tolerance test to be certain that he or she can handle the workload of diving, which can reach around 13 mets. Thirteen mets is the equivalent of about a ten minute mile jog. It is not a really heavy workload but it is significant, equivalent to swimming against a one knot current with full gear on. A sensible diver does not try to swim against a stronger current.

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OPHTHALMOLOGICAL ASPECTS OF FITNESS TO DIVE

Malcolm Le May

Abstract

The diving medical examiner may be faced with potential or current divers who exhibit either problems with vision or ophthalmic pathology. A review is presented in which the required visual standards are discussed, together with strategies for correction of common vision problems in the diver. Some of the more commonly encountered ophthalmic conditions are mentioned and their possible impact on fitness to dive is discussed. An attempt is made to consider how eye conditions might be adversely affected by the hyperbaric or aquatic environment. Among conditions reviewed are visual acuity, refractive errors, contact lenses, corneal disease, cataract, glaucoma, retinal detachment, ischaemic conditions, lacrimal duct and orbital abnormalities.

Key words
Eyes, fitness to dive.

Introduction

The diving medical examiner may be faced with questions of a potential diver's fitness in the presence of a previous ophthalmological condition or previous surgery. There have been considerable advances in ophthalmology in the last decade and many examiners may feel that there are gaps in their knowledge of eye conditions, particularly if this knowledge is based mainly on recollection of undergraduate tuition. This review attempts to cover aspects of vision and the eye that may concern the examiner regarding fitness to dive.

The purpose of being fit for a recreational pursuit is to increase both enjoyment and safety. In diving, fitness is important to ensure that the diver is not a danger to himself* or to others.

It is impossible to reduce this risk to zero. The diver may have a right to endanger his own life, but the possibility of endangering others is the more important consideration. It may not be possible or even desirable to reduce either risk to zero, but the diving medical examiner should regard the minimising of danger to others as the primary purpose of the diving medical. The secondary purpose of the diving medical is to minimise the risk to the diver.

* *I have written throughout in my own gender to indicate both sexes.*

Very few conditions encountered in ophthalmology are life-threatening. Very few eye conditions will be a contraindication to diving. Those that are relative contraindications are more likely to cause morbidity in the diver, without endangering the diver's companions or requiring the use of rescue services, and therefore even these conditions may not be reasons to prohibit diving.

Visual acuity

Adequate vision is essential for diving. Sight must be of a standard that enables the diver to locate exit points, such as the shore or the boat. He should be able to see his buddy, locate the shot line, boat and surface, as well as able to see the underwater scenery. Near vision should be adequate for reading gauges, watch, compass and other monitoring equipment.

An exact visual standard for diving is difficult to define. The answer is probably somewhere between the standard required for driving a car and being legally blind. A differentiation should be made between corrected and uncorrected visual acuity. In some subjects with poor vision these are the same. In others, a very poor acuity will be able to be corrected with lenses of some kind. Commercial divers require an uncorrected visual acuity of 6/24 binocularly or better (Australian and North Sea standards) and a corrected level of 6/12 for all divers is suggested,[1] but this is probably too strict. The legal limit for driving a car in Australia is 6/12, but there is little or no evidence for drivers with poor visual acuity having a higher accident rate.[2] Possibly the level of acuity should be set by the individual examiner and a decision made according to the examiner's perception of the subject's handicap and the likely impact on their ability to dive safely. A patient with congenital nystagmus, for example, might have corrected distance acuities of 6/60, but will be little handicapped by this and may have normal or only slightly reduced reading acuity, enabling gauges to be seen clearly.

Refractive errors

Divers with refractive errors are likely to be able to have vision correctable with lenses. The absence of good vision in one eye should not be considered an adverse finding and the vision in the better eye will therefore be the deciding factor.

Hypermetropia (hyperopia) may not need correction in the younger diver, but may cause the same problems as presbyopia, even in the young. The use of a mask with a prescription is probably the most satisfactory means of correction. A dive shop can substitute lenses of spherical equivalent power for the original plano lenses in the mask. This is satisfactory for all but the largest errors or for significant astigmatism. Alternatively a prescription lens can be custom made for the mask or lenses cemented onto the rear surface of the glass. The latter options are more expensive and the stated advantages of the abolition of prismatic effects from better centration are only likely to be of significance in the higher corrections. Custom lenses are the better and more comfortable option.

