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Many Are Cold But Few Are Frozen –
Marine Safety Issues from a Medical Sciences Perspective

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"MANY ARE COLD BUT FEW ARE FROZEN"

- Marine Safety Issues from a Medical Sciences Perspective-
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Historical

Ever since our ancestors first took to the seas to fish, trade, explore or make war, death from drowning or deprivation, following shipwreck, was accepted as an occupational hazard. Since those early days, the magnitude of some maritime disasters, or the perceived importance of some of those who lost their lives, has acted as a catalyst to stimulate research & development in technological life saving solutions.

In the days of sail, the biggest breakthrough in this respect was that made by John Harrison in 1762, with his invention of a reliable seagoing timepiece. Until the relatively recent introduction of satellite navigation, it proved to be one of the greatest contributors to accurate navigation, thereby drastically reducing incidents in which ships, and indeed even entire squadrons, were lost and ran aground (e.g. Admiral Sir Clowdisley Shovell on the Scilly Isles in 1707). Between 1793-1845, the Royal Navy alone lost 410 ships and over 16,000 lives through shipwreck. Although the loss of life was often very significant in many of those incidents, square-rig sailors did at least have the advantage that, weather permitting, there were ample wooden spars or hatches, ropes, canvas and barrels, etc., available from which to construct some form of suitable raft or platform to aid their flotation until they drifted ashore or were rescued. Such solutions took time but were of little use to those less fortunate who were obliged to abandon ship in a hurry.

Although the Assyrians used inflated animal bladders or animal skins to cross the great rivers of the Middle East, the first effort at producing a uniform individual life saving device, arrived in mid 19th century in the form of a personal lifejacket. Following the capsize of a lifeboat on the Tyne in 1851, with the loss of 20 of 24 of the best river pilots, Captain John Ross Ward of the RNLI examined a number of prototype lifesaving appliances and, in 1852, introduced a modified a cork lifejacket for lifeboat crews. 800 were issued to lifeboatmen around the coast of Britain and quickly proved their worth. In 1857, when rescuing survivors from a wrecked vessel, the whole crew of the Scarborough lifeboat were thrown overboard into the water; all were able climb back on board[1]. Henry Freeman, a lifeboatman for over 40 years, was wearing one when he was the sole survivor of the Whitby Lifeboat disaster of 1861, following a capsize outside the harbour. These lifejackets, or similar ones filled with kapok, horsehair, or even, nowadays, polystyrene, do not necessarily guarantee survival, as many of the 1,489 unfortunates who had to take to the calm icy water following the sinking of the "TITANIC" (1912) discovered to their cost.

The introduction of steam powered iron ships in the Victorian era and the associated large loss of life when many sank with great haste following collision triggered a host of weird and wonderful "lifesaving" appliances. Most, although sources of humour to us nowadays, were of little practical value as they paid scant regard to the physiological nature of the threat confronting the potential user. Needless to say, despite these best efforts, lives continued to be lost in great numbers, e.g. Canadian Pacific liner "EMPRESS OF IRELAND", which sank in 14 minutes in the icy waters of the St Lawrence river in May 1914, with the loss of over 1057 lives, and the "LUSCITANIA", torpedoed off southern Ireland in May 1915, with the loss of

[1] The Life Boat Journal of the Royal National Lifeboat Institution; p121-122. London Oct 1857.

1,198 lives. Apart from these isolated peacetime disasters, the problems of personal survival following ship sinking were really emphasised by the very large numbers of lives lost in both World Wars in the first half of the 20th century.

The alarming loss of life at sea following ship abandonment, among British Merchant Navy crews in the Atlantic convoys in the early years of WWII, prompted the British Government to ask the Medical Research Council for assistance. They appointed a special "Shipwreck Committee" to enquire into the physiological and medical issues involved. This committee collated the accounts of survivors and rescuers, identified areas needing research, and produced practical guidelines[2] on both the treatment of casualties and preventative measures necessary to improve survival prospects among them. Much of that advice is still valid today.

