sports and Fitness Industry Association 2015 report, there are approximately three million people who engage in scuba diving-related activities in the United States every year, and more than nine million people identify themselves as recreational divers. The incidence of diving-related accidents has increased steadily with the increase in divers. Despite the many improvements in technology and safe-diving techniques, the rate of recreational scuba diving fatalities remains steady at about two fatalities per 100,000 dives[4]. In the naval environment, typically sailors are trained to become ship divers, then upgrade to become clearance divers.

Barotrauma and decompression illness

Barotrauma describes the mechanical damage from gas released into the tissues caused by a difference in pressure between a gas space inside, or in contact with, the body, and the surrounding gas or fluid. Cases of barotrauma included trauma to the sinus, ear (external, middle and inner), thoracic, face, gastrointestinal and teeth[5]. Pulmonary over-inflation syndrome (POIS) is a specific group of barotrauma-related diseases caused by the expansion of gas trapped in the lung, or over-pressurization of the lung with subsequent over-expansion and rupture of the alveolar air sacs. Pulmonary barotrauma is related to Boyle's law where a volume of gas will expand when the applied pressure is reduced. This group of disorders includes arterial gas embolism (AGE), tension pneumothorax, mediastinal emphysema, subcutaneous emphysema and rarely pneumopericardium (air in the heart sac) [6].

On the other hand, decompression illness (DCI) cover a broad range of complex pathophysiological conditions associated with decompression [6]. DCI used to encompass Type I decompression sickness (DCS) (pain only, skin or lymphatic), Type II DCS (cardiopulmonary or neurological involvement) and AGE. In the United States, Barratt et al [5] estimated the prevalence of DCI among recreational divers was 13.4 cases and 1.3 fatalities in warm water, and 10.5 cases and 2.9 fatalities respectively in cold and deep water for every 100 000 dives. This prevalence was much higher among commercial(occupational) divers and submarine escape trainees.

In DCI, atmospheric nitrogen dissolve in the blood and tissues due to high external pressure forces, the amount being governed by Henry's law. Nitrogen narcosis, refers to the set of cognitive deficits, performance decrements, and alterations in mood and behaviour that result when exposed to increase partial pressures of nitrogen and it is a significant contributing factor in diving related accidents. This is usually happens at depths greater than 30 metre [8].

Rapid decompression leads to bubble formation and causing venous stasis, obstruct vessels and cause ischaemic injuries to tissues and endothelium. Intravascular bubbles formed by pulmonary barotrauma may enter arterial circulation when expanding gas stretches and ruptures alveolar capillaries. Gas bubbles, appear in circulation, tissues and joint cavities and can cause decompression sickness with a wide range of clinical signs and symptoms. Furthermore, passage of gas into the pulmonary veins and into the systemic circulation could lead to arterial air emboli occluding the coronary and cerebral vessels. This may result in a stroke-like syndrome known as Cerebral Arterial Gas Embolism (CAGE), which presents with neurological features such as hemiparesis and dysarthria soon after the diver surfaces [9]. If insufficient time is allowed for these bubbles to disperse, their presence in the skin and connective tissues leads to painful symptoms known as "the bends". The manifestations include arthralgia, myalgia and cutaneous features of pruritus, rash (*cutis marmorata*) on thigh and torso and marbling. In addition, the presence of bubbles in the bloodstream & vasculature can lead to complications such as haemoconcentration pulmonary oedema, circulatory collapse and neurological deficits.

Managing Diving Injuries and decompression illness in Malaysia

In Malaysia, there are very limited publications related to diving accidents. Military diving activities contributed the least to diving accidents compared to commercial and recreational diving. Loke et al. [10] reported six cases of DCI treated at a state government hospital related to underwater logging in Kenyir Lake. These cases presented with severe cardio-respiratory and neurological disturbances, resulting in two deaths, while the others survived after recompression treatment. Rozali et al. [11] reported a case of pulmonary overinflation syndrome (POIS) in a young underwater logger engaged in underwater logging activities at the same location.

Injured diver may need a special medical arrangement for optimum treatment. There are several recompression chamber available in Malaysia such as in army or naval bases, universities and private health sectors [12]. Diver has to be recompressed and given hyperbaric oxygen therapy (HBOT) in a recompression chamber. Recompression with HBOT must be started immediately to force obstructing air or gas bubbles into solution and restore blood flow. Mandatory chest radiograph should be taken to rule out pneumothorax, which if present necessitates chest tube insertion before starting the recompression treatment. Other treatment modalities include immediate basic life support (cardiopulmonary resuscitation) when the patient surfaces as well as adequate hydration. Early referral to a recompression chamber facility is vital in order to save lives. Delay in recompression treatment may lead to death or permanent residual morbidity.

Forensic Investigation of Deaths from Diving Injuries and decompression illness

Although diving-related deaths occur more frequently in certain jurisdictions, but in Malaysia, death is reported to police for investigation of circumstances of death and subsequently forensic pathologists may have to perform the post-mortem examination. In order to arrive at the correct conclusion regarding the cause and manner of death, forensic pathologists and investigators in-charge need to have a basic understanding of diving physiology, and preferably utilize more recently developed technology and ancillary techniques.