Upon loss of the mask, the normal diver becomes about forty dioptres hypermetropic underwater, a degree of hypermetropia much larger than that ever seen in practice. Those who have experienced loss of a mask will realise that it is still possible to terminate a dive safely, even with such a large uncorrected refractive error

Myopia gives poor distance vision. A majority of myopes are comfortable for near vision without correction. Again lenses incorporated in the mask are satisfactory. Contact lenses give a better correction of myopia than glasses. More myopes will wear contact lenses than hypermetropes.

Presbyopia is the loss of accommodation with age. A reduction in close-focussing ability begins about eight years of age. About three dioptres of accommodation are needed for reading at normal distance. People are comfortable when using about two-thirds of their available accommodation for any length of time, so difficulty begins to be experienced with lack of accommodation when accommodation is reduced to about four dioptres. This usually occurs after the age of forty. Normal print usually requires reading glasses in the forty five year old. Presbyopia is said to have appeared at this event. The presbyope will find reading easier in bright light due to the enhanced depth of field with a small pupil. Symptoms will be worse in poor light, especially in the evening when tired. Pre-existing myopia enables reading to continue unaided for longer and hypermetropia causes glasses to be required earlier.

The refractive index of water causes objects to appear closer and exacerbates presbyopia. The higher refractive index, as well as making objects effectively closer, causes magnification to the same degree. This magnification may decrease the effects of presbyopia. Available light is reduced as one goes deeper. At 10 m there is only 20% of the light available at the surface and only 1% at 85 m, which makes presbyopia a greater problem for the diver. A theoretical assistance with presbyopia is the chromatic shift of light towards the blue with increasing depth, which can assist with about half a dioptre. Early presbyopes can manage, for a year or two, by choosing new gauges, computers and watches with large clear displays but corrective lenses are eventually required. Presbyopic divers require a near lens to see their gauges and for close work. Some use a small lens cemented on one side of the mask. The diver looks at the wider world through the unmodified glass. Some presbyopes wear a near contact lens on the less dominant eye, to give a mixture of a focussed and unfocussed image at both distance and near. Presbyopic myopes can leave one lens of the mask unaltered if reading gauges is a problem. Many find this deliberate unfocussing of one eye, unacceptable. Unfortunately these are stop gap solutions as most presbyopes require stronger lenses with the passage of time and end up with bifocals on land. The most comfortable solution is to accept that one is ageing and have reading prescription lenses put, as the bottom half of bifocals, in one's mask as soon as one cannot read the telephone book without glasses. Not only can one then read one's gauges but also admire the details of small shrimps and other tiny sea life.

Contact lenses

For correction of both myopia and hypermetropia contact lenses can be worn in conjunction with the diving mask. Soft lenses are less likely to be lost than hard in the event of a mask flooding. Contact lens wearers should consider wearing a mask containing a purge valve as, in the event of a mask flooding, mask clearing may be achieved with less risk of losing a loose contact lens.

The formation of air bubbles under contact lenses on decompression has been described,[3] with localised transient corneal opacities. These are not likely to be harmful, or even likely, in recreational diving. Disposable lenses are a good option for the contact lens wearer. Their low cost and the need to carry spares assists easy replacement before the next dive, if lenses are lost.

Visual field defects

Visual field defects are commonly found in neurological disease, glaucoma, and disease of the retina and retinal pigment epithelium

Patients with field defects due to neurological disease may already be inherently unfit to dive. Hemianopia or quadrantanopia per se is not a contraindication to diving, but the causative neurological damage may make the diver more susceptible to other effects, such as cerebral decompression sickness, oxygen toxicity, the exaggerated effects of narcosis and exaggeration of other problems related to the hyperbaric environment.[1]

Severe visual field defects with restriction of field to less than 20° would be likely to be a visual handicap when diving, but the normal diver has a field restricted to about 30° on either side of the midline by the face mask.

In glaucoma, restricted fields are characteristic of the end stages of this disease. For other reasons patients with advanced field detects from glaucoma might be advised not to dive (see Glaucoma below).