At the end of the war, the Admiralty set up a Committee under Rear Admiral A G Talbot RN[3], to investigate the causes of the loss of life of naval personnel at sea in the course of the war, together with all aspects of naval lifesaving. The findings included the startling statistic that over two thirds (approximately 30,000) of all Royal Navy fatalities during the war, survived the action that sank their ship, only to die during the subsequent survival phase. That conclusion provided the stimulus for the research and development that resulted in modern marine lifejackets, inflatable liferafts, and the recommendations for the minimum sea survival rations.

The current record for the numbers of lives lost at sea in a single peacetime incident is the "DONA PAZ". She sunk following a collision with a small oil tanker in the Philippine archipelago, on a calm moonless night on the 28th December 1987. Of the estimated 3,156 people on board the ferry, only 24

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[2] War Memorandum No. 8: *A Guide to the Preservation of Life at Sea after Shipwreck* 1943. HMSO. London.

[3] *The Talbot Report on Naval Lifesaving.* 1946. HMSO London.

passengers survived and none of the crew. Greater losses of life in a single ship sinking have occurred in wartime, e.g. the British liner "LANCASTRIA" off St Nazaire in June 1940, with an estimated loss in excess of 6,000; towards the end of WWII, the German liner "WILHELM GUSTLOFF" was torpedoed and sunk in the Baltic Sea off Kalingrad by a Russian submarine, with an estimated loss of over 10,000 lives.

Sadly, unnecessary deaths still occur at sea. Between 1978-1998, over 5,300 passengers died in ferry accidents around the world, making ferry travel ten times more dangerous than air travel[4]. More recently the ferry "ESTONIA", which was lost on the 28th September 1994 in the Baltic Sea south of Finland, capsized and sank in water at 12°C in less than 30 minutes with the loss of 989 lives. Only 14% of those on board survived. The subsequent, very thorough, Board of Inquiry identified the many problems associated with that disaster, which led to such a large loss of life. Many are a sad indictment of the regulators, architects, and operators of such ships. Since then, new regulations have come into force in an endeavour to prevent a recurrence of some of the problems identified but there are still many areas that need addressing.

In both the Fishing industry and recreational boating world, there are also a large number of lives unnecessarily lost at sea every year. The majority of these are due to a general lack of appreciation of the threat, inadequate training, or a failure to purchase or maintain effective safety equipment, rather than being overwhelmed by extremes of weather, i.e. they are potentially both eminently preventable and survivable.

Understanding the nature of the threat is critical to the process of risk assessment and thus design of lifesaving equipment. Central to this is an understanding of how the body normally functions (physiology), how best to maintain this function in adverse conditions, and the level and consequence of

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[4] Faith N. 1998. *Mayday*. London: MacMillan.

the functional impairment likely to occur in a survival situation. These have recently been reviewed in some detail[5], and are briefly summarized in this lecture.

The nature of the overall threat

Following a collision, grounding, fire or explosion, there may be a requirement to 'abandon ship' sooner or later. In such situations, the level of the threat confronting the individual is dependant on a large number of interacting variables, viz.: integrity of the hull and thus possible sinking rate; the presence of fire or toxic contamination; environmental conditions; sea state; remoteness of incident from potential rescue facilities and their capability; presence of injuries/disabilities among crew or passengers; the quality of the survival aids available and the training/proficiency of the crew in their use. Any factor that hastens the abandonment of the relative safety of the hull increases the risk to life proportionately. Should abandonment prove necessary, then it is obvious that a slow orderly evacuation is preferable to a hasty one in which essential safety measures are frequently forgotten, or, worse still, one is forced to enter the water.

In the orderly evacuation, it is probable that the necessary distress messages have been transmitted (and hopefully acknowledged) and that survival is therefore only a matter of time before rescue will be at hand. Prior to leaving the parent vessel there should also have been sufficient time to cater for the ensuing interval before the rescuers arrive, thereby significantly reducing the risks. Modern satellite distress locator beacons greatly enhance the chances of successful rescue and thus the great privations of the past should be less likely to be encountered in the future. In addition, the availability of manually operated reverse osmosis equipment, for the production of potable water from

[5] Golden F & Tipton MJ *Essentials of Sea Survival.* Human Kinetics, Ill., USA. 2002

seawater, will help considerably in alleviating the distress associated with dehydration while awaiting rescue in some remote tropical areas of the oceans.

