CHAPTER 11

Dive Medicine

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One thorn of experience is worth a whole wilderness of warning.
James Russell Lowell

In diving, the predominant forces of nature are the gas laws, and the two most important ones are Boyle's law and Henry's law. Simply stated, Boyle's law refers to a pressure–volume relationship. As a diver descends in the water, each 33 ft of seawater (fsw) adds approximately one additional atmosphere of pressure. At that pressure (33 fsw = 1 bar = 1 atm = 760 mmHg = 14.7 psi) the volume in a closed space (e.g., the middle ear) is reduced by half. Descending to 66 fsw, the volume is reduced by half again, and divers affectionately call this "The Squeeze." Henry's law governs gas distribution in the body. At increasing pressure (and depth), the amount of gas dissolved in tissues of the body will increase proportionately. The diver absorbs extra nitrogen and oxygen, delivered by a pressure gradient that forces the gases into tissues of the body at a rate that is proportional to the partial pressure of the gas. This is the reason a diver cannot stay down indefinitely without incurring a penalty called decompression sickness (DCS). A third hazard present on virtually all dives is not actually related to a gas law. This is the inherent narcotic potential of dissolved inert gas at pressure. Inhaled gases under pressure have different characteristics, and the most important one for our purposes is the solubility of the gas. The higher the solubility of the gas, the greater the tendency for a given gas such as nitrogen to cause "narcosis" at high partial pressures. This is the so-called rapture of the deep and is one of the reasons deeper diving is so much more hazardous. Narcosis has been equated (approximately) to the effect of alcohol, and quantitatively the potency of the effect can be described by "Martini's law." This approximation of the narcotic potential of nitrogen on the central nervous system was devised by the US Navy to warn the uninitiated that at a depth of 50 ft a diver will feel the effects of narcosis approximately equal to drinking one martini. Double that to 100 fsw, and the effect is approximately equal to two martinis. By 150 ft of depth, this becomes an extreme hazard to all but the most experienced diver. Even breath-hold divers can be affected adversely by narcosis. An alcohol intoxication-like effect is just part of the experience, however, and many other changes in mood and perception also occur. A deep-diving individual can feel elated or high but is just as likely to feel confused, tense, and anxious, with a deep foreboding sensation that ominous shadows lurk everywhere. Without exception, everyone has difficulty concentrating, but with advanced training a diver can compensate for this mental clouding. This is one of the reasons why deep diving, beyond the 100-ft recreational depth limit, is hazardous, particularly for the novice diver.

PREPARATION FOR DIVE TRAVEL

The Divers Alert Network (dan.org) provides a valuable service to the dive traveler. Over the years the network has been updating dive injury and fatality statistics. The information is clearly useful in determining who might be at greater risk for dive injury. Fortunately, we as medical providers are also blessed with data that can be found in the subscriber-funded newsletter *Undercurrent*. The number of dive accidents is on the rise, according to last year's report, but fatalities have remained approximately the same. DCS incidents are down from the previous year's high of 91, and now DCS is hovering at 56 incidents (2014 statistics). *Undercurrent* goes on to reference statistics related to older divers:

> Five deaths involved divers who suffered heart attacks while in the water (out of 16 fatalities), and the average age of these divers was 60. In the last 2 years, nine in-water diving fatalities were attributed to medical causes in divers aged 50 or over. This number is significantly higher than the average age of non-medical fatalities, which is 42 years.

The British Sub-Aqua Club (BSAC) quoted these statistics in its Annual Diving Incident Report for 2014. The report goes on to say, "Older divers are advised to take account of the increased likelihood of a medical event when considering the type of diving in which they engage, and those diving with them should be more aware of the increased risk." The physician advising a dive traveler is in an excellent position to help reduce this number.

Divers usually do not ask for medical clearance unless it is required by the dive resort. Issues such as asthma, obesity, heart disease, and physical disability may limit a diver's tolerance for unanticipated adversity encountered on a dive, and there are well-defined parameters a physician can use to determine who may be at risk. That said, "fitness to dive" is a notoriously difficult issue to determine with certainty. Dr. Tom Neuman, of San Diego, California, has been quoted as saying, "It is probably more important to ask if someone has ever run out of gas on the freeway than to ask about most medical conditions." This comment is in reference to the well-known fact that some divers will run out of breathing gas in their SCUBA tank while diving due to inattention to air consumption. The ensuing emergency ascent is often not survived due to pulmonary barotrauma leading to air embolism. What is needed is a no-nonsense approach to dive fitness that could be applied to all divers whether they travel or not. It is essential to know what type of diving the traveler has planned. Will it be a low-stress dive vacation in warm, clear, tropical waters or is it going to be adventure diving in a cave or in deep shipwrecks in the North Atlantic using rebreather technology?