Patients with Retinitis Pigmentosa can appear quite normal and yet have problems with both night blindness and tunnel vision. Both these defects have the potential to cause problems diving in the dimly lit world at depth. Formal visual field testing should be performed if this condition is suspected. Not everyone with this disease knows that they are affected. The optic fundus can appear normal on ophthalmoscopy. Narrow retinal blood vessels, pale discs, and scattered pigmentation in the peripheral retina can sometimes be seen.

Corneal pathology

The main effect of corneal pathology will be to reduce visual acuity and reduced vision can be the only sign of corneal disease without slit-lamp examination. Corneal scars, corneal dystrophies, and keratoconus if significant, will result in reduced vision. Keratoconus (conical cornea) is a dystrophy that produces progressive myopia. In the later stages vision can only be corrected with contact lenses. Later even contact lenses are not able to correct the eyesight which can only be done by corneal grafting. Corneal irregularities due to scarring or corneal dystrophy render the eye more susceptible to abrasions and ulceration. Under normal circumstances this will not affect the diver, but a combination of exposure to non-physiological osmolarity and contaminated water could cause serious infection. Some tropical environments, where the coastal water has a heavy faecal contamination, cause a high incidence of eye infections and could be dangerous in the presence of corneal disease. The condition of recurrent corneal erosion can be treated with hypertonic saline eye drops and exposure to hypertonic sea water could be beneficial to patients with this condition.

Recurrent benign microscopic corneal ulceration occurs in the condition known as Thygesson's Keratitis. This is characterised by episodes of discomfort and photophobia and is believed to be due to residual virus in the corneal epithelial cells following infection with a number of infecting agents. Less benign ulceration, also of a recurrent nature, occurs in Herpes Simplex Keratitis. This is due to emergence of lysogenic phase virus in the corneal epithelial cells or keratocyte stromal cells following a primary herpes inoculation in infancy. The majority of people receive the primary inoculation through the oral mucosa and do not subsequently get herpetic keratitis. Exacerbations of corneal herpes occur following minor trauma to the cornea. Diving itself is not implicated, but sun exposure can be a predisposing factor. There are no absolute corneal pathologies that would debar the aspirant diver, but care could be advised.

Corneal surgery

Kluger[4] has recently published an excellent review on this subject. Surgical correction of myopia has been attempted since the work of Sato.[5] A more recent adaptation of Sato's operation has been popularised by Fyodorov,[6] and is known as Radial Keratotomy (RK). Many people have had this procedure done in order to participate in sport. The procedure involves several radial cuts through 95% or more of the corneal thickness avoiding the central optical zone. In practice, the depth of the cut often exceeds 100%, producing aqueous leaks and microscopic corneal perforations. The cornea is flattened by this procedure and myopia may be abolished. The corneal stroma effectively does not heal after RK, as evidenced by the continuing advancement of the correction in many patients, with eventual development of hypermetropia. Concerns about this procedure are the weakening of the corneal structure and the potential for infection. Many patients experience sensitivity to glare and fluctuating vision due to movements of the central flail section of the cornea. Mask squeeze has the potential for causing movement of the cornea, as well as reopening aqueous leaks. In practice, perforation or leaking due to mask squeeze has not been described. The strength of the cornea depends on epithelial healing, and reformation of the inner Decemet's membrane where micro perforation has occurred. Trauma can certainly cause rupture of the globe at these sites,[7] and infection remains a possibility. Because of potential problems military personnel are not permitted to have Radial Keratotomy,[8] The author has seen corneal abscess formation occurring in an RK wound eight years after surgery. The potential diver should be warned of the possible problems. RK is not a contraindication to diving, but diving should be avoided until the wounds have healed, externally. This should be complete after six weeks or less.

Myopic correction using the excimer laser in the procedure known as Photo Refractive Keratotomy[9] (PRK) is likely to become more common and may eventually replace Radial Keratotomy. In PRK, the central 5 mm or 6 mm of the cornea is reshaped according to a computer model, using the photoablation capabilities of the excimer laser. Many patients have now been treated by this technique and good success has been achieved even with patients with moderate myopia. The weakening of the cornea is minimal and once epithelial healing has occurred there is no increased risk of infection. Excimer is now being used to treat hypermetropia, by ablating layers of the corneal periphery under a superficial corneal flap, and thus creating a steeper central cornea. PRK is not a contraindication to diving The military may accept people who have had PRK. Patients may dive once external epithelialisation has taken place.