Alternatively, in a hasty abandonment, one is frequently dependant on the available survival aids already stowed in lifeboats or rafts as emergency equipment. Unfortunately, these are usually the bare minimum required to just sustain life for a few days. Thus, after a week without additional water supplies, one will be suffering from the effects of severe dehydration with the associated risk of dying, through that cause, rising exponentially with each succeeding day. This, not starvation, will prove to be the major threat to life in tropical regions for the lifecraft survivor. Outside the tropics however, the threat from cold may be devastating from the outset, with most suffering from cold injuries to the limbs and many dying from hypothermia long before water shortage becomes a significant problem.

Worse still are the immediate pathophysiological problems confronting the survivor in the water. These are discussed in broad outline in the next section.

The physiological threat to the immersed survivor

Drowning constitutes the greatest threat to life for the immersed individual and has been a recognised cause of death for many centuries. Sadly, the legal recognition of drowning as a certifiable cause of death in its own right has done little to foster investigation into its cause and thus question how it may be prevented.

The Talbot Committee in1946, and the MRC Shipwreck Committee a few years previously, rightly recognised the role of hypothermia as one of the major threats to life among survivors in waters outside the tropics. The physiological mechanisms are quite straightforward and have been well understood for many decades. From a thermoregulatory viewpoint, man is classed as a tropical animal; he is a warm-blooded creature with a normal deep body temperature tightly controlled at around 37°C. To achieve this, heat lost from the body must balance heat being produced through metabolism, and/or that gained from the environment. Conversely, in cold climates, heat loss from the body must be curtailed in order to conserve heat. Should either mechanism fail, then deep body temperature will either increase of decrease into a zone where at first function becomes impaired before eventually death ensues.

Temperature Regulation

Body heat loss is controlled, physiologically, predominantly through regulating blood flow from the metabolic producing core to the cooler superficial tissues. There, the blood offloads heat returning to the core somewhat cooler to pick up more heat to exchange when it again returns to the surface. Regulating the volume of blood flow between core and surface is carefully controlled by a central regulatory region of the brain, which receives inputs from temperature sensitive nerves around the body.

This mechanism works very satisfactorily at controlling body temperature when ambient temperatures are in the region of 26-30°C. Outside that environmental range, temperature regulation is only possible through either shivering or sweating; both of which are stressful and finite, depending on energy or water availability. Thus, from a thermoregulatory viewpoint, man, in his natural state, can only live in a tropical environment. Outside the tropics, extraneous measures must be adopted in order to survive. This is achieved by creating an artificial microenvironment adjacent to the skin in the thermoneutral range of 26-30°C. The regulation of the temperature of that environment is then maintained by behaviour, through adding or subtracting layers of insulation, and/or by altering the general environmental temperature of the habitat.

In water however, temperature regulation becomes much more challenging. The thermal conductivity of water is 24 times that of air and the volume-specific heat capacity of water is approximately 3,500 times that of air, giving water a vastly greater capacity to remove heat from the body than air. Therefore it is not surprising to find that the thermoneutral temperature of water, for human thermoregulatory purposes, is about 35°C. As there are very few open sea temperatures in the world with water temperatures in this range, it is easy to understand why hypothermia constitutes such a threat to immersed man. However, while hypothermia remains a possible cause of death to survivors in survival craft it is unusual for those who are immersed. Such individuals usually die from drowning shortly after they start to become incapacitated through cooling, and long before the deep body temperature falls near the lethal 26°C region.

Pathophysiology of Drowning

Seawater is twice as lethal as fresh water. Aspirating volumes in excess of 22ml/kg body weight (about1½ litres for the normal adult) of seawater is usually not compatible with survival[6]. Aspirating smaller volumes may be survivable provided the correct treatment is applied, as soon as possible.

Drowning *(def: "death through suffocation by submersion, especially in water")*.