The most recent dive accident statistics indicate a number of other near-miss incidents. The most recently compiled causes of death include rapid ascent due to problems with buoyancy control or out-of-air situations, equipment problems, and solo diving or snorkeling. Medical history obtained after a fatality has revealed surprisingly consistent findings over the years. Cardiovascular disease is always the most prevalent, present in over 10% of all fatalities (13.6% in 2009, 12% in 2010) and this is still true today.

Most reports list "drowning" as a cause of death because that is all the coroner can confirm at autopsy. It takes experience and skill to tell the difference between a fatality in the water caused by drowning and one that is caused by air embolism. If the diver makes an emergency ascent due to an out-of-air situation or other problem causing panic in the water, air in the lung expands at a faster rate than can be safely exhaled. Pulmonary barotrauma, sometimes called "pulmonary overpressure injury," allows a small amount of air to enter the pulmonary arterial system. Within three heartbeats this air is transmitted to the brain, causing momentary confusion or loss of motor control. The diver can no longer protect the airway, and the final common pathway for death is indeed drowning, but the antecedent cause is "air embolism," and before that it is running out of air to breathe.

Scuba diving can be divided into several categories depending on the physical and technical demands of the anticipated dive and the remoteness of the dive location. This easily breaks down into three manageable categories:

- Recreational diving for the beginner or occasional diver in warm, clear water breathing compressed air, the maximum depth limited to 100 ft of seawater.
- Advanced deeper, multiday diving often using Nitrox (also known as enriched air nitrox). Nitrox refers to a modified breathing gas with a higher concentration of oxygen than is found in air (21%). The oxygen concentration is higher in order to lower the concentration of inert gas and lower the risk of DCS. The diver gets to dive longer, but the trade-off is that diving must be done at a shallower depth due to the potential for CNS oxygen toxicity.

- Technical diving, usually done with either multiple tanks or rebreather technology and requiring long decompression times before surfacing. Often the dives are deep and penetrate into caves or sunken vessels where there is no possibility of direct return to the surface. The dive sites are often in remote locations with virtually no access to medical care or a hyperbaric treatment facility.

In actuality there are many other subsets of diving. To name a few, there is the instructor, commercial diver, scientific diver, engineer, seafood harvester, public safety diver (usually performed by police and fire departments), military diver including marine mammal training for guard duty, and unexploded ordinance removal diving. The care of most of these fall under the general category of occupational medicine, and physical requirements are much more rigorous and are usually specified by the agency responsible for certification of the diver. It is beyond the scope of this chapter to review the requirements of each one.

Concerning a diver's "fitness to dive," Dr. Richard Moon has stated that:

1. A diver should be able to do the "work" of diving. That is, to breathe, swim, and exercise underwater. Note here that some dives are more work than others, but if a diver is called on to rescue his or her partner, intense physical exertion will be required. This is why the minimum standard of physical fitness for any type of diving is the ability of the diver to achieve 13 metabolic equivalents (METS) or better of exercise, running on a treadmill. This is only one of many different ways in which physical fitness can be assessed. Each test of cardiovascular fitness has its strengths and weaknesses; one of the easier, cost-effective tests to administer in a medical clinic is the Harvard step test. This test is designed to work best for healthy individuals of normal weight. One of the weaknesses of the test is that it does not accurately predict fitness swimming or diving or apply to anyone with a partial disability or who is markedly overweight. Disadvantages include Biomechanical characteristics. They vary between individuals. For example, considering that the step height is standard, taller people are at an advantage as it will take less energy to step up onto the step. Body weight has also been shown to be a factor. Testing large groups with this test will be time consuming. Those in the latter categories will have trouble performing up to their physical potential with a Harvard step test. A bicycle ergometer can also be used, but its availability is somewhat limited.
2. A diver should not be unusually susceptible to barotrauma, which is pressure-related damage to the ears, lungs, or gastrointestinal tract. Barotrauma is the most common injury for any class of diving but happens most often to the novice diver.
3. A diver should not be susceptible in any way to loss of consciousness caused by seizures, hypoglycemia related to insulin-dependent diabetes, or heart block.
4. A diver should not have any disease that diving (exercising underwater) could make worse. This includes sinus or middle-ear disease, previous labyrinthine window rupture, or heart failure.
5. If female, a diver should not be pregnant, as the risk of bubble-related birth defects (decompression injury) is thought to be significant.
6. A diver should not be "overly" susceptible to DCS. There are 24 known variables that affect an individual's susceptibility to DCS at any given time. Some of these factors are increasing age, first day of menses, previous undeserved DCS, fatigue, dehydration, vigorous exercise at depth underwater, or heart disease such as an atrial septal defect or a patent foramen ovale.

