REVIEW

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Scuba diving: What you and your patients need to know

ABSTRACT

Self-contained underwater breathing apparatus (SCUBA) diving continues to gain popularity. General practitioners need to know the health requirements and contraindications so they can counsel patients appropriately. SCUBA diving injuries may not be apparent immediately and require knowledge and understanding for accurate diagnosis and treatment.

KEY POINTS

General considerations for diving clearance, requirements for further workup, and contraindications to diving must be reviewed for each patient.

In the event that a patient presents with health concerns after a diving trip, barotrauma, decompression sickness, and air embolus should be considered as possible diagnoses.

Divers Alert Network (DAN) is a good medical resource for physicians and patients should they have more specific questions. DAN can be contacted at 1-919-684-2948, www.diversalertnetwork.org, or www.WRSTC.com.

MORE THAN 7 MILLION PEOPLE are estimated to participate in self-contained underwater breathing apparatus (scuba) diving,[1] so you are highly likely to encounter one in your practice.

Scuba diving requires rigorous health screening to prevent injury or accidents. Most reputable diving instructors and schools require a medical statement from prospective divers. Health care professionals must be aware of the requirements, contraindications, and possible injuries of diving so that they are able to advise their patients properly and diagnose diving-related injuries.

This article describes general recommendations for screening scuba divers and suggests specific workups and contraindications to diving. It also provides an overview of potential diving injuries and their treatment.

PREDIVE MEDICAL CLEARANCE

General considerations for screening patients are shown in **TABLE 1**.[2]

Each patient should have a predive clearance workup based on his or her medical history and current complaints. The patient's medical and surgical histories should be reviewed and further evaluation considered on the basis of the medical history (**TABLE 2**).[2–5] A review of systems will ensure that no current health condition will hinder diving, and a physical examination should be performed to complement the history.

Absolute contraindications to scuba diving include, but are not limited to, hyper-

TABLE 1

General considerations for assessing capacity to dive

Exercise tolerance

- Equipment is bulky and heavy (> 35 lb) and sometimes must be carried over uneven terrain and for excessive distances or up and down the ladder of a boat
- Swimming is easier in fins and a buoyancy vest, but is still difficult in certain currents

Breathing

- When ascending from depth, any process that prevents airflow from the lungs (eg, emphysema, bulla, other causes of air trapping) puts the diver at risk for pulmonary overinflation, which can lead to alveolar rupture and air embolus

Mental status

- Life-threatening events can occur underwater that require certain actions
- A diver must not be at increased risk of change or loss of consciousness such as would occur with a seizure or hypoglycemic episode
- Panic is a normal response to even non-life-threatening events at depth, but a diver with an abnormal panic or anxiety response may put himself or others at risk if he or she reacts inappropriately

Recent health

- A vomiting or coughing diver can drown
- A diver with an upper respiratory infection who cannot equalize the pressure in the ears or sinuses can rupture a tympanic membrane or sinus
- Recent surgical wounds can easily get infected
- Uncontrolled hypertension puts a diver at increased risk of pulmonary edema

Medications

- Review medications that can alter mental status or impair exercise tolerance
- The real bottom line is: if a patient *requires* a medication to dive (eg, a decongestant, antiemetic, antiseizure medication, or antidysrhythmic), he or she should be advised not to dive

trophic cardiomyopathy, right-to-left intracardiac shunt, seizures, history of cerebrovascular accident, spontaneous pneumothorax, gastric outlet obstruction, recurrent bowel obstruction, claustrophobia, untreated panic disorder, and numerous ear, nose, and throat disorders. The major concern in these cases is sudden loss of consciousness, increased risk of decompression sickness and barotrauma, or risk to other divers due to inappropriate response to stress while diving.

There are many other situations in which a patient should be cautioned or sent for further evaluation prior to clearance. For instance, a history of coronary artery disease may necessitate a stress test to prove exercise tolerance. Patients with a pacemaker must ensure the device is certified to withstand changes in pressure. Patients who have had previous decompression sickness or dive-related injury should have a specialist evaluation prior to clearance to determine risk of recurrence. Pregnant women should be advised of the unclear risk of fetal emboli. Abnormal facial anatomy may affect mask or mouthpiece fit. None of these examples is an absolute contraindication, but all must be addressed fully prior to clearing a patient to dive. A more complete list of considerations can be found in TABLE 2.