Following submersion, tidal volumes of water will be moved in and out of the lungs with each breath as long as respiration lasts, thus preventing the normal process of gas transfer between the blood and the small terminal air sacs ("alveoli"). Blood levels of oxygen quickly fall and levels of carbon dioxide rise. As a consequence, brain activity becomes impaired and consciousness is quickly lost (<1min). Respiration ceases in about 70 seconds. Cardiac activity continues for a little longer (about 2 min) but eventually, the combination of the workload of pumping blood through waterlogged lungs, coupled with the

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[6] Modell JH. *Pathophysiology and treatment of drowning*. Charles C Thomas, Springfield; Illinois. USA 1971

shortage of oxygen, makes the strain on the heart pump excessive. Cardiac output declines rapidly, blood pressure falls, and cardiac arrest ensues in about 4-5 min. Brain death will occur shortly after; the time being dependant on brain temperature at the time when oxygen starvation occurs.

Near Drowning *(def: "survival at least temporarily, after aspiration of fluid into the lungs).*

When the volume of water aspirated is less than that required to cause immediate death, difficulties in respiration may still occur and, if untreated, may result in death some time later. Water, especially salt or contaminated fresh water, irritates the lungs and produces an acute inflammatory reaction resulting in an outpouring of serum into the alveoli. This mixes with the fluid that has been aspirated, resulting in a frothy mixture that impairs the normal gas transfer process. The magnitude of the effect will be proportional to the volume aspirated and amount of irritant debris, or salt, contained. Small volumes may have little initial effect leaving the victim completely asymptomatic, apart from some coughing, but as little as one tenth of the lethal volume may produce significant changes in blood gas levels without the victim being necessarily aware of the situation, while at rest. Slightly larger volumes may also be asymptomatic initially, but the secondary inflammatory reaction in the lungs may subsequently leave the victim experiencing some breathing difficulties with wheezing or "crackles" in the lungs. In many, even in those who aspirate clean fresh water, which is quickly absorbed across the alveoli into the blood, some inflammatory damage to the alveoli walls will occur resulting in small-localised areas of lung collapse. Blood passing through areas of collapse will obviously not be able to exchange gas and thus will leave the lung in the same deoxygenated state it arrived in. Large areas of collapse will therefore produce significant changes in arterial oxygenation, respiratory embarrassment, resulting in breathlessness and even loss of consciousness.

Regardless of whether the response is an acute inflammatory one, or a localised area of lung collapse, or, as usual, a combination of both, gas transfer will be impaired and breathing difficulties (increased breathing rate associated with complaints of difficulties in "getting enough air into the lungs") will progressively increase in the succeeding hours. The patient may show some associated blueness of the lips and nail beds and a rise in pulse rate. Eventually, consciousness becomes impaired, followed by respiratory failure and death. It is important therefore that, as soon as possible following rescue, a doctor examine all survivors suspected of suffering near drowning.

Likely causes of death following shipwreck

Following the Talbot report at the end of WWII, attention was focused on the role of hypothermia as the major threat to survivors. While the incapacitating effects of cold remain indisputable, further insights into the overall nature of the problems confronting survivors have since been gained from analysing other immersion incidents, in addition to more recent maritime incidents, together with laboratory experimental work. These shed further light on the nature of the threat, and helped Golden & Hervey[7] to identify four stages of immersion associated with specific risks:

1. Initial responses (0-5 minutes)
2. Short-term response (5-30 minutes)
3. Long term responses (30 minutes +)
4. Post immersion responses (during and following rescue)

[7] Golden F & Hervey GR. The "afterdrop" and death after rescue from immersion in cold water. In "*Hypothermia ashore and afloat*" ed. JA Adam. Aberdeen University Press. 1981. Aberdeen UK.

The hazards at each of the first three stages are caused by cooling of different regions of the body, starting with the skin (initial responses) and proceeding through the muscles which lie close to the surface of the body, particularly in the arms and legs (short-term responses). In this context, it is worth noting that 50% of the tissues of the body are within 2.5 cm of its surface. Thereafter the cooling spreads to the organs in the core of the body (long term responses). In adults, hypothermia cannot occur until stage 3; it is a physical impossibility to lose heat from the surface of the body during immersion at a rate that will cause hypothermia-related problems within 30 minutes. Thus, newspaper reports, such as those following the capsize of the Herald of Free Enterprise which said, "*Following immersion in the icy waters, death from hypothermia occurred within minutes*" can be regarded as misinformed. Before they become hypothermic, immersion victims must survive two hazardous stages, the fatal consequence of which is usually drowning rather than hypothermia. Finally, some 20% of survivors die during or following the rescue process.