DECOMPRESSION SICKNESS

DSC goes hand in hand with physical fitness and an individual's "fitness to dive." Microscopic bubbles are formed constantly in the body under normal circumstances from heterogeneous sources and are known to be present to a greater extent when a diver becomes fully saturated with inert gas. It has been known for many years that clinical symptoms of decompression sickness are determined by the body's ability to withstand and tolerate the effect of bubbles and not by the presence of bubbles themselves. Vascular bubbles produced by "provocative diving" (diving in a manner more likely to produce DCS) can cause disruption of the vascular endothelium. This in turn triggers a cascading sequence of events, the first of which is believed to be activation of white blood cell (WBC) adhesion molecules on the surface of the endothelium. WBCs adhere at the site of injury and trigger a chain of events resulting in increased permeability of the vessel, localized tissue edema, and intravascular plasma loss. Vessel occlusion ultimately results from a combination of bubble obstruction and circulatory sludging (localized intravascular dehydration). This in turn results in tissue hypoxia and release of inflammatory cytokines (signaling molecules), including the very important class of molecules called eicosanoids. The inflammatory cascade caused by WBC adhesion also fosters the production of newly discovered microparticles (MPs) in the bloodstream. These MPs are small fragments of membranes and nucleic acids (also termed "cellular dust") that arise from the damaged endothelial tissue. The magnitude of MP production is highly variable and to some extent genetically mediated. This means that some individuals are more likely to get DCS on any given dive due to genetic variability. This finally explains the phenomenon of the "bends prone" individual. It is known but not well understood that diving leads to the activation of genes that are mainly triggered by hyperoxia. While some individuals are more prone to DCS, others (especially those who dive frequently) are rather immune to the effect of bubbles in the circulatory system. This is termed "DCS acclimatization" or the "work-up" dive effect. In some individuals, repeated exposure to high levels of inert gas can trigger an adaptive immunoinflammatory response by modulation of nuclear factors.

If tissue damage occurs and progresses, excitatory neurotransmitters are released, and ultimately reperfusion injury occurs. This is progressively irreversible tissue damage from reactive oxygen species (chemically reactive molecules containing oxygen). If DCS is allowed to progress untreated, the injury also triggers apoptosis (programmed cell death), the final and irreversible outcome of untreated DCS.

Overt DCS is an outward manifestation of this highly variable and multifaceted inflammatory disorder. Aerobic exercise can reduce bubble formation in animals and humans. The mechanism for this is probably the effect of nitric oxide liberated by exercise, but this is not known with certainty. What is known for certain is that the addition of nitric oxide in test animals who have been subjected to potentially lethal dives results in survival with no neurological injury. Nitric oxide has the ability to remove vascular bubbles; this raises the question of whether medication can potentially help treat DCS.

A thorough diving history and physical examination might uncover risk factors, but the examining provider needs to know what to look for. Certainly, a genetic predisposition for the inflammatory response associated with bubble formation is something that could be suspected only after multiple episodes of undeserved DCS. Fortunately, there are many guidelines available for determining a diver's fitness, and to a large extent the risk to any individual diver depends on the type of diving he or she will be doing.

A helpful strategy for quickly assessing a diver's risk is simply to review the medications the diver has taken recently. Certain medications are not recommended during diving, but, more importantly, some drugs signal the presence of medical or psychological conditions that should be taken into account when clearing someone for diving. **Table 11.1** lists potentially problematic drug classes along with specific problems encountered in each class. The author has used this table for a number of years at the National Oceanic and Atmospheric Administration (NOAA) Physicians Training Course in Undersea and Hyperbaric Medicine lecture on the effect of medications and diving.

If a diver has normal exercise tolerance for age, a normal pulmonary function test with no evidence of significant reversible obstruction, low risk of heart disease, and no evidence of diabetes or other chronic or debilitating diseases, then you are well on the way to granting unrestricted clearance. A diver's psychological profile should be included in your assessment; the diver should not have a history of disabling anxiety, psychosis, or suicidal ideation. Psychological fitness to dive is much more difficult to define in some individuals, and occasionally it is necessary to get clearance from a mental health provider when unsure of the diver's safety in the water. Of course, the diver should not be taking any significantly problematic medications.