POTENTIAL DIVING INJURIES

In the unlikely circumstance that you are the first person to evaluate a patient for a complaint after a recent diving trip, you should be familiar with the potential diving injuries and their treatment.

Barotrauma

Barotrauma can involve any gas-filled body space and involves tissue damage due to a failure of that space to equalize its pressure with the ambient water pressure.[6] All forms of barotrauma can occur even at very shallow depths if the proper procedure for ascent is not

followed or if preexisting conditions allow for air trapping.

Middle ear barotrauma. The most prevalent injury associated with diving is middle ear barotrauma or "ear squeeze." Middle ear barotrauma most often occurs on descent when a diver fails to equalize the pressure between the air in the middle ear and the ambient water. Pressure and volume follow Boyle's law: $PV = K$ (where K is a constant; at a constant temperature, the volume [V] of a gas varies inversely with the pressure [P] to which that gas is subjected).[7]

For example, as a diver descends, the increase in ambient water pressure compresses the gas in air-filled body spaces such as the middle ear. The diver must address this volume loss by adding more gas to this space (equalizing it) to prevent injury.

Divers equalize the pressure on descent with a gentle Valsalva maneuver, but this maneuver may be impaired if the eustachian tube is blocked. The external pressure may be so great as to implode (rupture) the tympanic membrane, or it may just cause pain and tympanic membrane hemorrhage. Other associated symptoms may include vertigo, tinnitus, and hearing loss.

The most common diving injury is middle ear barotrauma ('ear squeeze')

Treatment of middle ear barotrauma includes decongestants, and if the tympanic membrane is ruptured, the addition of antibiotics (only if there is purulent drainage, in which case one should start with typical treatment for otitis media), analgesia, and referral to an otolaryngologist. No diving should be permitted until symptoms are improved and the tympanic membrane is healed.

Inner ear barotrauma. Similar symptoms (vertigo, tinnitus, hearing loss) may occur with inner ear barotrauma, which is generally caused by a too-forceful Valsalva maneuver, resulting in rupture of the round or oval window due to unequalized pressure between the middle and inner ear. If inner ear barotrauma is suspected, no findings will be noted on evaluation of the tympanic membrane (which distinguishes it from middle ear barotrauma). It must, however, be distinguished from inner ear decompression injury, as the treatments for each are markedly different. The two conditions can usually be distinguished by the history. Barotrauma more often occurs on descent and continues thereafter, whereas decompression injury is noted gradually on ascent or after exit from the water.[7]

Treatment of inner ear barotrauma involves referral to an otolaryngologist, bed rest, elevating the head of the bed to 30 degrees, and stool softeners to avoid increasing intracranial pressure.

Sinus, tooth, and facial barotrauma. Barotrauma can also affect the sinuses, causing headache, epistaxis, and sinus pain, or the teeth, causing localized dental pain, usually at the site of a filling.

Tooth squeeze will require treatment by a dentist with replacement or repair of the filling, and sinus barotrauma is treated with decongestants.[8] If a sinus has ruptured, further workup is needed to assess for pneumocephalus, and the patient should be referred to an otolaryngologist.[7]

Gastric barotrauma. By the same mechanism, barotrauma on ascent can occur in the gastrointestinal tract, where gas is trapped, and may lead to rupture of a hollow viscus.

Gastric barotrauma or hollow viscus rupture is rare but requires emergency treatment.

Pulmonary barotrauma. If the diver holds his or her breath on ascent and does not exhale properly or has significant underlying pulmonary disease, the lungs can overinflate. Overinflation of the lungs can lead to barotrauma of the alveoli, causing them to rupture, with emphysema extending into the neck or mediastinum, and possibly to air embolus. Pneumothorax is rare, but it must be considered if the symptoms are suggestive.[9]

Pulmonary barotrauma rarely requires specific treatment other than observation, but as indicated in TABLE 2, evaluation by a pulmonologist is needed before the patient dives again.

Eye injury. Diving mask pressure must be equalized by gentle exhalation through the nose on descent; mild superficial trauma can occur to the skin and eyes in the form of petechiae and subconjunctival hemorrhages if this is not done.