<u>Initial Responses ("Cold Shock")</u>

The initial responses to immersion in cold water, for those who are not habituated to cold, are characterised by an initial gasp response followed by uncontrollable rapid breathing, which make breatholding impossible. In addition there is an accompanying very rapid increase in heart rate and a rise in blood pressure; both of which may result in a cardiovascular accident ("Stroke", Heart attack) should the individual be unfit or suffering from existing heart disease or hypertension. These responses are collectively termed "Cold Shock". They commence within about 30 seconds of immersion and last for about 3-4 minutes before waning. They frequently cause temporary incapacitation resulting in drowning.

Short term Responses (Swim Failure)

Approximately 55% of the annual open water deaths in the UK occur within about 3 meters of a safe refuge, and about 42% within 2m. Two thirds of those who die are regarded as 'good' swimmers[8]. Such statistics do not suggest the protracted period of cooling required for hypothermia. Rather, they are more indicative of some incapacitating response that is rapid in onset, and prevents individuals swimming 3 meters to save their lives. Some of these deaths, undoubtedly, will be associated with the cold shock response but others, who suffer swim failure at a slightly later stage, will be the result of a progressive cooling of muscles and nerves sited in the cooler outer tissues of the body[9].

Long term responses

In cold environmental conditions when body temperature is being threatened, the physiologically induced shut down of peripheral circulation will result in rapid cooling of the limbs, the hands and feet in particular. Thus, those immersed in water below 15°C quickly become impaired as the muscles cool below about 27°C. This impairment makes it increasingly more difficult to keep the airway clear of the surface of the water, even when wearing a lifejacket. When floating passively in the water, the natural tendency is to be turned by the moment of the wave to face the oncoming sea. If the wave is steep, there will be insufficient energy in the crest to overcome the inertia of the body. As a consequence, the wave crest will wash over the face thereby making it necessary to hold ones breath in order to avoid aspiration. In such circumstances, it is much more comfortable to keep ones back to the wave, particular if the wave frequency is high. Failure to do so may result in drowning relatively quickly. Laboratory cold immersion studies have shown that when the average person has cooled to 35°C, muscle temperature will

[8] Home Office. *Report of the working party on water safety*. HMSO. 1977. London.

[9] Tipton MJ, Eglin C, Gennser M, Golden F. Immersion deaths and deterioration in swimming performance in cold water. *Lancet*. 1999; 354: 626-629.

have fallen to about 27°C. The time taken to achieve this level of cooling, determined through laboratory studies, is also comparable with many of the anecdotal accounts of the time to death from drowning among survivors, thus supporting the requirement for some form of splashguard to be fitted to the lifejacket.

Even for those survivors in open boats or liferafts, not threatened with drowning, the early loss of sensation and impairment of manual dexterity, associated with the rapid cooling of limbs, may make it extremely difficult to perform actions that may be lifesaving. Actions taken in the initial hours in a survival craft are often the key to successful survival. Sadly much of the safety equipment carried routinely in survival craft, and it's packaging in particular, is not compatible for use by people with cold impaired manual dexterity. Anecdotal accounts of survivors unable to open the plastic packaging of flares are reasonably common. Likewise, in many commercial rafts, people with very cold hands find it extremely difficult to use the securing ties necessary for ensuring environmental integrity. These are areas that need addressing in the design and development stage of all marine safety equipment. The threat of hypothermia, and indeed the time to onset of cold induced dexterity problems, can be greatly reduced by wearing appropriate protective clothing. The old adage that 'a warm body will ensure warm hands' is equally true in this situation.

