Underwater Oxygen Treatment of decompression sickness

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Introduction: Since 1970, in remote regions of the Indo-Pacific, a new option was added to the armamentarium for treatment for decompression sickness. It was closely supervised and directed by the respective officers-in-charge of the Royal Australian Navy School of Underwater Medicine. Initially it had no official sanction, but developed in response to an urgent need for management of cases in remote localities - remote in both time and distance from the few hyperbaric facilities. This is elaborated further under the section termed "The Problem".

Because of the success of this treatment, and its ready availability, it became known and practiced, even when the experts were not available to supervise it. The reasons for this were twofold. Firstly, the non-recompression ancillary therapies are not particular efficacious on their own. Secondly, the conventional underwater air decompression treatments posed considerable operational difficulties - elaborated in the section termed "Traditional Solutions".

The techniques of underwater oxygen therapy, and the equipment used, are described under their respective headings. It was designed to make for safety, ease and ready availability, even in medically unsophisticated countries. Advantages and disadvantages of this type of therapy, together with many of the questions that have arisen because of it, are described under the section labelled "Discussions".

The physiological principles on which this treatment is based are well known and not contentious, although the indications for treatment have caused some confusion. Like conventional oxygen therapy tables, it was first applied mainly for the minor cases of decompression sickness, but was subsequently found of considerable use in the potentially serious cases. This is considered under sections labelled "Case Reports" and "Underwater Oxygen in Perspective".

The Problem

For almost two decades the Royal Australian Navy, at the School of Underwater Medicine, accepted responsibility for the treatment of cases of decompression sickness presenting in this part of the Indo-Pacific region. During most of this time, it had the only large recompression chamber permanently staffed with experienced diving medical personnel. The catchment area extended to a radius of about 6,000 kilometres around Sydney, Australia.

Australia is an island continent, with one of the longest habitable coastlines of any single country - approximately 30,000 kilometres - and eminently suited to diving. Amateurs relish the warm waters of the Great Barrier Reef, while professional diving encompasses the pearl, abalone, salvage and oil industries. There are traditional ties, and often protectorate or treaty responsibilities with other countries of the Indo-Pacific. Many of these islands have either very limited or no airport facilities. Medivac of decompression sickness patients to Australia often required a return flight originating in Sydney. Where possible, use was made of aircraft that would be cabin pressurised to ground level, and in many cases there would be a time lapse in excess of 24 hours between the patient being "bent" and receiving treatment. The costs, in time and money, and the commitment of service facilities and aircraft, made treatment of minor cases impracticable. The delays made serious cases worse. As an aggravating factor, the clear warm waters encourage the type of diving which results in severe decompression sickness.

During the middle of the ’70s, the incident rate of decompression sickness reported to the Navy School of Underwater Medicine was approximately one every two weeks. The majority of these cases were far distant from Sydney locality, and in many cases the medivac transfer of these patients to Sydney was not possible.

Traditional Solutions

A whole gamut of treatments, other than the conventional recompression therapy, have been applied to decompression sickness. These include some which have a physiological basis, some which are of interest from the pharmacological aspect, and others which are merely novel in their approach. None have received universal acceptance as an isolated therapy. They include such regimes as: intravenous fluid replacement, with low molecular weight dextran, plasma and other fluids; anticoagulants; anti-lipaemic agents; steroids; hypothermia; etc.

By far the most traditional of the non-chamber treatments, is the underwater recompression therapy. In this situation the pressure is exerted by the water, instead of a recompression chamber. Air supply is usually from compressors sited on the diving boat. Although this treatment is frequently ridiculed by those in the cloistered academic environs, especially when they possess elaborate recompression facilities, it has frequently been the only therapy available to severely injured divers, and has had many successes. This is certainly so in those remote localities such as Northern Australia, in the pearl fishing areas, where long times were spent underwater and standard diving equipment was used. Underwater air treatment continued to be used, in the absence of available recompression chambers.

Despite the value of the underwater recompression therapy, many problems are encountered with it. These are well recognised by both divers and their medical advisers. It is of interest that two of the diving medical text books written in English, do not mention this therapy at any stage! The US Navy Diving Manual briefly mentions it as a possible treatment and recommends the application of the conventional air tables as far as possible and seems to infer that Table 2A is perhaps the acceptable one. This involves taking divers underwater, to a maximum depth of 165 feet or 50 metres and with an overall duration of 11 hours. The Royal Navy Diving Manual recommends a somewhat more reasonable approach with Table 81, at a depth of 100 feet or 30 metres and duration of almost 5 hours. Most of the underwater air treatments are more practical than these and a typical example is that given by Sir Robert Davis, in which the duration depends upon the depth required for relief of symptoms. Most regimes are makeshift, and are varied with experience.