Corneal grafting means a penetrating keratoplasty in most cases. Precautions need to be taken while the corneal wound heals and develops strength. Typically, sutures will remain in place for up to a year and much of the early strength will depend on the suture. Severe squeeze, and even minor trauma should be avoided. Three to six months should elapse after grafting before diving. There will be some risks up to twelve months. Onlay grafts are sometimes used for refractive correction and are unlikely to cause problems beyond the postoperative period.

Cataract surgery

Cataract surgery is the commonest operation in the world. Today, surgery for cataract means a lens implant procedure. Even young patients can have cataract surgery although the majority of patients are over sixty. There are basically two different techniques used for cataract removal. In extracapsular cataract surgery, the lens is removed through an upper corneal or corneo-scleral wound. This wound is sutured and sutures remain in place below the epithelium or are subsequently removed. The wound has little inherent strength, and surgeons may advise against stooping or straining for some weeks. The wound will have gained strength after three to six months. In the second technique, a small wound is used to insert the instrument known as a phacoemulsifier, and the cataract is removed in the process of phacoemulsification. It may be possible to achieve lens removal and the insertion of a folded lens implant through wounds as small as 2 mm to 3 mm. Such wounds are constructed to be closable flaps and may be so stable that one or even no sutures are required. These wounds are corneal or scleral and have strength even before healing has commenced. Contact with the aquatic environment should be avoided until the external wound is sealed, but this may be only days after surgery. Since the eye is fluid filled there are no special problems with depth as such, but avoidance of mask squeeze is wise, especially in the extracapsular procedure.

Glaucoma

There is no single disease called glaucoma but many glaucomas. Because some of these conditions are characterised by the presence of raised pressure inside the eye, there is often concern about the possible impact of exposure to hyperbaric conditions on the glaucoma patient. The short answer to this is that diving has no adverse effects, but this ignores some of the possible less direct effects of both the diseases and their treatment.

Glaucoma is characterised by progressive visual loss due to a perfusion failure of the circulation of the anterior optic nerve. Such visual loss is seen in characteristic patterns. Glaucoma is an ischaemic disease rather than a pressure disease. A common cause of this ischaemia is raised intraocular pressure. Currently reduction of pressure is the therapeutic approach to improving perfusion, or preventing perfusion failure from developing. This approach is not successful in all people. Raised ocular pressure may be the commonest cause of reduced ocular circulation, but it is not the only one, and other means may have to be taken in an attempt to improve perfusion. For example, patients with glaucoma must not smoke. Patients with established field defects are more susceptible to further damage.

Like all liquid filled organs the eye assumes ambient pressure and is unaffected by diving. The diver with glaucoma may however encounter other problems. The mainstay of current glaucoma treatment is the β-blockers. Timolol (Timoptic) may cause bradycardia and reduce tachycardia on exertion, which could affect the diver's fitness. Bronchospasm may also occur. Betaxolol and other selective β-blockers are less likely to cause these unwanted effects and may be inherently better for the ocular circulation.[10] Oral carbonic anhydrase inhibitors are used less than in former times for long-term control of glaucoma, but they will affect carbon dioxide (CO_2) transport, with possible concerns of the effects of enhanced CO_2 retention, and metabolic acidosis. Increased retention of CO_2 may enhance the effects of nitrogen narcosis.[11] Diving should be considered unsafe with a drug which directly affects gas transport.

Glaucoma surgery is designed to reduce ocular pressure by producing a fistula by which aqueous humour can bypass the poorly functioning drainage meshwork and gain access to the circulation. Aqueous leaks from the eye into the subconjunctival space and is absorbed by the episcleral vessels. A closed system such as this is unlikely to be affected by diving, but occasionally drainage blebs are extremely thin walled and, although not affected by overall changes in ambient pressure, can be perforated by direct trauma. The chance of this happening during diving activities seems unlikely. A thin bleb may allow access of bacteria to the inside of the globe during a conjunctival infection. Ophthalmologists whose patients have thin blebs should warn patients to seek treatment for episodes of conjunctivitis.

Other potential ocular ischaemic problems

It is convenient to consider these immediately after glaucoma. A condition indistinguishable from glaucoma but with normal or low ocular pressures is known as normal (or low) tension glaucoma. This is commoner in subjects with a tendency to vasospasm or migraine. It is unknown whether exposure to cold would worsen ocular perfusion. Carotid insufficiency is exacerbated by head position and exposure suits. Patients with normal tension glaucoma or carotid disease should probably not dive.