Rescue and Post Rescue

While the majority of those who die during or shortly after rescue are the result of the delayed effects of near drowning, some are a consequence of the cardiovascular effects of the sudden removal of the hydrostatic pressure to which the body was subjected during the period of immersion. Although the hydrostatic pressure is very small relative to atmospheric pressure, it is very significant in relation to venous pressure, particularly when the person is floating in a vertical posture. As a consequence, it will help to squeeze the venous blood back to heart, thereby increasing the cardiac output, with a number of associated benefits to the circulation. On removal from the water, this supportive pressure is suddenly removed simultaneously to the re-exposure to the full effects of gravity. As a consequence venous blood tends to pool towards the lower extremities, thereby reducing venous return and thus cardiac output. Under normal circumstances, the body's auto regulatory physiological reflexes will compensate for this and make the necessary adjustments to the circulation, however, when cold, these reflexes are impaired and the individual may faint or worse, collapse and die. The rescue process is therefore critical in many respects. Firstly location must be achieved quickly and the condition of the casualty speedily assessed as an approach is being made. If the airway is being threatened by wave splash then it is imperative that the victim is rescued speedily in any way that is practical. If not, then a slightly more guarded approach to rescue can be considered with the view of conducting it in a manner that is safest for both victim and rescuer.

One of the critical factors in rescue is the potential danger to the airway of the victim when in close proximity to the rescue boat. The normal mouth to water distance is in the region of 6cm, a clearance that is only achieved with swimming ability (muscular effort) and the confidence to relax in the water. When that muscular effort is compromised by cooling, or reduced by the victim reaching to grab a rope or the helping hand of the rescuer, the body will sink a little thus possibly facilitating aspiration of water. Once that happens, it is likely some degree of panic will ensue together with a bout of coughing during which the airway may be further compromised. Another threatening factor that occurs in close proximity to a rescue boat is the occurrence of some back splash or displacement wavelets from the hull. Thus while the victim may have been relatively happy coping with the rhythmicity of the wave formation in the open sea, that encountered near the hull may be short, steep and of high frequency. There may also be some collision between wavelets producing a spiky type of wave pattern. Such waves, although not necessarily substantial, in terms of mouth to water distance, may be quite critical and can be notoriously difficult for a person, even in full control of respiration, to deal with;. for someone who is likely to be cold, fatigued and very stressed, they may prove to be the last straw.

It is important therefore to have a proven procedure and a well-rehearsed technique to get these people out of the water as soon as they are adjacent to the boat. There is little point in having the capability of getting to the rescue site at 25knots if on arrival one is unable to get the victim out of the water safely. Conversely, there is little point in having an excellent recovery capability if it takes too long to reach the victims while they are still alive, or if the equipment only works in relatively calm water. Similarly, if the speed of the rescue boat is too slow, the casualty may drift towards a lee shore thus resulting in an added danger for both the casualty and rescuers. Therefore, the optimum design criteria should be a boat with a good all-weather performance, a capability to tow a casualty away from danger, and, if required, the capability of speedy recovery of victims from the water, regardless of their condition. To date, that remains an engineering challenge.

Finally, another remaining rescue challenge is that confronting crews of high sided ships. Currently, following the "ESTONIA" incident, there is a requirement for high-sided passenger vessels to carry a davit launched rescue boat to facilitate the safe recovery of people from the water. Unfortunately, the majority are unable to safely recover the craft if the sea state is more than 5-6. Until a more practical method, capable of operating in more severe weather conditions, is devised they will be unable to rescue personnel who accidentally fall overboard, or survivors from other smaller vessels who may have encountered difficulties in adverse conditions.

Conclusions

Physiological research carried out since the end of the Second World War has provided a very good understanding of the medical problems facing survivors at sea. Naval architects and engineers likewise have made very significant advances in design and construction of vessels that have reduced the incidence of major disasters at sea. Unfortunately, some disasters still occur, not just through overwhelming or unforeseen circumstances but also because of commercial pressures and vested interests. Regrettably, in many such circumstances, individuals die as a consequence of not having the correct equipment or the knowledge and training on how to use it effectively. Finally one remaining area in particular is deserving of some innovative research, viz. the rescue/recovery phase. It is tragic both for the victim and the rescuers, to arrive at the point of rescue and be unable to recover the individual safely from the threatening environment.