To maximize the value of the post-mortem examination, procedural modifications are recommended for autopsies on divers. It is recommended that the autopsy itself should be conducted in a decompression chamber in order to prevent the post-mortem dissipation of gas that take place if the body is brought into atmospheric pressure. Full photography at every stage of dissection and radiological imaging of the head, neck, chest and abdomen as well as major joints is essential before autopsy. Chemical analysis of lung to determine the oxygen: nitrogen ratio and toxicology laboratory are compulsory [13]. Modifications in autopsy techniques allow for the demonstration of gas in atypical sites, such as the cardiac chambers, vessels, pleura, peritoneum, and in other tissues. This can be achieved by opening these sites underwater or by perfusing vessels with inserted gas traps [14]. Gas analysis is performed by special laboratories, and the results supplied to the diving physician and pathologist. The amount and location of gas present in the body at the time of autopsy may be very meaningful or may simply represent a post-mortem artifact. In addition, forensic pathologists should consider employing ancillary techniques to more thoroughly investigate the factors contributing a death associated with SCUBA diving. Caruso [14] suggested reconstruction of accident scenarios, interrogation of dive computers, post-mortem CT imaging, and slight alterations in autopsy technique may allow some of these diving related deaths to the better characterized. The diving apparatus must be inspected by an expert, including photography of the equipment. Use of dive computers accurately depict the details of the fatal dive. Accurate depths, dive durations, ascent rates, the number of ascents, decompression staging and decompression stress, dive profiles(reverse or forward), water temperature, gas pressures, and gas consumption are all informative and are accessible by downloading the data from the dive computer using suitable computer software.

In the majority of diving related deaths, the cause of death is drowning, but this more often represents a final common pathway due to a water environment. The chain of events leading to the death is just as important to elucidate if similar deaths are to be minimized in the future.

Conclusion

Although the number of fatalities is small, diving activities must be regulated by authority. Professional training bodies do require divers to declare their health status by filling a standard questionnaire and medical opinion is only required if there are uncertainties about their fitness to dive. It is recommended that preventive measures need to be accentuated in order to lessen the cases of diving accidents among the military personnel. Legislations, notification, centralised data registration, occupational diving training facilities as well as medical surveillance which also include examination prior to diving are essential to ensure sufficient monitoring of all diving accidents in Malaysia [12]. Forensic pathologists require constant updating of test procedures since frequent modifications of diving equipment and diving techniques (re-breather apparatus, technical diving, varying dive profiles, and newer decompression algorithms, etc.).

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References

(1). Manual, U. N. D. (1993). 6th revision. United States: US Naval Sea Systems Command. 2006.
(2). to Dive, B. T. S. F. (2003). British Thoracic Society guidelines on respiratory aspects of fitness for diving. *Thorax*, *58*(1), 3-13.
(3). Solé-Violán, J., & de Castro, F. R. (2001). Medical problems associated with underwater diving. *Clinical Pulmonary Medicine*, *8*(4), 242-247.
(4). Penrice, D., & Cooper, J. S. (2017). Diving Casualties.
(5). Barratt, D. M., Harch, P. G., & Van Meter, K. (2002). Decompression illness in divers: a review of the literature. *The Neurologist*, *8*(3), 186-202
(6). Rozali, A., Rampal, K. G., Zin, B. M., Sherina, M. S., Khairuddin, H., Halim, M. A., & Sulaiman, A. (2006). Development of underwater and hyperbaric medicine in Malaysia. *Medical Journal of Malaysia*, *61*(5), 647.
(7). Mathieu, D. (Ed.). (2006). *Handbook on hyperbaric medicine* (Vol. 27). New York:: Springer.
(8). Hobbs, M. (2008). Subjective and behavioural responses to Nitrogen Narcosis and Alcohol. *Undersea & Hyperbaric Medicine*, *35*(3), 175.
(9). James, P. B. (1993). Dysbarism: the medical problems from high and low atmospheric pressure. *Journal of the Royal College of Physicians of London*, *27*(4), 367.
(10). Loke, Y. K., Tee, M. H., & Tan, M. H. (1998). Decompression illness associated with underwater logging: 6 case reports from Kenyir Lake, Malaysia. *The Medical journal of Malaysia*, *53*(1), 100-103.
(11). Rozali, A., Sulaiman, A., Zin, B. M., Khairuddin, H., Halim, M. A., & Sherina, M. S. (2006). Pulmonary overinflation syndrome in an underwater logger. *Medical Journal of Malaysia*, *61*(4), 496.
(12). Rozali, A., Khairuddin, H., Sherina, M. S., Halim, M. A., Zin, B. M., & Sulaiman, A. (2008). Diving accidents treated at a military hospital-based recompression chamber facility in Peninsular Malaysia. *The Medical journal of Malaysia*, *63*(2), 91-95.
(13). Saukko, P., & Knight, B. (2016). Self-inflicted injury. *Forensic Pathology*, 235-244.
(14). Caruso, J. (2011). Autopsy protocol for recreational diving fatality. In *Proceedings of the Divers Alert Network workshop on recreational scuba diving fatalities. Durham: Divers Alert Network*.