The development of hyperbaric and diving medicine in Singapore

Chng J, Low C T E, Kang W L

ABSTRACT

Hyperbaric oxygen therapy is a noninvasive therapy used in the treatment of diving-related medical illnesses. It is an important adjunct in the management of a variety of medical conditions. The Republic of Singapore Navy Medical Service (NMS) is the main driver of the development of hyperbaric and diving medicine in Singapore. The practice of hyperbaric medicine has inherent risks, and unregulated application of this therapy may do more harm than good. NMS and Singapore General Hospital (SGH) signed a Memorandum of Understanding to combine NMS's experience with the clinical expertise of SGH to provide holistic care for diving and clinical hyperbaric treatment patients. This collaboration would increase the profile of this clinical specialty in Singapore, and help to establish safe clinical practice guidelines, training and accreditation requirements for diving and hyperbaric medicine practitioners in Singapore, thus ensuring that the practice of bona fide hyperbaric medicine is safeguarded and patient care is not compromised.

Keywords: compressed air works, diving and hyperbaric medicine, hyperbaric oxygen therapy, Republic of Singapore Navy Medical Service, Singapore General Hospital Hyperbaric and Diving Medicine Centre

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Navy Medical Service, Republic of Singapore Navy, 126 Tanah Merah Coast Road, Singapore 498822

Chng J, MBBS, DFD
Head, Hyperbaric Medicine Section

Kang WL, MBBS, MRCSE, FAMS
Chief of Medical Corp

Strategic Human Resource/ Office of Academic Medicine, Singapore Health Services, 31 Third Hospital Ave, #03-03, Bowyer Blk C, Singapore 168751

Low CTE, MBBS, FRCA, MPH
Group Director and Visiting Consultant, HDMC, SGH

Correspondence to:
Dr Chng Jeremiah
Tel: (65) 9172 8590
Fax: (65) 6796 4198
Email: chngjeremiah@hotmail.com

INTRODUCTION

Hyperbaric oxygen therapy (HBOT) is a noninvasive therapy used in the treatment of diving-related medical illnesses, and is an important adjunct in the management of a variety of medical conditions such as poorly healing wounds and carbon monoxide poisoning. HBOT is defined as a treatment in which a patient intermittently breathes 100% oxygen while the hyperbaric chamber is pressurised to a pressure greater than that at sea level.[1] This increases the absorption of oxygen by the tissues, enhances antimicrobial activity, reduces tissue hypoxia and promotes angiogenesis, thus accelerating the healing process.[2]

HBOT has had a long history that began when the first hyperbaric treatment chamber or 'domicilium' was constructed in 1662 by a British clergyman named Henshaw, who utilised it to treat a multitude of medical conditions.[3] Since then, there have been many reports of the beneficial effects of increased pressure, and by 1877, chambers were used widely for many conditions.[4] In 1879, the use of hyperbaric therapy to prolong safe anaesthesia during surgery was realised.[5] In the early 1900s, the use of HBOT to treat medical problems became more prevalent. The late 1950s and early 1960s are believed by many to be the birth of modern-day hyperbaric medicine. One large contribution was made by Dr I Boerema. He conceived the idea of 'drenching' tissues with oxygen by increasing the ambient pressure surrounding the patient. The ensuing experiments, where fatally anaemic pigs were successfully treated with volume expansion and pressurised hyperoxygenation, were so promising that he had a large operating-room chamber built at the Wilhelmina Gasthuis, the academic hospital of the University of Amsterdam. There, he conducted surgical operations under pressure for a variety of conditions, including surgical correction of transposition of the great vessels, tetralogy of Fallot and pulmonary stenosis.[6]

In the 1970s, with the use of HBOT producing seemingly dramatic results in potentiating the effects of radiotherapy,[7] prolonging circulatory arrest time during cardiac surgery and treating anaerobic infections[8] and carbon monoxide poisoning,[9] researchers were eagerly seeking other uses for HBOT. Patients with a variety of other chronic conditions were treated in chambers, often without much scientific rationale. Patients suffering from emphysema, stroke, senility, arthritis and other debilitating conditions that had not responded to conventional therapy were treated in the hope that some change might be noted. Unfortunately, many of these experiments were poorly controlled and 'good results' were usually reported anecdotally. Meanwhile, the development of improved cardiopulmonary bypass equipment had progressed, and with the advent of better heart-lung machines and deep hypothermia, the need for performing surgery under hyperbaric conditions decreased dramatically. By the early 1970s, early enthusiasm and good quality research had declined.