The problems are as follows. Most amateurs or semi-professionals, other than the navies and multinational diving companies, do not carry the compressed air supplies or compressor facilities necessary for the extra decompression. Most have only SCUBA cylinders, or simple portable compressors that will not reliably supply divers (the patient and his attendant) for the depths and durations required. Environmental conditions are not usually conducive to underwater treatment. Often the depth required for these treatments can only be achieved by returning to the open ocean. The advent of night, inclement weather rising seas, tiredness and exhaustion, and boat safety requirements, make the return to the open ocean a very serious decision. Also because of the considerable depth required, hypothermia from the compression of wet suits, becomes very likely. Seasickness, in the injured diver, the diving attendants and the boat tenders, becomes a not inconsiderable problem. Nitrogen narcosis produces added difficulties in the diver and attendant. The treatment has often to be aborted because of this. These difficult circumstances, producing decompression sickness in the attendants, and aggravating it in the diver. Underwater air treatment of decompression sickness is not to be undertaken lightly. In the absence of a recompression chamber, it may be the only treatment available to prevent death or severe disability. Despite considerable criticism from authorities distant from the site, this traditional therapy is recognised by most experienced and practical divers to often be of life saving value.

Underwater Oxygen Therapy

The value of substituting oxygen for air, in the recompression chamber treatment of decompression sickness, is now well established. The pioneering work of Yarborough and Behnke (1939) eventuated in the oxygen tables described by Goodman and Workman (1965). They received widespread acceptance, and revisions and modifications are now incorporated in Tables 5 and 6 by the US Navy Diving Manual, the Comex tables, and the Australian Therapy Tables. The advantages of oxygen over air tables include: increasing nitrogen elimination gradients; avoiding extra nitrogen loads; increasing oxygenation to tissues; decreasing the depth required and the hyperbaric exposure time; and improving the overall therapeutic efficiency. The same arguments are applicable when one compares underwater air and underwater oxygen treatment.

a. Technique

Oxygen is supplied at a maximum depth of 9 metres, from a surface supply. Ascent is commenced after 30 minutes in mild cases, or 60 minutes in severe cases, if significant improvement has occurred. These times may be extended for another 30 minutes, if there has been no improvement. The ascent is at a rate of 12 minutes per metre. After surfacing the patient should be given periods of oxygen breathing, interspersed with air breathing, usually on a one hour on, one hour off basis, with vital capacity measurements and chest x-ray examination if possible.

b. Equipment

The equipment required for this treatment includes the following: a G size oxygen cylinder (220 cu ft or 7000 litres). This is usually available from local hospitals, although in some cases industrial oxygen has been used from engineering workshops. This volume of oxygen, at the depth varying between 9 metres and the surface, is insufficient to produce either neurological or respiratory oxygen toxicity. A 2-stage regulator, set at 550 kPa is fitted with a safety valve, and connects with 12 metres of supply hose. This allows for 9 metres depth, 2 metres from the surface of the water to the cylinder, and 1 metre around the diver. A non-return valve is attached between the supply line and the full face mask. The latter enables the system to be used with a semi-conscious or unwell patient. It reduces the risk of aspiration of sea water, allows the patient tot speak to his attendants, and also permits vomiting to occur without obstructing the respiratory gas supply. The supply line is marked off in distances of 1 metres from the surface to the diver, and is tucked under the weight belt, between the diver’s legs, or is attached to his harness. The diver must be weighted to prevent drifting upwards in an arc.

A diver attendant is always present, and the ascent is controlled by the surface tenders. The duration of the 3 tables are 2 hours 6 minutes; 2 hours 36 minutes, and 3 hours 6 minutes. In the unit currently marketed in Australia by Commonwealth Industrial Gases, there is an optional extra piece of equipment - a positive pressure mask. This allows the unit to be used for the treatment of drowning victims, with intermittent positive pressure oxygen resuscitation.

Discussion

It was originally hoped that this treatment regime would be sufficient for management of minor cases of decompression sickness, and to prevent deterioration of the more severe cases while suitable transport was being arranged. When the regime is applied early, even in the severe cases, the transport is often not required. It is consistent observation that improvement continues throughout the ascent, at 12 minutes per metre. Presumably the resolution of the bubble is more rapid at this ascent rate, than its expansion due to Boyle’s law.

Certain other advantages are obvious. During the 3 hours continuous hyperbaric oxygenation, the tissues become effectively denitrogenated. Bubbles are initially reduced in volume, in accordance with the hyperbaric exposure and the resolution is speeded up by increasing the nitrogen gradient from the bubble. Attendant divers are not subjected to the risk of decompression sickness or nitrogen narcosis, and the affected diver is not going to be made worse by premature termination of the treatment, if this is required. Hypothermia is much less likely to develop, because of the enhanced efficiency of the wet suits at these minor depth.

The site chosen can be in a shallow protected area, reducing the influence of weather on the patient, the diving attendants and boat tenders. Communications between the diver and the attendants are not difficult, and the situation is not as stressful as the deeper, longer, underwater air treatments or even as worrying as in some recompression chambers. (When hyperbaric chambers are used in remote localities, often with inadequate equipment and insufficiently trained personnel, there is an appreciable danger from both fire and explosion. There is the added difficulty in dealing with inexperienced medical personnel not ensuring an adequate face seal for the mask. These problems are not encountered in the underwater environment.