Some dive resorts provide appropriate warnings regarding possible dangers encountered while diving at the resort, but more often than not it is difficult to actually obtain

TABLE 11.1 Various Drugs and Their Effects on Diving

Class of Drugs	Drug Effects Adverse to Diving
Anticoagulants	Hemorrhage from barotrauma or spinal DCS
Narcotics, marijuana, and alcohol	Impaired judgment and problem solving; aggravation of nitrogen narcosis
Tranquilizers	Impaired judgment and problem solving; aggravation of nitrogen narcosis
Antidepressants	Risk of seizures with bupropion (Wellbutrin)
Decongestants and antihistamines	Sleepiness and nasal rebound congestion; risk of ear barotrauma and oxygen toxicity with pseudoephedrine (Sudafed)
Motion-sickness drugs	Sedation, impaired judgment, and aggravation of nitrogen narcosis
Beta-blockers	Reduced ability to respond to needs of stress; aggravation of Raynaud phenomenon and asthma
Antimalarials	Mefloquine (Lariam) psychological and neurological side effects are similar to symptoms of DCS. Doxycycline causes disabling photosensitivity
Sympathomimetics	Amphetamines, methylphenidate, and, to a lesser extent, pseudoephedrine (CNS stimulants) increase risk of CNS oxygen toxicity. Amphetamines can distort or amplify self-confidence (grandiosity) or increase risk of panic during frightening narcosis.

CNS, Central nervous system; *DCS*, decompression sickness.

up-to-date information. Some resorts suppress bad or conflicting news so as not to deter potential customers. It is well known that the Centers for Disease Control (cdc.gov) offers advice regarding food and water precautions and malaria prophylaxis, but it is more difficult to get information regarding in-water hazards such as serious marine envenomation, which is the fourth highest cause of dive injury as reported by DAN. Assessing the safety of dive sites for the beginner, disabled, or older diver is not possible until the diver is actually at the location. To stay up-to-date on a host of other dive safety issues, it is useful to have access to the monthly DAN newsletter, *Safety Stop*. Another monthly publication, *Undercurrent* (www.undercurrent.org), is probably the best source for this type of information and has a large, searchable database online with specific information about most dive resorts. There is also region-specific jellyfish information, constantly updated with an online database for Mediterranean waters, that is free for all interested users: the CIESM Jellywatch Program (www.ciesm.org/marine/programs/jellywatch.htm). The Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée, or simply the Mediterranean Science Commission, is an intergovernmental body with 23 member states that border the Mediterranean coast; using Jellywatch anyone can easily track population blooms of stinging jellyfish in a region of interest during a specified period of time. This is quite significant in light of fatal or severely disfiguring aquatic envenomation from jellyfish such as the Sea Nettle and the Box Jellyfish to name a few.

I find it valuable to remind travelers about dive accident insurance and travel insurance before the trip. Dive accident insurance can be literally purchased at the last minute from several sources, but this is not the case with travel insurance. Just to remind you, if a dive accident were to occur, especially if hospitalization, hyperbaric treatment, and a pressurized air ambulance is needed, the cost would be in the hundreds of thousands of dollars. Travel insurance is also useful to have, as it is not unusual for travel to an exotic dive location to cost many thousands of dollars. Divers often do not recognize that once the first arrangement for a trip has been made, whether a payment is involved or not, that day becomes what the insurance industry terms "the deposit date." Travel insurance needs to be purchased immediately once the first arrangement has been made or else it is often simply not available.

An up-to-date diver's first-aid kit is highly recommended, especially when diving in remote locations. This is a fairly comprehensive list; the actual contents needed may vary depending on where the diving will take place. The following items are recommended (★ indicates items that requires doctor's prescription):

1. Concise medical problem list of the individual diver for emergency use (with emergency phone numbers)
2. Assortment of water-resistant generic adhesive dressings, moleskin, chlorhexidine 4% surgical soap, 2-inch-wide elastic bandage, mupirocin★ ointment, folding scissors
3. White wine vinegar and disposable razor for jellyfish stings
4. Prophylactic eardrops for swimmer's ear (otitis externa) containing acetic acid 2% (many over-the-counter products are available for this). Drops are best applied before and after a day of diving, as long as the drops are allowed to stay in the ear for a contact time of 5 minutes
5. Neomycin★, polymyxin B, hydrocortisone generic otic drops or ofloxacin otic★ for treatment of swimmer's ear
6. Melatonin for jet lag (circadian rhythm sleep disorder)
7. Loperamide for traveler's diarrhea. Azithromycin★ (for treatment of severe symptoms or infection)
8. Sunscreen with sun protection factor (SPF) 15 for normal sun sensitivity and SPF 30 or above for those unusually sensitive to the sun or who have a history of skin cancer (reapply often if swimming)
9. Insect repellent containing greater than 35% *N,N*-diethyl-meta-toluamide (DEET) or CDC recommended equivalent. Reapply three times a day
10. Hand sanitizer
11. Personal medications and 1% hydrocortisone ointment or stronger if allergic reaction to bug bites have occurred in the past. Consider acetaminophen and diphenhydramine
12. Birth control (condoms).