Just as important as the lack of scientific progress in the research fields were the problems in the regulatory area. There was no general textbook available for hyperbaric treatments and no distinction was made between conditions for which good evidence of the efficacy of hyperbaric oxygen existed and those for which such evidence was sparse. To help establish such guidelines, a panel of Undersea Medical Society members in the clinical hyperbaric field was formed. However, that panel met informally only once, for a few hours, and issued some broad recommendations that were only slowly implemented over the ensuing years. By 1976, a number of hyperbaric clinicians in the Undersea Medical Society had become appalled by the indiscriminate use of hyperbaric oxygen. These concerns led the society to form a Committee on HBOT in the mid 1970s. This committee is now the international authority on HBOT, and continuously reviews research and clinical data on the use of hyperbaric oxygen treatment so as to provide evidence-based recommendations on the indications, clinical efficacy and cost effectiveness of HBOT. In 1986, the members at the Undersea Medical Society annual scientific meeting voted to change the name of the Undersea Medical Society to the Undersea and Hyperbaric Medical Society (UHMS), to embrace both the diving and clinical hyperbaric fields. Since then, the UHMS has become widely recognised as the international body regulating the practice of hyperbaric and diving medicine.

HYPERBARIC MEDICINE IN SINGAPORE

The history of diving medicine in Singapore can be traced back to the 1960s when the Royal Malaysian Navy (RMN) Headquarters was based in Woodlands, Singapore. A multiplace recompression chamber, which was initially used by the British Royal Navy before they left Singapore, was used as part of the dive training of RMN divers. This carried on until the 1970s.[10] Clinical hyperbaric medicine in Singapore started when the Orthopaedic Department in Singapore General Hospital (SGH) obtained a monoplace chamber, the 'Normalair Garette', for HBOT. However, the usage was low and few physicians understood the basis for HBOT at that time. This monoplace chamber was subsequently handed over to the Republic of Singapore Navy (RSN) to support the fledging development of hyperbaric, diving and submarine medicine in the Navy under the first Senior Medical Officer (Navy). The subsequent acquisition of the Navy's first multiplace hyperbaric chamber, a 10-man chamber, in 1973 enhanced the HBOT capabilities available at that time. It also allowed the Navy to support her divers in salvage operations as well as treat the many fishermen divers (some of whom were foreigners) who developed severe decompression illnesses as a result of diving with only rudimentary diving knowledge and techniques. Knowledge and experience in the practice of diving and hyperbaric medicine was thus slowly built up within the Navy in the 1970s.

THE COMPRESSED AIRWORKS ERA

In 1982, the Singapore Government announced its decision to build the Mass Rapid Transit (MRT) System, and the RSN was approached in August that year to provide the overall medical support for the project.[11] RSN's Diving and Hyperbaric Medical Centre (DHMC) was the only centre with the necessary experience and facilities to perform pre-employment selection and treatment of injured compressed air workers. In the initial phase, DHMC helped the then-Ministry of Labour to draft the regulations that would govern the conduct of Compressed Air Works (CAW). DHMC was heavily involved with the screening of all the potential compressed air workers, many of whom were from other nationalities. CAW was used by six contractors from September 1984 to April 1987 for the construction of 11 km of the total 20 km underground tunnels.

Over the three-year period, a total of 2,932 workers were screened for fitness to work in compressed air environment, of which 1,737 or 72.6% were found to be fit to work in the project. 188,538 decompressions were carried out during the entire project, and from these, only 164 cases of decompression illness were seen. 160 of these were classified as Type 1 or mild decompression sickness, while the remaining four were considered to be the more severe Type 2. This gave an overall incidence of 0.087%, which was quite favourable when compared to other CAW data available at that time. The presence of onsite chambers allowed for early and often immediate treatment, which resulted in 100% recovery for all injured workers and no disability. Throughout this period, RSN provided continual onsite consultancy and medical services for Singapore's MRT project, thus making significant contributions to the most important public transport project of that time, while cementing her position as the subject matter expert in hyperbaric and diving medicine.