Normal divers have been shown to have closure of capillaries in the juxtamacular capillary bed of the choroid on routine fluorescein angiography (M Cross personal communication). The significance of this finding has yet to be established. It is thought to have been caused by silent bubble formation. Vision was not affected. There is no recorded higher incidence of macular degeneration or other problems even in occupational divers

Patients with demyelination of the optic nerve may exhibit Uthoff's Syndrome, a reduction in visual acuity with a rise in core temperature, due to exercise.[11] Such patients may demonstrate an improvement in vision with cooling. Uthoff's Syndrome can be present in otherwise fit athletes and might present in a diver during suiting up on a hot day or during a strenuous surface swim.

Retinal conditions

Patients with moderate to high myopia (more than six dioptres) have an increased risk of retinal detachment. Retinal detachment is often precipitated by ocular trauma. Football, boxing, and other contact sports should be prohibited. Scuba diving is unlikely to cause a significantly increased risk of eye injury and should be permitted if corrected vision is adequate.

After retinal detachment surgery, diving will be permitted after the initial post-operative period. The purpose of surgery is to reattach the retina and successful surgery will produce a stable retina, unlikely to detach again. Diving will not increase the risk of re-detachment. Surgery consists of sealing the holes present in the retina by laser or cryotherapy. This produces a scar which attaches the retinal hole on to the retinal pigment epithelium and choroid. Usually this is combined with some kind of volume reducing procedure to assist in the development of good adhesion between the retina and the wall of the eye. A localised indent of the ocular wall can be produced by an external or internal plomb. An external plomb can consist of synthetic foam rubber. Although some of the cells will become fluid filled after surgery, a number of small gas-filled cells will be present in this type of plomb and the plomb will behave like a small piece of neoprene. It may therefore compress with depth. This is not likely to cause detachment of the retina, as once reattachment of the retina has occurred, many plombs can safely be removed. Sometimes a plomb is essential to relieve traction on the retina from internal strands within the vitreous, but problems from a combination of vitreous traction and plomb compression seem unlikely. The relief of traction from the vitreous is more commonly achieved by its removal and relies less on external indentation. Many surgeons use solid silicone plombs and the use of sponges is now less common

Air or inert gas bubbles are used for internal tamponade of retinal holes during retinal detachment surgery. A gas such as Sulphurhexafluoride (SF6) is chosen for its high molecular weight and slow dispersal rate. If pure inert gas is injected (the patient remaining at 1 ATA), the bubble will subsequently expand to undesirable size due to its initial low partial pressure of nitrogen and proximity to the blood supply. Conversely, a pure air bubble will disappear rapidly. If a mixture of air and inert gas is used then a bubble can be introduced which lasts up to several weeks. A typical mix of 20% SF6 and 80% air behaves as a "volume neutral" bubble, remaining of similar size for some time. Obviously diving, involving changes in both ambient pressure and tissue partial pressures, is not advisable during the persistence of such bubbles. Patients will be unlikely to feel well enough to dive for some weeks and therefore not diving while under post-operative care is sufficient prohibition.

Lacrimal and orbital conditions

The lacrimal sac and tear passages normally contain some air. A free communication exists between the lacrimal duct and the nasal cavity through an opening below the inferior turbinate bone. Raised pressure inside the nasal cavity during equalisation manoeuvres normally does not cause inflation of the lacrimal sac, since this opening acts as a valve, but occasionally air entering the tear passage can cause a jet of liquid to eject through the lacrimal punctum. Following surgery on the tear passages, nose blowing frequently causes a draught of air onto the eye. Partial blockage of the tear passages can occur with disease of the lacrimal sac, or following nasal fractures, creating a potential enclosed air space susceptible to barotrauma.

Fracture of the medial orbital wall of the orbit is common with blows to the eye or orbit.[13] Air can enter the orbit, causing surgical emphysema during ascent or the Valsalva manoeuvre.