PREVENTION OF SWIMMER'S EAR (OTITIS EXTERNA)

Swimmer's ear is a very painful bacterial infection of the external auditory canal. It occurs suddenly and progresses rapidly in swimmers and divers. It can be caused by swimming in polluted waters, but the most crucial factor is maceration of the external ear epithelium caused by constant moisture, breaking down the skin barrier to infection. Infections are usually caused by *Pseudomonas aeruginosa* (the most common pathogen), although many different organisms can contribute to ear inflammation, including fungi.

The person who gets all the credit for devising a workable prophylactic strategy for swimmer's ear is Dr. Edley Jones, who was a YMCA summer camp physician who noticed this condition occurring in his camp swimmers in the 1920s. Dr. Jones found that 5% acetic acid in 85% isopropyl alcohol worked well to inhibit pathogenic bacterial growth as long as a contact time in the ear of 5 minutes was maintained prior to swimming. This was reported in 1971 and provides us with the gold standard prophylaxis for swimmer's ear we use today. The Navy adopted Dr. Jones' technique utilizing a 2% acetic acid solution (pH of 3.0) and found that this mixture dropped the ear canal pH to 4-5 and confirmed that this level of acidity (applied over 5 minutes) was bactericidal to *Pseudomonas*. Straight white wine vinegar alone is too irritating to be used on external ear tissues by itself, but in the absence of commercial products, a 50/50 mixture of vinegar in isopropyl alcohol should work well. The key to success is a 5-minute contact time.

RECREATIONAL DIVING

Scuba diving is a demanding sport, and the underwater environment is unforgiving. This is why training in local waters (before travel) with fully certified dive classes utilizing local dive instructors and with opportunity to learn skills such as buoyancy control critical for dive safety is recommended. Resort courses are usually short, introductory sessions that rarely provide the training necessary for a diver to respond to unexpected emergencies. Learning how to manage gear problems, gas consumption, effective underwater communications, and emergency ascent techniques takes time and takes practice to perfect. As long as everything goes according to plan, warm, clear water can be very enticing. It is the unexpected issues that one has to train for, and this is where the injuries often occur. The DAN has been keeping dive injury statistics for more than 20 years, and that database has proved to be invaluable, as it can focus attention on the most frequent and most deadly of the injuries that divers sustain. The two groups that seem to have emerged as having the most problems with diving are newly introduced divers (<10 dives) and older, more experienced divers (>60 years of age). Of the medical problems that can be predicted and prevented, heart disease stands out as the most glaring example of a preventable tragedy. A cardiac event underwater is usually fatal; in 2010 (the last year statistics were available) well over 30% of the fatalities were due to some type of coronary event (arrhythmia or infarct). The striking detail to remember is that this is often a preventable issue. Cardiac risk factors should always be assessed in every older diver.

Immersion has a large effect on the cardiovascular system, but when immersion, cold water, and exercise during a dive are combined, the effects can be dramatic and widespread. From a physiological perspective, not only is cardiac preload increased (central venous pressure increased) due to the redistribution of fluids, but also we find that cold water and exercise increase arterial tone and virtually all pulmonary pressure parameters. Dr. Richard Moon explains in his lecture entitled “Fitness to Dive and Return to Diving after an Incident” given to the Undersea and Hyperbaric Medical Society (UHMS) in 2009 that “Immersion causes a displacement of approximately 500-800 mL of blood from the legs into the central circulation. This effect is even greater during cold water immersion. If a diver’s heart is unlikely to tolerate a sudden transfusion of fluid, diving and swimming should be restricted”. Dr Moon goes on to say that a diver must have clean coronary arteries and an ejection fraction greater than 40% to be declared fit to return to diving after myocardial infarction (MI).

BAROTRAUMA

The most common preventable injury while diving is middle-ear barotrauma. A middle-ear squeeze will curtail all diving activities and even make the trip home painful. It is not well appreciated, but hearing may be permanently impacted. In the worst-case scenario, permanent hearing loss and vertigo can ensue, and if the injured diver is also a musician, the impact on hearing can easily impair professional musical ability. With few exceptions musicians are not warned that permanent, irreversible high-frequency hearing loss could occur with a single diving mistake. Armed with this knowledge, a travel medicine consultation should include examination of the ears and verification that the diver knows how to compensate for the pressure he or she will be experiencing during a dive.

