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LUNG ASSESSMENT FOR SUBMARINE ESCAPE TRAINING

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Introduction

The successful completion of pressurised submarine escape training (PSET) is a pre-requisite for qualification as a submariner in the Royal Australian Navy (RAN). There are two principle methods of leaving a disabled submarine, escape and rescue. Escape is where the survivors leave the submarine through an escape hatch and make an ascent through the water to the surface. This escape may be from the escape tower (SET), where the submariner spends the least time exposed to ambient environmental pressure or from a flooded compartment that is in direct contact with the outside environment.[1] This is known as compartment escape and exposes the individual to the ambient environment for a greater period of time. It is possible to perform a SET escape from a depth of 180 msw and a compartment escape from a depth of 60 msw.

Rescue involves the use of a submersible to transport any survivors from a disabled submarine to the surface where decompression can be undertaken if required.[2,3] The depth of the submarine and the operating capability of the rescue craft generally limit rescue. As it can not be assumed that rescue will always be possible, the RAN requires all submariners to have demonstrated confidence in the escape procedure.

The RAN conducts PSET at HMAS STIRLING. The submarine escape tower is a purpose built column of water 22 m deep. Participants can enter the water at the surface or at various depths (through air locks) to practice different methods of escape. The environment is strictly controlled, the water temperature warm and the tower brightly lit. While this does not equate to the likely scenario of a disabled submarine, which may be cold and dark with a contaminated atmosphere, the training environment affords a higher level of safety.

Training methods

Escape training methods taught include buoyant ascents and hooded ascents. During buoyant ascents a buoyancy aid (inflated life jacket or submarine escape jerkin) is worn to assist the escaper to the surface and the escaper is required to perform a controlled exhalation all the way to avoid pulmonary over inflation. During buoyant ascents escapers can achieve ascent rates of between 92-120 metres per minute. During hooded ascents the escaper breathes normally from air retained in a hood worn over the head. The RAN uses a submarine escape immersion suit during hooded ascents and the escapers can reach an ascent rate of 150 metres per minute. These ascent rates are up to 15 times greater than those routinely practiced by recreational divers.

While hooded ascents are the preferred escape method a buoyant ascent may be required if the hood ruptures or leaks during the ascent and the escaper finds his head in water.

Escape tower

The escape towers in RAN submarines accommodate one person only. During an escape the pressure within the escape tower is equalised with the outside water which then allows the outer hatch to spring open. During the compression phase the ambient pressure within the tower accelerates exponentially, the pressure doubling every four seconds. To achieve the maximum escape depth of 180 metres, pressurisation of the escape tower takes less than 20 seconds. This short time under pressure reduces the risk of serious decompression illness.

Medical risks

Medical risks associated with PSET include pulmonary barotrauma, arterial gas embolism (AGE), middle ear, sinus and facial nerve barotrauma, decompression illness and drowning, albeit unlikely in this highly controlled environment.

A medical risk assessment of PSET conducted by Weathersby et al. revealed hooded ascents appear safest with an AGE incident rate of 0.1 – 0.6 per 1000 escapes with a fatality rate of 10 – 50 times lower.[4]

They also noted a trend of a higher incidence rate of AGE for each type of escape with increasing depth. Factors known to increase the risk of pulmonary barotrauma are buoyant ascents, novice trainees, increasing depth of ascent, increasing rate of ascent, some pre-existing lung diseases and small lung size in relation to body size. In one large study of SET accidents the incidence of pulmonary barotrauma among initial trainees was almost double that of requalifiers.[5] It is not intuitive to continue to breathe or exhale during an escape – it is a learned response.

It is also important to note that in a number of patients who have suffered pulmonary barotrauma with AGE, no predisposing factors have been identified. AGE has also occurred in individuals who have been observed to exhale normally during the ascent. There appears to be a substantially random component to the occurrence of pulmonary barotrauma and there is no completely safe training depth. PSET carries a real risk of morbidity and mortality.

In 109 cases of non-fatal pulmonary barotrauma associated with PSET, 104 cases suffered AGE and only 5 suffered pulmonary barotrauma without AGE (4 subcutaneous emphysema, 1 pneumothorax).[6] Of the 104 cases with AGE, 82 suffered AGE alone, 15 had AGE and mediastinal emphysema and 7 had AGE with pneumothorax.

Mechanism of Pulmonary Barotrauma

It is now thought that the over stretching of lung parenchyma causes the injury of pulmonary barotrauma by a transmural pressure change rather than a change in the volume of intrathoracic gas.[7] Experiments on positive pressure inflation of fresh human cadavers revealed that lungs expanding in an unsupported thorax burst at 70 mmHg, but if the lungs are confined they rupture in a different manner at pressures approximating 110 mmHg.[8] Some spontaneous pneumothoraces are associated with forced inspiratory manoeuvres such as hiccupping or the completion of functional tests of total lung capacity or peak inspiratory pressures.[7] In other words voluntary high inflations can stretch some parts of the lung beyond their elastic limits.