Decompression sickness

One form of decompression illness, termed *decompression sickness* or "the bends," results from the inflammatory response to bubbles of inert gas forming in the blood and body tissues when the pressure is significantly and rapidly

TABLE 2

Suggested predive evaluation based on medical history

Cardiovascular conditions
- Coronary artery bypass grafting
- Percutaneous coronary angioplasty
- Coronary artery disease
  - **Concerns:** Exercise tolerance is vital to diving—a stress test in which 13 metabolic equivalents (METs) is accomplished with no electrocardiographic changes or symptoms is required for clearance to dive if ability is in question and may be helpful for coronary artery disease risk assessment in patients > 40 years old
- Congestive heart failure
  - **Concerns:** Significantly decreased left ventricular function may affect the body's ability to handle the excess volume load, as the body shunts blood centrally in cold water, putting patients at increased risk of pulmonary edema.
- Hypertension
- Dysrhythmia requiring medication
- Significant valve regurgitation
- Pacemakers
  - **Concerns:** Consider the condition that necessitated placement
  - Pacemaker must be certified to withstand pressure changes involved in recreational diving

Cardiovascular contraindications
- Intracardiac right-to-left shunt
  - **Concerns:** Increased risk of venous emboli entering the cerebral and spinal cord circulation
- Hypertrophic cardiomyopathy and valvular stenosis
  - **Concerns:** Increased risk of unconsciousness during exertion
- History of ventricular tachycardia or > 1 episode of sustained ventricular tachycardia

Neurologic conditions
- Complicated migraines
- Head injury
- Herniated nucleus pulposus
- Multiple sclerosis
- Trigeminal neuralgia
- History of cerebral gas embolism
  - **Concerns:** Ability to exercise in patients with certain neurologic disorders should be considered
  - Patients with symptoms that come and go may be incorrectly diagnosed with decompression sickness if symptoms present after diving
  - Risk of seizure should be considered
  - Those with previous cerebral embolism must be fully evaluated to determine that risk of recurrence is low

Neurologic contraindications
- History of seizure other than childhood or febrile
  - **Concerns:** Significant probability of unconsciousness puts a diver at risk of drowning
- History of transient ischemic attack or cerebrovascular accident
  - **Concerns:** Spinal cord or brain areas with abnormal perfusion may increase risk of decompression sickness
- History of previous serious decompression sickness with residual deficit

Pulmonary conditions
- Asthma or reactive airway disease
- Exercise-induced bronchospasm
- Solid, cystic, or cavitating lung lesion
- Pneumothorax secondary to thoracic surgery, trauma, or previous dive injury
- Obesity
- History of immersion pulmonary edema
- Other previous lung-related dive injury
- Interstitial lung disease
  - **Concerns:** Any active disease, abnormal pulmonary function tests, or positive exercise challenge is very worrisome for diving
  - Increased risk of breathing challenge with scuba device as well as possible increased risk of pulmonary overexpansion
  - Forced expiratory volume in 1 second and peak expiratory flow rate should be within normal limits for diver's age, sex, race, and height
  - Exercise test should be negative
  - Pulmonology consult should likely be arranged before clearance for diving in any of these cases

Pulmonary contraindications
- History of spontaneous pneumothorax

Gastrointestinal conditions
- Peptic ulcer disease associated with pyloric obstruction
- Severe gastroesophageal reflux disease
- Unrepaired hernia of the abdominal wall big enough to become incarcerated
  - **Concerns:** The concern is for air trapping and expanding on ascending
- Inflammatory bowel disease (if debilitating)
  - **Concerns:** May impair abilities, or if diving in distant locale, treatment may not be available

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Gastrointestinal contraindications
- Gastric outlet obstruction of a degree sufficient to produce recurrent vomiting
  - **Concerns:** May cause vomiting, which can lead to drowning
- Chronic or recurrent small-bowel obstruction
- Achalasia
- Periesophageal hernia
  - **Concerns:** Air trapping and expansion could lead to rupture

Orthopedic conditions
- Amputation
- Scoliosis
- Back pain
  - **Concerns:** Impairment of mobility or respiratory function must be considered
- Aseptic necrosis
  - **Concerns:** Aseptic necrosis may progress if decompression sickness affects the joint

Hematologic and rheumatologic conditions
- Sickle cell disease
  - **Concerns:** Increased risk of decompression sickness may exist (theoretically), and sickle cell crisis may be incorrectly diagnosed as decompression sickness
- Polycythemia vera
- Leukemia
- Hemophilia, impaired coagulation
  - **Concerns:** Bleeding disorders could worsen the effects of barotrauma and exacerbate injury associated with decompression sickness
- Raynaud syndrome
  - **Concerns:** Digit function may become impaired, hindering diving abilities
- Systemic lupus erythematosus
  - **Concerns:** Pulmonary function and exercise tolerance should be evaluated prior to diving

