Exposure suits: a review of thermal protection for the recreational diver

Guy Williams and Christopher J Acott

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Thermal protection, hypothermia, wetsuit, drysuit, diver training

Abstract
Some basic diving science on diver thermal protection is reviewed. The common methods of thermal protection used by recreational divers and the potential advantages and disadvantages of various forms of exposure protection are discussed. Diving suit related incidents in the Diving Incident Monitoring Study and fatalities in Project Stickybeak are reported.

Introduction

Exposure suits/thermal protection, as used by recreational divers can be categorised into the following groups: skin; Lycra™ suits; 'steamers' (2–4 mm thick neoprene wetsuits with or without legs); wetsuits (5–9 mm or more, usually with arms and legs covered and often with a neoprene hood); semi-drysuits and drysuits. Some revision of basic diving science and diver cooling is required to review the need for exposure protection.

The thermal conductivity of water is 20 times that of air; that is, it absorbs heat more efficiently. In addition, water movement around the diver causes rapid convection of heat away from the body. As a result, thermal neutrality requires a water temperature of 34°C or more for diver comfort, in less than 34°C all divers will eventually cool to some degree. However, prolonged exposures in wetsuits in water less than 20°C without significant falls in body core temperature have been reported.

In the 1950s, when I joined the Royal Navy (RN) as a medical officer, the RN did not use contents gauges for scuba diving. Instead, they used twin tanks yoked together. The tanks were 'upside down', with the valves within easy reach just above the diver's bottom. The diver turned on one cylinder (A) and used it until it ran out; he then knew that he had used half his air. Turning on the second cylinder (B) equalised the pressures in both cylinders and then cylinder B was turned off. At this stage, the diver had used half his available air and was breathing from half the remaining half. When that air ran out, he still had a quarter of his original air supply in cylinder B. At this point, the diver turned off cylinder A and used cylinder B to return to the surface. This procedure was still in use in 1972.

Having a contents gauge, and looking at it, is much easier than remembering how many times you have decanted. The problem is that many divers do not look at their contents gauges often enough to avoid running out of air underwater. Even in the 1990s, running out of air underwater was the most common cause of death in Australian divers.[1]

Contents gauges

Until recently, all contents and depth gauges were Bourdon tube gauges, which are coiled tubes that uncoil or recoil as the pressure within them changes. This movement is transmitted to the needle gear system. If treated with loving care, as on anaesthetic machines and recompression chambers, they are reliable. However, when dropped or shaken the calibration may no longer be relied on. Nevertheless, divers do not have their contents or depth gauges checked every time they are bumped. The only way to conveniently check a contents gauge is to compare it with another. A contents gauge that does not return to empty when taken off the cylinder must be considered to be faulty.

The Diving Incident Monitoring Study DIMS has records of 37 contents gauge incidents, 10 (27%) of which were associated with morbidity. The divers involved suffered decompression illness (DCI), cerebral arterial gas embolism, salt water aspiration and pulmonary barotrauma. Inaccurate gauges were one of the frequently reported causes of running out of air underwater. Gauge problems from the Project Stickybeak database are also listed in Table 1.

Some divers did not understand the units used, mistaking imperial (pounds per square inch, psi) for metric ($kg.cm^{-2}$ or kiloPascals, kPa) or bar. Other problems were rupture of the high-pressure hose or of an 'O' ring during the dive. Some divers were unable to read the gauges either because of poor visibility or because the numbers were difficult to decipher (Table 1).

The important thing about reading a contents gauge is the proportion of the contents remaining rather than the actual pressure (e.g., the rule of thirds). Many divers are also unaware that fluctuation of the gauge needle when a breath is taken indicates that the cylinder is not fully turned on.

Turning on the cylinder when the regulator is first attached is a sensible way of checking that the cylinder is full. But forgetting to depressurise the system after that can lead to trouble, as although the cylinder appears to be turned on it is, in fact, turned off. One should always take a few breaths from the regulator while watching the contents gauge before entering the water. Some years ago a buddy of mine entered the water without a buddy check and only obtained one breath before running out of air for this reason.