Boyle’s law describes the pressure–volume relationship affecting a diver on descent. Simply stated, pressure and volume of a gas are inversely related. When descending in the water at the beginning of a dive, pressure increases in a linear fashion. At the same time, the volume of that gas in a closed space such as the middle ear or a sinus is compressed in a linear but inverse fashion. This pressure–volume relationship is most significant in the first 33 fsw, as the magnitude of volume change in a closed space is one-half at a depth of 33 ft and is half again at 66 ft. Every 33 ft the remaining volume in a closed air space decreases by half unless the diver finds a way to compensate for this volume change as pressure increases. Novice divers usually underestimate the effect of Boyle’s law, and severe middle-ear injuries can occur even while training in a swimming pool.

The volume change under pressure occurs in all closed spaces of the body. This includes sinuses and even under dental fillings and caps if airspace is present. This effect is particularly devastating in facial sinuses. If effective equalization of pressure does not occur, that volume change becomes excruciating for the diver. If the airspace gradually equalizes in a sinus during a dive but causes bleeding and swelling, then when the diver attempts to ascend the volume expansion becomes excruciating in the reverse direction. This is termed a "ball-valve" effect (also known as one-way valve) and will prevent air from leaving the sinus altogether. Facial bones can become grotesquely swollen in some unfortunate individuals. The diver is then experiencing what is termed "reverse block" as air expands at the end of the dive. "Reverse block" can be so painful it becomes debilitating. The effect can last minutes, hours, and, in some cases, weeks. This condition requires specialty consultation and, if medical treatment is ineffective, occasionally surgical correction of enlarged turbinates to avoid recurrences.

During a pre-dive physical examination the physician should look in the ear and directly visualize the tympanic membrane with an otoscope. If cerumen is present, blocking the view of the tympanic membrane, it should be removed. The patient should be asked to "pop" the ears. If the patient instinctively pinches the nose, building up a modest amount of pressure in the nasopharynx, and the tympanic membrane bulges out slightly as seen with an otoscope, this change in appearance signals a successful Valsalva maneuver and should be recorded in the chart as (+) Valsalva.

The Valsalva technique is easy and intuitive for most people, but there are many ways it can be done incorrectly. A moderate amount of pressure is first built up in the chest. Fingers keep the air from escaping through pinched nostrils. If the soft palate is not preventing the air pressure from reaching the nasopharynx, the pressure will also be transmitted to the soft tissues of the nose. A slight bulge of the nose can be visualized if the procedure is performed correctly. A Valsalva maneuver should be a short maneuver with a moderately quick upstroke of pressure to the opening pressure of the eustachian tube. It is held for a second to allow the tissues of the eustachian tube to dilate, and then the pressure should be allowed to escape as the middle ear returns to ambient pressure. If the pressure builds up too quickly, the lumen of the eustachian tube often will not have time to dilate. If the pressure is held too long, venous engorgement of the middle ear can occur, and diminished cardiac return of venous blood to the heart is well documented, lowering the cardiac output and blood pressure.

A Valsalva maneuver can be safely performed only when the ear is not squeezed by pressure. It is very safe to use as a pre-pressurization technique, but dangerous once a squeeze has occurred. If a middle-ear squeeze is present, a forceful Valsalva maneuver can create an "air-hammer" effect. Delicate tissues such as the round window and the hair cells of the cochlea can be damaged with this forceful maneuver. Interestingly, the reverse situation is most often the cause of ear injury while diving. Instead of trying too hard, a timid diver may never generate enough pressure to open the eustachian tube under any circumstances, and that is why visualization of the tympanic membrane movement is essential to verify adequacy of middle-ear pressurization. There are so many ways to perform the Valsalva incorrectly that I call it the "Much Maligned Valsalva."

Luckily, there are many other ways to compensate for pressure changes while diving, and most of these are much safer to perform. It is actually quite rare for a diver to truly be unable to equalize pressure with any technique. I estimate that as many as two-thirds of new divers are able to pressurize their middle ear effortlessly without specific training once they are informed of the need to do so. For those individuals, merely puffing into a snuggly fitted diver's face mask or gently puffing with pinched nostrils will do the trick. Those individuals rarely get in trouble with ear squeeze, but for the other recreational divers who do have difficulty equalizing, help will be needed. Middle-ear pressurization can be challenging, and for those divers, equalization techniques must be tailored to the individual. Swallowing is a good, simple, and safe technique that often helps the diver equalize pressure to the middle ears, but side effects occasionally limit the usefulness, as a diver can swallow large amounts of air. When pressurization alone is ineffective, it can be combined with another method such as swallow, yawn, or maximal jaw thrust to enable air flow through the eustachian tube. Once an effective technique has been found, the diver should be encouraged to practice it several times a day. I always encourage new divers to listen to the sounds that their ears make with various maneuvers. This simple form of biofeedback will help a novice diver perfect the technique before he or she damages their ears in the pool.