Metabolic and endocrine conditions
- Hormonal excess or deficiency
- Obesity
- Renal insufficiency
  - **Concerns:** Exercise tolerance must be proven

Metabolic and endocrine contraindications
- Insulin-dependent diabetes mellitus
  - **Concerns:** Risk of potential rapid change in consciousness resulting in drowning
- Pregnancy
  - **Concerns:** Risk to fetus of venous emboli formed during decompression is unknown

Mental health conditions
- Developmental delay
- History of drug or alcohol abuse
- History of psychosis
- Use of psychotropic medications
  - **Concerns:** Patient must be mentally able to learn the information vital to diving safety and react appropriately as instructed

Mental health contraindications
- Claustrophobia
- Agoraphobia
- Active psychosis
- Untreated panic disorder
- Drug or alcohol abuse
  - **Concerns:** Diver would be ill-equipped to handle stressful situations in diving

Otolaryngologic conditions
- Recurrent otitis externa
- Significant obstruction of external auditory canal
- Eustachian tube dysfunction
- Recurrent otitis media or sinusitis
- History of tympanic membrane perforation, tympanoplasty, mastoidectomy
- Significant conductive or sensorineural hearing loss
- Facial nerve paralysis not associated with barotrauma
- History of round window rupture or inner ear barotrauma
  - **Concerns:** Any of these conditions is likely to affect the ability to equalize pressure of sinuses or ears during ascent and descent and to increase the possibility of barotraumas
- Full prosthedontic devices
- History of mid-face fractures
- Unhealed oral surgical sites
- Therapeutic radiation to the head or neck
- Temporomandibular joint dysfunction
  - **Concerns:** These conditions may affect the manner in which the mouthpiece fits or is held or the way the mask fits

Otolaryngologic contraindications
- Monomeric tympanic membrane
- Open tympanic membrane perforation
- Stapedectomy
- Tube myringotomy
- Ossicular chain surgery
- Inner ear surgery
- Facial nerve paralysis due to barotrauma
- Inner ear disease other than presbycusis
- Laryngectomy or partial laryngectomy
- Tracheostomy
- Uncorrected laryngocele
- History of vestibular decompression sickness

lowered, as on rapid ascent from diving or from flying too soon (earlier than 18 to 24 hours) after diving. This is a result of Henry's law: $c = p/H$ (where c is the concentration of the gas dissolved in liquid, p is the partial pressure of the gas, and H is a constant, taking into account the solubility of the gas and atmospheric pressure).

Therefore, the amount of nitrogen dissolved in the diver's body tissue or blood is directly proportional to its partial pressure, which in a diver's case is determined by the time and depth of the dive. In contrast to barotrauma and classic air embolus, the patient must have spent significant time at depths greater than about 30 feet for nitrogen to accumulate in the tissues.

The volume and location of bubbles determine whether symptoms will occur and how the patient will present. A large collection of bubbles can cause mechanical obstructive symptoms. In 75% of cases, patients note the onset of their symptoms within 1 hour of ascent (their "decompression"). In 90% of cases, symptoms begin within 12 hours; very few patients present with symptoms more than 24 hours after a dive.[7]

Recompression is best done within 12 hours, but it should still be pursued even later

Symptoms. General symptoms may include fatigue, malaise, and a sense of foreboding, all of which may predict further progression. If the location is in the skin, itching, erythema, cyanosis, and mottling may occur. A *peau d'orange* effect may be seen with bubbles that cause blockage of the lymphatic drainage.

Fifty percent to 70% of patients describe achy limb pain that is initially vague and then becomes periarticular, most often around the shoulder.

Extremity symptoms are the single most common presentation of decompression sickness, and few patients have objective physical findings. Sixty percent of patients have some nervous system effects in a spinal cord distribution, which may include weakness or paraplegia. They may also complain of hypoesthesia, hyperesthesia, or paresthesia, which indicates peripheral nerve involvement.

Further central nervous system symptoms can include personality change, memory loss, seizures, visual disturbance, and acute psychosis.

As noted in the section on barotrauma, inner ear and vestibular decompression sickness can occur, causing vertigo, tinnitus, nausea, vomiting, nystagmus, and hearing loss.