CLINICAL HYPERBARIC MEDICINE ERA

Until the turn of the century, diving and hyperbaric medicine has remained a military medicine specialty, with its practice largely confined to the Singapore Armed Forces (SAF) Medical Corp. The RSN Medical Service conducts a basic course in diving and hyperbaric medicine for military doctors and nurses. Regular Navy Medical Officers are

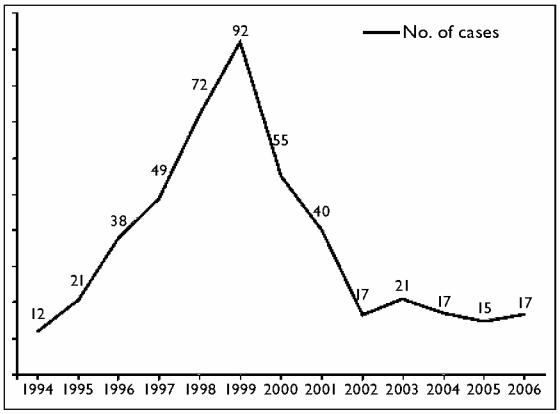

Fig. 1 Number of cases treated in the Naval Hyberbaric Chamber from 1994 to 2006.

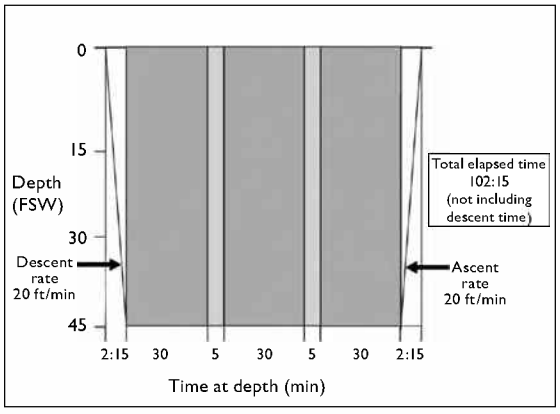

Fig. 3 Treatment Table 9–Depth/time profile.

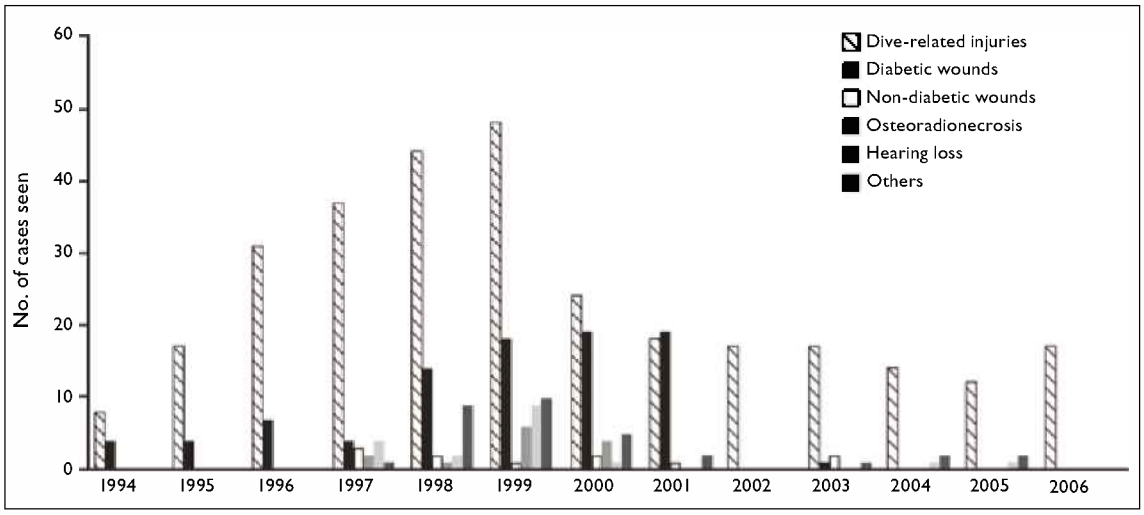

Fig. 2 Types of clinical cases seen in the Naval Hyberbaric Chamber from 1994 to 2006.

then sent overseas for specialised military diving medicine courses, as well as clinical attachments in renowned hyperbaric treatment centres. This in-depth training, coupled with the experience garnered from treating diving and clinical hyperbaric cases, is the bedrock on which Regular Navy Medical Officers build their clinical expertise in diving and hyperbaric medicine. It is this core group of Medical Officers, both current and retired, who continue to contribute to diving and hyperbaric medicine in Singapore. In fact, three out of four of the visiting consultants in the Hyperbaric and Diving Medicine Centre in SGH originated from the RSN Medical Service.