TABLE 11.2 Ear-Clearing Techniques[a]

	Valsalva	Frenzel	Toynbee	BTV[b]
Nose	Pinched	Pinched	Pinched	No restriction
Mouth	Closed	No restriction	Closed	No restriction
Glottis	Opened	Closed	Closed	No restriction
Action	Puff in the nose	Throat piston	Swallow	Tubal opening
Air Flow	Active	Active	Passive	Passive
Result	Overpressure from lungs	Overpressure from nasopharynx	Sinusoidal pressure changes	Balanced pressure
Achievement	Easy	Moderate	Easy	Difficult
Safety	Danger	Good	Good	Excellent
Complications	Hypotension, tympanic membrane or round window rupture	None	Flatus	None

[a]This table first appeared in the French language journal referenced below. Translation is provided along with additional information on risks associated with each technique for middle-ear equalization.
[b]Béance tubaire volontaire (BTV) was first described by G. Delonca in Prévention des accidents: la plongée santé-sécurité [Prevention of Accidents: Diving Safety and Health, FRUCTUS (X) / SCIARLI (R), Publisher: Atlantic 1980 1980, p.118.

The faint clicking sound heard during swallowing is caused by the moist membranes of the eustachian tube separating as the tube dilates. Hearing that clicking sound and voluntarily manipulating the sound is what may be termed developing "eustachian tube awareness." New divers who have trouble equalizing can also practice tubal aerobics as described in the *Manual of Freediving* by Pelizzari and Tovaglieri. The exercise techniques described are designed to improve awareness and control of the eustachian tube and middle ear.

In all cases, pre-pressurization of the middle ear is far superior to "clear as you go" techniques. This is especially true for the diver who is a bit squeamish and reluctant to adequately pressurize the middle ear. One of the worst things that can happen to a diver while equalizing is a round window rupture (inner ear barotrauma), also known as a labyrinthine fistula. If the diver does not seek prompt remediation or if the diagnosis is not made promptly, permanent vertigo and hearing loss can ensue. Verification of an adequate ear-clearing technique (middle-ear pressurization) is a requirement for any type of dive physical examination.

There are volumes written about ear-clearing techniques. **Table 11.2** is provided as a baseline. It underscores the multitude of possible techniques for ear-pressure equalization while diving. The technique chosen must always be optimized for the diver who has trouble clearing his or her ears.

Not everyone is comfortable performing a Valsalva maneuver. I call this phenomenon "ear fear," and it is often caused by memory of painful events in the past, perhaps an episode of otitis. To fully understand what is happening, attention must be paid to the effort displayed by the diver while attempting to pressurize the ears. Some individuals will grimace and struggle in a manner that I call the "excessive effort sign." No matter how hard they try, no pressure reaches the soft tissues of the nose or middle ear. Another tipoff that the individual is not performing a Valsalva maneuver correctly is to look for what I call the "Dizzy Gillespie sign." If a diver's cheeks are bulging but the nose is not, the diver is involuntarily blocking pressure from reaching the opening of eustachian tubes in the nasopharynx. A reluctance to build up adequate pressure in the nasopharynx can also be caused by retrograde inflation of the lower tear duct. This inflation usually causes an itchy, fizzing sensation as air bubbles exit through the lacrimal puncta of the lower lid. The diver is usually concerned that this will somehow cause an infection or simply does not like the sensation. Retrograde inflation of the tear duct is totally harmless, except that it is one of the causes of "ear fear"; this anxiety while pressurizing almost always leads to a middle-ear squeeze.

The astute provider will also occasionally note rather dramatic expressions that accompany successful inflation of the middle ear. If the person wrinkles his or her nose in disgust or shakes the head from side to side with a sad or angry expression, exclaiming, "I hate that!" you will have a better understanding of their risks of barotrauma. If they hate the feeling of middle-ear pressurization, it is unlikely that they will generate enough pressure to prevent middle-ear barotrauma. Worse yet, they may decide to forcefully pressurize while the squeeze is present and thus set up the necessary conditions for inner-ear barotrauma (round window rupture). Most providers who recognize this will simply tell the traveler not to dive rather than spend the time necessary to teach the proper technique.