Depth gauges

DIMS has nine depth gauge incidents recorded. Two were associated with morbidity (decompression illness in both cases). Problems recorded included inaccuracy, a stuck maximum depth indicator and the maximum depth indicator not being zeroed before the dive. If the maximum depth indicator is stuck, it may prevent the depth gauge needle from moving properly. Such problems can be avoided by regular testing and servicing of depth gauges, and attention to maximum depth indicator usage.

In the mid 1980s a British magazine reported a study of over 100 Bourdon tube depth gauges. Approximately one third were accurate, one third overstated the depth (safe), and one third read shallow (dangerous). At the 1986 SPUMS Annual Scientific Meeting, I tested about 20 gauges in a small water-filled compression chamber consisting of a small perspex pot with a screw-on lid and a calibrated pressure gauge. Pressure was applied by screwing a 10 mm diameter perspex screw into the case. As there was no air in the 'pot', any reduction in volume increased the pressure. The results were similar, and the errors, whether too deep or too shallow, tended to be proportionately the same over any particular gauge's tested range.

One recommended solution is a back-up depth gauge. I usually wear a capillary gauge, which is accurate in shallow water, but difficult to read accurately at depth. As long as it

TABLE 1
TYPES OF CONTENTS GAUGE PROBLEMS REPORTED IN THE DIVING INCIDENT MONITORING STUDY AND PROJECT STICKYBEAK

DIMS

1. Inaccurate gauge
2. Hose leak
3. Unable to read the gauge – poor visibility or legibility of numbers
4. Maximum depth indicator stuck
5. Maximum depth indicator not zeroed at start of dive

Project Stickybeak

1. Dangling and became snagged
2. Needle was loose

Exposure suits reduce convective heat loss, as well as providing varying degrees of thermal insulation. They will slow the cooling rate of water, especially the initial dissipation of heat on immersion. Water temperature, time of exposure, thermal protection, body fat, surface area of the diver, acclimatisation, and level of activity by the diver all contribute to cooling rates. The aim of exposure suits is to avoid hypothermia in the diver. Figure 1 summarises comfort ranges for exposure suits.

Skin

Skin is the most basic thermal protection. The advantages and disadvantages of skin are summarised in Table 1. Skin is best suited to short-term exposure in warm tropical waters.

Lycra™

Lycra™, or other thin non-neoprene materials (a variety of materials are available), provides minimal thermal protection, but excellent UV protection. Lycra™ suits are very user friendly, in that they are easy to don, dry rapidly and are lightweight. They also provide some protection from marine stings, and have a role as an undergarment for wetsuits, aiding donning and increasing thermal protection. Lycra™ suits come in a variety of designs, materials and colours. Their main disadvantage is that they provide poor thermal protection, making them suitable only for tropical waters.

Wetsuits and 'steamers'

Wetsuits and steamers provide the next level of thermal protection, and are usually constructed from neoprene and lined internally and externally. There are multiple options for styles, short and full length limb versions, thickness of insulation, and may include hoods, gloves and boots. The thickness of material determines its suitability for thermal protection. In general, 2–4 mm thickness ('steamer') is adequate for water temperatures above 24°C, 5 mm thickness for water temperatures 18°–29°C, and 7 mm thickness for water temperatures 10°–26°C.

Wetsuits provide insulation and slow down heat loss to the environment by restricting water circulation around the diver's body. Therefore to function correctly, the suit must