Ways of decreasing the risk of PSET

There are 3 possible ways of decreasing the risk associated with PSET:

a adequate training to decrease the likelihood of incidents associated with panic,
b slowing the rate of ascent, (however there are no practical means of achieving this), and
c medical screening to identify those with clinically detectable, pre-existing lung disease.

Training methods

As previously stated evidence suggests that hooded ascents carry less risk than buoyant ascents and there is a general trend to higher incident rates with deeper escape depths. Overall the frequency of incidents and the risk of injury is decreased by limiting the number and depths of ascents conducted. The RAN PSET program prior to 1995 included 2 buoyant ascents from 9 metres and 1 buoyant ascent from 22 m wearing the submarine escape jerkin, 1 hooded ascent (compartment escape) from 22 metres and 2 hooded ascents (escape tower) from 22 metres. After an extensive review in 1995 this program was amended to reduce the risk of injury to trainees. The program now comprises 2 buoyant ascents from 9 m wearing the submarine escape jerkin and 2 hooded ascents (escape tower) from 22 m.

Medical screening

To join the RAN submarine service all potential submariners must have successfully passed the RAN entry medical, be less than 35 years of age, have no history or evidence of pulmonary disease, no cysts, blebs or scarring and have a forced expiratory volume in one second/ forced expiratory capacity (FEV_1/FVC) of greater than 75%. They also require a normal inspiratory and expiratory full plate chest X-ray.

Age limit

Lung compliance describes the extent to which lungs expand for each unit increase in transpulmonary pressure. A fall in vital capacity and an increase in residual volume and functional residual capacity accompany aging.[9] These changes can be accounted for almost entirely by the changes in lung elasticity with reduced elastic recoil in the older patient. Mitman concluded that with increasing age there is a decrease in chest wall and total lung compliance and the associated increase in residual volume limits the extent to which you can exhale.[9] He also noted that the biggest reduction in lung compliance occurred in the 30 – 39 year age group.

Colebatch et al. have shown that individuals with small stiff lungs are more liable to lung rupture.[10] It is also known that as the lung reaches total lung capacity, compliance decreases, and in the setting of pulmonary over inflation is more likely to rupture. Lung compliance measurement is not simple and requires invasive techniques that can also be expensive. It has also been demonstrated that compliance measurements by themselves are inadequate as an index of pulmonary barotrauma susceptibility because they may not detect regional variations in lung compliance. For this reason the measurement of compliance is not recommended as a screening test and the RAN has therefore decided to use 35 years as the maximum age permitted for initial PSET.

Spirometry

In 1975 spirometry was introduced as a measure of respiratory fitness in the screening of Royal Navy (RN) divers and submariners. Clinical opinion in the RN was that, dependent upon age, a FEV_1/FVC of less than 75%

suggested abnormal lung function and further investigation was warranted prior to declaring the individual fit for diving or PSET. However, the predictive value of spirometry as an indicator of risk for PBT had never been established.

Brooks et al. reviewed the data from the Institute of Naval Medicine as a step towards validating the use of spirometry as a screening tool.[11] They included all Caucasian submariners and submariner candidates who had presented for screening between late 1983 and mid 1986. All had passed the RN medical and submarine medical examination and smoking history was accounted for. A major advantage of this study was the consistency of data collection from using the American Thoracic Society standards for spirometry. The study compared lung function variables for predictive value for pulmonary barotrauma. No association was found for the FEV_1/FVC ratio, however, a highly significant association for PBT risk was found for a low FVC. They concluded that up to 25% of submarine escape and perhaps diving accident cases involving PBT could be prevented by making those with an abnormally low FVC (less than 2 standard deviations below normal) medically unfit. However, the exclusion rate by this criteria would be far less than that of the FEV_1/FVC ratio currently in use.

The RAN uses spirometry as a screening tool for the presence of obstructive disease and prompts the requirement to discuss the results with an experienced underwater medicine clinician. A low FVC will also be detected and such candidates will be scrutinised carefully. Spirometry should be avoided on the morning of PSET to minimise the risk of a spontaneous pneumothorax.

Chest X-ray

Scarring within the lung has been associated with an increased risk of PBT, however, the site of injury may be inconsistently related to the scar.[7] Pleural scarring may predispose for PBT but the magnitude of this risk is uncertain. A chest X-ray may also detect clinically asymptomatic cysts, blebs or bullous areas. Full plate inspiratory and expiratory films are taken as it is considered that expiratory films enhance the detection of fibrosis or bullous lesions.

Daily Review

All candidates are questioned each morning of PSET for symptoms of cough, upper respiratory tract infection, malaise etc. Any positive response requires clearance by the Medical Officer prior to the start of training.

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