Although there is growing understanding and acceptance among clinicians of the benefits of HBOT as an adjunct treatment, many do not receive formal training in it or fully understand its mechanisms, and thus tend to use it as a treatment of last resort, unsure as to whether it will benefit their patients. It should also be noted that it is only in recent years that the practice of hyperbaric medicine started in local hospitals.

The RSN is the foremost authority on diving and underwater medicine, and operates the most number of recompression chambers in Singapore. The Naval Hyperbaric Chamber (NHC) operates three 10-men multiplace chambers located in the Naval Diving Unit at Sembawang Camp. Besides this centre, RSN also operates a recompression chamber complex dedicated for submarine rescue operations that is capable of treating up to 40 patients. This chamber complex is situated onboard MV Swift Rescue, a submarine search and rescue vessel that was launched in 2008.

As the recognised authority in diving and hyperbaric medicine in Singapore, the Navy Medical Service (NMS) has been called upon on many occasions to avail its expertise in treating and managing decompression illness and clinical conditions requiring HBOT not only within, but also beyond the borders of the SAF. Throughout the 1990s, the number of cases referred to NHC for HBOT and diving-related decompression injuries gradually increased, reaching a peak in 1999, with the majority of clinical hyperbaric cases being problem wounds (Fig. 1). From 1994 to 2002, NHC was the main referral centre for diving and clinical hyperbaric treatment cases. A total of 466 cases were referred to NHC, of which 304 were

dive-related injuries and 162 were for clinical HBOT. The breakdown of the indications is shown in Fig. 2.

Poor healing wounds were by far the largest number, followed by radiation injuries and sudden hearing loss. At the NHC, the treatment table used for these conditions was the United States Navy Treatment Table 9 (Fig. 3), and almost all patients used face masks. Of the poor healing wounds, diabetic wounds were the most common, with the remainder being ischaemic or neuropathic wounds. The median age of the patients was 63 years and the median length of treatment was 2.5 weeks or about 14 treatments. Short-term outcome was good in 50% of the patients.

However, as the chambers were located in an SAF camp, one of the main challenges in offering treatment to civilians was the difficulty for hospital in-patients to endure the long transfers from hospitals to Sembawang camp, complicated by the need for security screenings before the patients could enter the military camp. It was, therefore, difficult to treat critically ill patients, e.g. severe gas gangrene patients who needed life-saving HBOT were too unstable for the transfer. It was clear then that for clinical hyperbaric care to succeed, it had to be situated in a hospital, tapping on the hospital's expertise in critical care and multidisciplinary approach to patient management so as to enhance the level of care provided for the patient.

The first hyperbaric medical centre in a civilian hospital was opened by ST Baromedical Services in January 2002, and it treated mainly clinical hyperbaric cases. The startup of this alternative clinical hyperbaric facility was opportune for the RSN, as it could then concentrate on its development in military diving and submarine medicine. However, with only a three-man (sitting) chamber, the number of patients this clinical hyperbaric centre could treat was limited. The development of hyperbaric and diving medicine in Singapore took a big step forward in October 2008 with the setting up of the SGH Hyperbaric and Diving Medicine Centre (HDMC). With a triple lock and a main hyperbaric chamber capable of treating up to ten patients each time, it is capable of managing the full spectrum of clinical and diving medicine cases. To date, besides the RSN hyperbaric facilities, these are the two other hospital-based hyperbaric centres that provide HBOT.