TABLE 1
THE ADVANTAGES AND DISADVANTAGES OF SKIN FOR DIVING

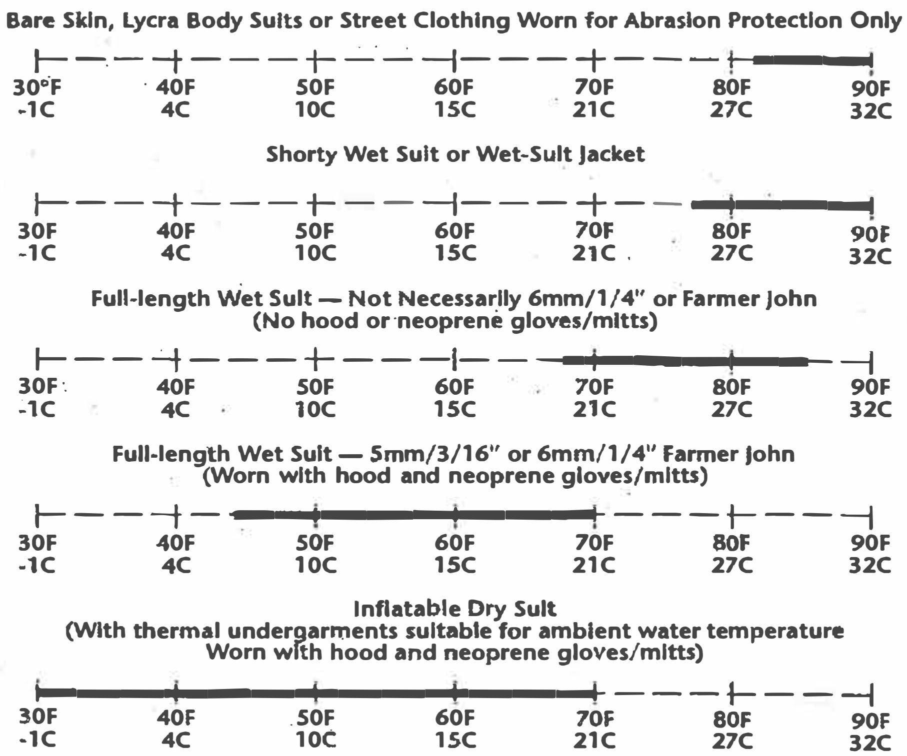
Advantages

Cheap
Dries quickly
Self repairs (up to a point)
Education – a "skin" diver learns quickly what stings
Suits water 27°C (80°F) or warmer
Fits most divers
Maximum comfort

Disadvantages

Sensitivity to ultraviolet (UV) radiation exposure
Poor abrasion resistance
Sensitive to marine stings
Little thermal protection

FIGURE 1. EXPOSURE SUITS (reproduced from reference 1.)



fit the diver's body shape adequately. Most neoprene wetsuits are relatively easily donned. Zippers on sleeves, legs, and along the chest will assist donning, but reduce thermal insulation.

Advantages of wetsuits are that they are generally inexpensive, easily obtainable, and easily repaired with a minimal maintenance requirement. In general, extra training is not required to use a wetsuit, unless the diver has been unfamiliar with wetsuit diving previously, e.g., tropical divers heading into cold waters.

Disadvantages of wetsuits are that they restrict body movement, and are buoyant. The latter property necessitates compensation by way of more lead on the diver's weightbelt. Perhaps the most significant disadvantage is that a wetsuit lets the diver down the most when insulation is needed the most. By the nature of their construction, wetsuits compress with depth underwater and lose thermal insulation as a result of this compression. Also, as a result of compression there is a loss of buoyancy at depth, which results in the need for a buoyancy compensator.

Divers often complain that wetsuits shrink with age. Certainly, as the air cells in the material collapse as a result of neoprene ageing, the suit may become stiffer and therefore less easy to don and less comfortable to wear, but mainly the 'shrinkage' is due to the diver's configuration changing with age! Wetsuits are in general bulky and difficult to pack. Wetsuit hoods restrict hearing and wetsuit gloves will significantly restrict digital function.

Semi-drysuits

Semi-drysuits are fundamentally a variation on traditional wetsuits, that is, less wet wetsuits, in that they usually have neck, wrist and ankle seals to restrict water entry into the suit and a single non-gastight zipper to allow diver entry. In general, these suits are less restrictive and more comfortable than the comparable wetsuit, but tend to be more expensive and have higher maintenance requirements due to the seals being more delicate.

Drysuits

Drysuits are becoming very popular with divers. They are constructed from a variety of materials such as neoprene, trilaminates, crushed neoprene, polyurethane and rubber. Drysuits have watertight/gastight zippers, neck and wrist seals, and commonly boots attached to the suit. Drysuits trap air (and sometimes other gases such as argon) within them, and in most cases require an undergarment to be worn for thermal insulation.