Underwater Oxygen - Perspective

The underwater oxygen treatment table is an application, and a modification of current regimes. It is not meant to replace the formal treatment techniques of recompression therapy in chambers. It is an emergency procedure, able to be applied with equipment usually found in remote localities and is designed to reduce the many hazards associated with the conventional underwater air treatments. The customary supportive and pharmacological adjuncts to the treatment of recompression sickness are in no way avoided, and the superiority of experienced personnel and comprehensive hyperbaric facilities, is not being challenged. The underwater oxygen treatment is considered as a first aid regime, not superior to portable recompression chambers, but sometimes surprisingly effective and rarely, if every, detrimental.

Case Report

Because of the nature of this treatment being applied in remote localities, many cases are not well documented. Twenty-five cases were well supervised before this technique increased suddenly in popularity, perhaps due to the success it had achieved, and perhaps due to the marketing of the equipment by CIG (Medishield). Three more recent cases are now described.

Case 1

A 68 year old male salvage diver.

Two dives to 100 feet for 20 minutes each were performed with a surface interval of 1.5 hours - while searching for the wreck of the Pandora, about 100 miles from Thursday Island in the Torres Strait.

No decompression staging was possible allegedly because of the increasing attentions of a tiger shark. A few minutes after surfacing, the diver developed paraesthesia, back pain, progressively increasing inco-ordination and paresis of the lower limbs.

Two attempts at underwater air recompression were unsuccessful when the diving boat returned to its base mooring. Symptoms were worrying and the National Marine Operations Centre was finally contacted for assistance.

It was 36 hours, post dive, before the patient was finally flown to the regional hospital on Thursday Island. Both the Air Force and the Navy had been involved i the organisation, but because of very hazardous air and sea conditions, and very primitive air strip facilities, another 12 hours would be required before the patient could have reached an established recompression centre (distance 2000 miles).

On examination at Thursday Island, the patient was unable to walk, having evidence of both cerebral and spinal involvement. He had marked ataxia, slow slurred speech, intention tremor, severe back pain, generalised weakness, difficulty in micturition, severe weakness of lower limbs with impaired sensation, increased tendon reflexes and equivocal plantar responses.

Because of the involvement with pearl divers, an underwater oxygen unit was available on Thursday Island, and the patient was immersed to 8 metres depth (the maximum depth off the wharf). Two hours were allowed at that lesser depth and the patient was then decompressed. There was total remission of all symptoms and signs, except for small areas of hypoaesthesia on both legs.

Case 2

23 year old female sports diver.

Diving with 72 cu ft SCUBA cylinder in the Solomon Islands. (Nearest recompression chamber is 2000 miles away and prompt air transport was unavailable). Dive depth was 110 feet and duration approximately 20 minutes, with 8 minutes decompression. Within 15 minutes of surfacing she developed respiratory distress, then numbness and paraesthesia, very severe headaches, involuntary extensor spasms, clouding of consciousness, muscular pains and weakness, pains in both knees and abdominal cramps. The involuntary extensor spasms recurred every ten minutes.

The patient was transferred to the hospital, where neurological decompression sickness was diagnosed, and she was given oxygen via a face mask for three hours without significant change. During that time an underwater oxygen unit was prepared and the patient was accompanied to a depth of 9 metres, in the bay. Within 15 minutes, she was much improved, and after 1 hour she was asymptomatic. Decompression at 12 minutes per metre was uneventful and the patient was subsequently flown by commercial aircraft to Brisbane.

Case 3

A 19 year old male trainee diver, under dubious instruction.

Depth approximately 150 feet duration 15 minutes. Twenty minutes after surfacing, he had the first of three epileptic convulsions, extending over a one hour period. Between convulsions there seemed no other evidence of decompression sickness other than mild back pain. There was no personal or family history of epilepsy.

A 9 metre oxygen treatment was given, without complication and without sequelae.

This is presented for discussion as it is an excellent example of the type of case that can be made complicated by the 60 foot oxygen therapy tables, when a convulsion during treatment can be attributed to either decompression sickness or oxygen toxicity. This would cause considerable management problems - especially if one is not sure of the original diagnosis! To subject such a patient to the deeper air tables may considerably hinder treatment if one's provisional diagnosis is wrong. Alternately to not recompress may result in further damage from decompression sickness or the perseverance of a potentially remedial epileptogenic focus.

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Is father unfair to his son?

Patricia Sneddon, blonde haired and ten years old, has earned her title of "Bubbles". She has been scuba diving for 18 months and swims in the Manly Marineland tank, mainly for fun. Apart from the sharks the pool contains a few gropers, stingrays, and turtles, as well as hundreds of small fish. She says that the sharks don't worry her (there is only one big male she won't pat, because he snaps), but the turtles are apt to bite fingers. Her father, who has been diving in the pool for a few years, organised her first dive after she pleaded for a go. "Her mother was worried stiff - when Bubbles first went in, but I know she is safe", he said. That was a year ago. "I love it. It's better than ordinary diving. And they wouldn't touch me: I'm a girl", she told and interviewer.

This happy-go-lucky schoolgirl is too young to dive for money, so she does it for experience, and to overcome school holiday boredom. Her younger brother Adam, aged 6 years, is considered to be still too young to dive, with or without sharks. But then everyone knows that fathers tend to spoil their daughters".

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