In this decade, the main focus of the RSN has been to seek synergistic collaborations with civilian hospitals in order to elevate the overall standard of hyperbaric and diving care through education, training and research, as well as through providing recompression treatment to military and civilian divers. With this goal in mind, the setting up of SGH HDMC presented an excellent opportunity for collaboration between NMS and SGH, to combine NMS's expertise and experience in diving and hyperbaric medicine with the clinical expertise of SGH in critical care and its multidisciplinary approach to patient management. A Memorandum of Understanding was therefore signed between the RSN and SGH in 2008 to provide recompression treatment to military and civilian divers, education and training for doctors, nurses and medics in diving and hyperbaric medicine, as well as clinical hyperbaric research and medical equipment testing for use in the hyperbaric environment.

Table I. Undersea and Hyperbaric Medical Society-approved indications for hyperbaric oxygen therapy.

Air or gas embolism
Carbon monoxide poisoning, including carbon monoxide poisoning complicated by cyanide poisoning
Clostridal myositis and myonecrosis
Crush injury, compartmental syndrome and other acute traumatic ischaemias
Decompression sickness
Enhancement of healing in selected problem wounds, e.g. arterial insufficiencies and central retinal artery occlusion
Severe anaemia
Intracranial abscess
Necrotizing soft tissue infections
Refractory osteomyelitis
Delayed radiation injury (soft tissue and bony necrosis)
Compromised skin grafts and flaps
Acute thermal burn injuries

Toward furthering education of diving and hyperbaric medicine in the local medical community, RSN and SGH HDMC co-organised the inaugural Singapore Hyperbaric and Diving Medicine Course (SHUMEC) in 2009. The response was overwhelming, with all the places taken up within one month by both local and foreign medical practitioners. In 2010, SHUMEC achieved accreditation by the Diving Medical Advisory Committee (DMAC) for possessing a rigorous teaching standard in line with international best practices. DMAC is the internationally recognised authority on diving medicine, and SHUMEC is one of only eight courses worldwide that has achieved this accreditation.

CHALLENGES FACING CLINICAL HBOT IN SINGAPORE

The recognition of HBOT as an acceptable form of treatment continues to be hampered by a lack of large scale, high-quality (Level 1) evidence, the only exception being that of decompression illnesses, where HBOT has been accepted as the standard definitive treatment despite the lack of high-quality clinical evidence.[12] This lack of Level 1 evidence has been recognised by the hyperbaric

medicine community, and has resulted in an increased emphasis on clinical research and rise in the number of high-quality trials investigating the efficacy of HBOT in certain clinical conditions such as radiation cystitis,[13] crush injuries[14] and mandibular osteoradionecrosis.[15] The UHMS has laid out 13 HBOT indications[16] as a guideline for HBOT treatment, as seen in Table I. These UHMS indications are accepted worldwide as evidence-based conditions where HBOT can significantly improve outcome.

Unfortunately, HBOT has also been used in many other conditions that may not be suitable for HBOT. There has been keen interest in using HBOT to treat conditions such as autism and cerebral palsy.[17] This is despite strong evidence regarding its lack of efficacy and the distinct lack of solid scientific evidence base to support its use. The use of HBOT for conditions, such as musculoskeletal sprains,[18] plantar fasciitis and acute coronary syndrome,[19] is also debatable, as there have been few or no studies done to support its use.[20] It must be understood by medical practitioners that HBOT is not without its risks. A recent pilot study has found that instead of promoting recovery, HBOT may be harmful in patients with ischaemic stroke.[21] To safeguard the safe practice of medicine and also to prevent possible risk to patients, SGH HDMC and NMS adopt the UHMS indications in their clinical practice.

Although there has been progress in the development of diving and hyperbaric medicine locally, on the international scene, Singapore still lags behind other developed countries such as the United States and Canada, where hyperbaric medicine is already recognised as a subspecialty and hyperbaric physicians routinely form part of the medical team providing treatment for cases, such as poorly healing diabetic wounds and delayed radiation wounds. It is important that awareness of hyperbaric and diving medicine and the clinical efficacies of HBOT among medical practitioners in Singapore be raised so that patients who would benefit from this treatment can be appropriately referred.

It is hoped that the amalgamation of diving and hyperbaric expertise between the Navy and SGH will increase the profile of this clinical specialty in Singapore, as well as facilitate the establishment of safe clinical practice guidelines, training standards and accreditation requirements for diving and hyperbaric medicine practitioners in Singapore, thus ensuring that the practice of bona fide hyperbaric medicine is safeguarded and that ultimately, patient care is not compromised.