Drysuits have advantages in that they provide excellent insulation both in and out of water and may increase a diver's duration of dive by virtue of increased diver comfort. This may also result in reduced gas consumption by the diver. With a drysuit, the insulation remains constant with depth, and the design of drysuits is such that a perfect fit is not essential; divers can vary the level of thermal insulation by increasing or decreasing undergarments.

Drysuits have some disadvantages. In general, they are expensive and have much more elaborate maintenance requirements than wetsuits, particularly with regards to zippers and seals. Many drysuits require a second person to assist with donning, particularly the zipper closure.

In general, drysuits are bulky and difficult to pack, and may require more lead ballast. Hyperthermia is a potential problem, particularly on the surface. Drysuits require an extra dedicated inflator system, which adds extra complexity to the diver's equipment, and they still require a buoyancy compensator. Drysuit divers will often require a hood and gloves as well. On prolonged dives, drysuits pose difficulty with urination, and may require the fitting of 'pee valves'.

The use of drysuits requires formal training, which is available through training agencies. This extra training is required due to the potential problems associated with drysuit diving. These include:

- suit squeeze, which occurs when the diver descends without adding gas to the suit;
- excessive buoyancy, usually due to poor technique, but may be due to equipment failure (inflation valve/exhaust valve problems);
- excess gas building up in the suit legs, which may cause rapid ascent in an upside-down ('suit inversion') position;
- flooded drysuit with loss of buoyancy and thermal insulation (zipper problems or trauma to the suit may be responsible).

Drysuit insulation can be increased using argon gas inflation, as argon is a better thermal insulator than air.[2] However, this system adds complexity and expense, as it requires a dedicated gas supply system and clear marking of argon cylinders.

Problems with diving suits

The types of suit-related incidents reported to the Diving Incident Monitor Study (DIMS) and fatalities in Project Stickybeak are listed in Table 2. There were 10 suit incidents in the 457 equipment-related incidents reported in the DIMS.[2] One fatality related to the diver's suit was reported in Project Stickybeak.[3]

Discussion

There are some general measures that facilitate diver thermal comfort. You must commence a dive in a warm state, and stay warm between dives. A diver standing around in wet gear increases thermal loss. Loss of body warmth and hypothermia can occur insidiously, be aware of the potential for hypothermia in yourself and other divers. Remember that alcohol consumption exacerbates thermal loss. Hot water systems are used commercially to maintain diver warmth; recreationally, a warm shower on a dive boat may speed up the warming process, but may also increase the risk of decompression illness.

TABLE 2
SUIT-RELATED MORBIDITY AND MORTALITY FROM THE DIVING INCIDENT MONITORING STUDY AND PROJECT STICKYBEAK

There were 10 incidents in 457 equipment-related incidents and one fatality reported.

Types of incidents reported

Tight wetsuit causing difficulty breathing
New wetsuit, altered buoyancy and diver failed to adjust weights
Inadequate thermal protection
Inadequate protection from marine stings
Hood causing claustrophobia
Tightness causing difficulty with breathing

Types of morbidity caused

Decompression sickness
Pulmonary barotrauma
Hypothermia
Coral and jellyfish stings
Acute cardiac failure (wetsuit compression)
Pulmonary barotrauma (drysuit overinflation)

Some of the difficulties with exposure suits may be quite unusual, such as allergy to suit components like glues, rubber, contaminants and latex.

References

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Guy Williams, MB, BS, FRACGP, is Immediate Past President of SPUMS and a general practitioner in Victoria.
Rosebud Medical Centre,
1239-41 Point Nepean Road, Rosebud,
Victoria 3939, Australia.
***Phone:** +61-(0)3-5981-1555*
***Fax:** +61-(0)3-5981-2213*
***E-mail:** <rmc@surf.net.au>*

Dr CJ Acott, FANZCA, DipDHM, is the Coordinator of the Diving Incident Monitoring Study (DIMS) and a consultant for the Diver Emergency Service.

Editor's note: For a useful review of drysuits see:
Strike D. A dry-suit primer. *Nekton*, edition 4, Jan/Feb 2003; <http://www.e-nekton.com/mag.html>

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