If bubbles form in pulmonary arteries, symptoms can mimic pulmonary embolus, with cough, substernal chest pain, dyspnea, cyanosis, and shock. Coronary artery bubbles can cause myocardial infarction or dysrhythmias.[7]

Management. Evaluation and treatment of decompression injury includes hydration, supplemental oxygen, evaluation of electrolytes (hypokalemia and hyperkalemia have both been noted), a chest radiograph to rule out pneumothorax, and arterial blood gas measurements.

The necessary treatment in all of these cases, no matter how inconsequential the initial symptoms may seem, is recompression in a hyperbaric oxygen chamber. Recompression decreases bubble volume and therefore decreases tissue distortion and vascular compromise. Results are best when recompression is done within 12 hours of the onset of symptoms, but recompression should still be pursued even outside this window. En route to the dive chamber, 100% oxygen should be provided, as well as intravenous hydration. Although symptoms may completely resolve with this pretreatment by itself, recompression should still be undertaken because relapse is possible without it.[7]

Air embolus

Air embolus, another form of decompression illness, is ultimately caused by any breach of a vascular wall that allows contact of air and blood. In scuba diving, these breaches most commonly occur in uncontrolled ascents with breath-holding and pulmonary overinflation (ie, pulmonary barotraumas). The alveolar-capillary wall ruptures, and air enters the vascular system.

If the injury is due to pressure gradients on descent, pneumothorax or tension pneumothorax may result on ascent (decompression).

Air embolus can also occur from venous bubble formation associated with decompression sickness; the bubbles coalesce and cross a cardiac septal defect or pass through the pulmonary capillary network to enter the arterial system. As little as 0.5 cc of air can cause fatal dysrhythmias or acute myocardial infarction. Central nervous system symptoms can result, such as seizure,

hemisensory or motor deficits, loss of vision, and altered level of consciousness.[7] Bilateral asymmetrical deficits are common.

An embolus can also affect the kidneys, with hematuria, proteinuria, and acute renal failure, or the gastrointestinal tract causing bleeding.[1]

Evaluation of suspected air embolus should routinely include a chest radiograph to evaluate for pneumothorax, but otherwise depends on the symptoms and may include measurement of blood urea nitrogen, serum creatinine, cardiac serum markers, hemoglobin, hematocrit, and glucose; urinalysis; electrocardiography; an examination for gastrointestinal or vaginal bleeding; and possibly computed tomography of the head.

Treatment of air embolus is recompression in a hyperbaric chamber, intravenous hydration, and 100% oxygen. Repetitive recompression treatments may be required. Outcomes are best if treatment is within 4 hours. Flying may worsen the patient's condition, and flight by helicopter or at the lowest safe altitude to the recompression chamber may be necessary.[7]

Distinguishing air embolus from decompression injury does not alter the treatment but is accomplished in most cases by history. For example, a diver who has spent time at depths of more than 30 feet and has spinal cord or peripheral neurologic symptoms is likely to have decompression sickness. On the other hand, a diver who has spent little time below 30 feet, gives a history of holding his or her breath on ascent, and has neurologic lesions more like those of a stroke is more likely to have an air embolus.[8]

PATIENT EDUCATION: DIVING PRECAUTIONS

Reminders for your scuba diving patients should include the following.

- Assess your health prior to each dive. If you have had a change in a chronic medical condition or need medications in order to dive, you should not dive without a medical reevaluation.
- Do not fly less than 24 hours after a dive.[3] This is a general recommendation that is critical after longer, deeper, or repetitive dives but should be applied if there is any uncertainty.
- Do not dive until the symptoms of a previous injury are resolved and you have been cleared to resume.
- If you have developed air embolus or pulmonary barotrauma on past dives, you need a full evaluation before diving again to ensure that your risk is not increased for further adverse events.
- If unusual symptoms occur after diving, seek medical care and evaluation immediately.
- If you plan to leave the country to dive, you may be required to bring supporting paperwork to confirm your current health status.

OTHER RESOURCES

For other specific questions, a good medical resource for you or your patients is DAN (Divers Alert Network), 1-919-684-2948, **www.diversalertnetwork.org** or **www.WRSTC.com**. More details may be found in standard diving texts, if desired.[10,11]

In suspected air embolus, obtain a chest radiograph to evaluate for pneumothorax

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