Blind divers

Blind people, unlike the deaf, will be disadvantaged in the subaquatic environment. Diving is a very visual sport and there seems little point in the blind wishing to dive. However there are programs for blind divers in various parts of the world where they follow ropes over the bottom and markers are provided so that they can explore various features of the bottom by feel. Adequate backup and safety provisions should be in place in case of difficulties. Experienced sighted divers sometimes find themselves in a zero visibility dive and the blind person will obviously cope well with a dive under similar conditions. To dive safely the individual diver has to be able to cope with his own problems, and if timers and gauges are not able to be read or felt by the individual, then diving should not be permitted. Under some circumstances, diving might be permitted with a one-to-one supervision and tethered by a buddy line to an experienced diver, but should be restricted to safe and shallow dives. The blind should not be medically certified as fit to dive unless for single resort-type dives as part of a life experience under expert supervision.

Conclusion

Providing criteria for corrected visual acuity can be met, eye conditions rarely affect a diver's fitness to dive. Those that do may only be a relative contraindication. General rules about diving and medications apply. Glaucoma medications, and in particular carbonic anhydrase inhibitors, are likely to be the main reasons for a diver being classed as unfit. Previous eye surgery should not prohibit diving once the immediate post-operative period has passed. Some surgical procedures create a wound which affects the strength of the ocular integument, but this is not adversely affected by changes in ambient pressure. Severe mask squeeze and direct trauma to the eye should be avoided following eye surgery.

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DIVING MEDICAL DILEMMAS

Cathy Meehan and Guy Williams
with audience participation

Key Words

Asthma, cardiac problems, drugs, ENT, injuries, investigations, medical conditions and problems, treatment.

Introduction

We offer some examples of common diving medical problems seen by us in our diving medical practices. We hope that members of the audience who have opinions will state them.

Ventricular septal defect

A medical practitioner came to see me last year for a diving medical. She had a small ventricular septal defect (VSD) that had been proven on echocardiogram many years ago. She was otherwise completely well. When I saw her I understood that the standard practice in diving medicine in Australia was that candidates with atrial (ASDs) and ventricular septal defects were both classed as being unfit for diving. She is quite interested in the results of this discussion. The cardiologist, who performed her echocardiogram last week, suggested that he would advise her to have her VSD repaired to reduce the risk of endocarditis.

I would like to have opinions on this matter from anyone.

Andy Veale

If you move away from the concept of fitness or unfitness this person is at low medical risk and may well choose to dive.

Bove

The important thing about a VSD is whether it is haemodynamically significant. The pulmonary artery pressure is stated as being normal in the cardiologist's report. The only chamber that gets volume overloaded in a VSD is the left atrium, the flow just squeaks across the septum and out up the pulmonary artery so it does not load the right ventricle. The left ventricle is not affected unless the VSD is very large. She has a small VSD that makes noise. The general practice has been to leave them alone and warn the patient about antibiotic prophylaxis for endocarditis. A VSD does not reverse to right to left so the shunt is not a risk for bubbles to reach the left circulation. She is fit for diving.

Chest injury

Williams

Two or 3 years ago a 29 year old came in for a diving medical. In the past he had had a motor vehicle accident, sustained some fractured ribs and had, from his description, a haemopneumothorax that required a chest tube. He did not know much more than that. His chest X-ray was normal, his lung function tests were normal. I tried to obtain details of his medical history from the treating hospital, but they still have not arrived. The candidate never contacted me again, so he either lost interest in diving or went somewhere else. I would be interested in the audience's comments on somebody diving after they have had a penetrating chest injury of this sort.

Veale

On the data provided his potential medical risk is areas of varying lung compliance within the area of lung damaged beneath the rib fracture. Whether you believe Colebatch's data or not this individual may have a small increased risk over the risk that he would have had had he not been injured. You could help quantitate that a little better by doing a high speed helical CT scan in inspiration and in expiration to see if there were areas of air trapping within that area of lung. If there were not I would say that he was at low medical risk and that he may well choose to dive.

Bove

I do not worry about pneumothoraces in someone who had a traumatic pneumothorax. He is not in the category of someone who had a spontaneous pneumothorax . The main concern is the possibility of regional differences in lung expansion. There are many people diving who have had traumatic pneumothoraces. I had a pneumothorax from chest compression in a near drowning accident a long time ago and I have had no trouble yet I know many people who have had traumatic pneumothoraces who have not had any problems diving. I think the shear force problem would occur with over expansion, which might make the lung more sensitive to