REFERENCES

1. UHMS Hyperbaric Oxygen Committee report. Undersea and Hyperbaric Medicine Society [online]. Available at: www.uhms.org/ResourceLibrary/Indications. Accessed October 26, 2010.
2. Marx RE, Ehler WJ, Tayapongsak P, Pierce LW. Relationship of oxygen dose to angiogenesis induction in irradiated tissue. Am J Surg 1990; 160: 519-24.
3. Simpson A. Compressed Air as a Therapeutic Agent in the Treatment of Consumption, Asthma, Chronic Bronchitis and Other Diseases. Edinburgh: Sunderland and Know, 1857.
4. Jacobson JH 2nd, Morsch JH, Rendell-Baker L. Clinical experience and implications of hyperbaric oxygenation. The historical perspective of hyperbaric therapy. Ann N Y Acad Sci 1965; 117: 651-70.
5. Gill AL, Bell CN. Hyperbaric oxygen: its uses, mechanisms of action and outcomes. QJM 2004; 97:385-95.
6. Boerema I, Huiskes JW, Kroll JA, et al. High atmospheric pressure as an aid to cardiac surgery. Arch Chir Neerl 1956; 8:193-211.
7. Churchill-Davidson I, Sanger C, Thomlinson RH. High-pressure oxygen and radiotherapy. Lancet 1955; 265: 1091-5.
8. Brummelkamp WH, Hogendijk J, et al. Treatment of anaerobic infections (clostridial myositis) by drenching the tissues with oxygen under high atmospheric pressure. Surgery 1961; 49:299-302.
9. Weaver LK, Hopkins RO, Chan KJ, et al. Hyperbaric oxygen for acute carbon monoxide poisoning. N Engl J Med 2002; 347: 1057-67.
10. Rozali A, Rampal KG, Zin BM, et al. Development of underwater and hyperbaric medicine in Malaysia. Med J Malaysia 2006; 61:647-50.
11. How J. Singapore Mass Rapid Transit Project. Singapore Med J 1990; 31: 515-8.
12. Bennett MH, Lehm JP, Mitchell SJ, Wasiak J. Recompression and adjunctive therapy for decompression illness. Cochrane Database of Systematic Reviews 2007; 2:CD005277.
13. Clark RE, Tenorio LM, Hussey JR, et al. Hyperbaric oxygen treatment of chronic refractory radiation proctitis: a randomized and controlled crossover trial with long term follow up. Int J Radiat Oncol Biol Phys. 2008; 72:134-43.
14. Bouachour G, Cronier P, Gouello JP, et al. Hyperbaric oxygen therapy in the management of crush injuries. J Trauma 1996; 41:333-9
15. Bui QC, Lieber M, Withers HR, et al. The efficacy of hyperbaric oxygen therapy in the treatment of radiation-induced late side effects. Int J Radiat Oncol Biol Phys 2004; 60:871-8.
16. Gesell LB. Hyperbaric Oxygen Therapy Indications. 12th Ed. Durham: Undersea and Hyperbaric Medical Society, 2008.
17. Bennett M, Newton H. Hyperbaric Oyxgen Therapy and Cerebral Palsy – where to now? Undersea Hyperb Med 2007; 34:69-74.
18. Yagishita K,Yamami N, Togawa S, et al. The effect of HBOT on patients with ankle sprains [online]. Available at: archive.rubicon-foundation.org/3742. Accessed July 13, 2011.
19. Bennett MH, Jepson N, Lehm JP. Hyperbaric oxygen therapy for acute coronary Syndrome. A cochrane systematic review [online]. Available at: archive.rubicon-foundation.org/1658. Accessed July 13, 2011.
20. Aksenov IV, Tonkopi F. Hyperbaric Oxygen Therapy in Russia - More than 60 Indications: Literature Review [online]. Available at: archive.rubicon-foundation.org/1545. Accessed July 13, 2011.
21. Rusyniak DE, Kirk MA, May MD, et al. Hyperbaric oxygen therapy in acute ischaemic stroke. Results of the Hyperbaric Oxygen in Acute Ischaemic Stroke Trial Pilot Study. Stroke 2003; 34:571-4.