Another technique that I call the "throat piston" is formally known as the Frenzel maneuver and was developed during World War II to help dive-bomber pilots equalize their ears while preparing to release their munitions on a bombing run. In this technique, the larynx and tongue can be turned into a "piston" and used to pressurize air in the nasopharynx. The diver must first gain control of the larynx, voluntarily moving it up and down at will. This can be first achieved with vocalization and easily practiced in a repetitive manner while watching in a mirror. Bobbing the thyroid cartilage (Adam's apple) up and down while the nose is pinched closed is a good way to learn the technique.

The most challenging technique, béance tubaire volontaire (voluntary tubal opening), was first reported by the French diver Georges Delonca. Some divers seem to be anatomically gifted with control over the tissues in the back of the throat and the soft palate. Those divers can voluntarily raise the soft palate so that the uvula almost completely disappears upward. At the same time the diver must tense the tongue so as to create a solid base in the back of the throat that can then be used to tug on nasopharyngeal tissues. A natural yawn can accomplish the same thing—opening the eustachian tube orifice—but the yawn itself is too prolonged and cumbersome to be functionally useful while diving. Commercial divers can develop the ability to perform this maneuver by first thrusting the jaw forward in a maximal manner while tensing the tongue and opening the back of the throat. Practicing the maneuver can be accomplished if one rides an elevator in a tall building up and down, gradually gaining control through repetition.

Sinus barotrauma also occurs, but for different reasons. Unlike the middle ears, which are constantly drained and pressure equalized by the undulating motion of the eustachian tube, the sinus ostia are fixed openings buried underneath the turbinates. It is through these ostia that ventilation of the sinuses is accomplished. Turbinate hypertrophy can be due to chronic allergies or anatomical distortion from a deviated sinus, and there might not be an adequate opening for equalization of the sinus to occur. Chronic nasal congestion, chronic allergies, frequent sinus infections, or previous facial fractures are all risk factors. Unfortunately there is no easy way to tell whether air will move easily into and out of a sinus. This is why the novice diver should always be trained in local waters to ensure adequate supervision. If a diver has never had sinus problems and can clear ears and sinuses easily with air travel, it is not likely that he or she will have a problem, but it still can occur. Nasal decongestants should never be used at the start of a dive vacation. Decongestants such as oxymetazoline have a rebound effect, termed "tachyphylaxis." This means the drug will last for shorter and shorter durations, and intranasal tissues will become engorged (hypercongestion) much more rapidly when the drug wears off. If necessary to ensure that a diver can travel safely on the homeward leg of a vacation, it is certainly acceptable to use a generous amount of oxymetazoline (only for the trip home), but it never should be used at the start of a dive vacation. Chronic use of nasal decongestants will result in permanent changes in the nasal mucosa. The natural vasoactive signals of nasal mucosa gradually become lost by chronic decongestant use. Mild chronic intranasal and turbinate hypertrophy can be dealt with by using intranasal corticosteroids but at times require surgical intervention. Fortunately we now have office procedures such as radiofrequency tissue reduction (somnoplasty) to shrink tissues with relatively short healing time.

AFTER THE TRIP

A diver returning from a tropical dive vacation will occasionally have coral abrasions that are slow to heal or painful sea urchin punctures. Recalcitrant infections can occur, as the ocean is full of opportunistic bacteria. The incidence of multidrug-resistant bacterial infections is on the rise, and it is prudent to culture any infection in a diver. Treat any injury in the water with caution and follow up closely until it is clear that the condition is under control. If there is no improvement, prompt referral to a dermatologist is warranted.

Stings and scratches that burn should be treated on-site with full-strength vinegar as soon as the injury occurs. Jellyfish tentacles have stinging cells (nematocysts) but jellyfish stings due to the occasional encounter with floating jellyfish debris are usually simply an annoyance. Unfortunately, some very small jellyfish carry very potent venom. The most potent and dangerous of these are the box jellyfish: in particular, Irukandji. If one encounters these miniscule jellyfish, a characteristic syndrome will occur that usually results in hospitalization of the diver. Symptoms include severe headache, backache, muscle pains, chest and abdominal pain, nausea and vomiting, sweating, hypertension, and extreme pain characterized by the sensation that your skin is being ripped off. Local information on jellyfish risks will help a diver stay out of trouble, but as the waters of the earth warm, the distribution of tropical species of all types will continue to change; that change has already started. In the future, changes to venomous jellyfish habitat may be more widespread.

Invasive species of fish are also a problem for the diver, as lionfish are now present in all of the world's oceans. A puncture from the poisonous spines of a lionfish causes acute pain and local swelling, occasionally causing systemic symptoms. The site of envenomation can be treated with applications of very hot water, but this should be applied promptly if it is to be effective. Heat denatures the poison delivered by the lionfish via thermolysis, but the hot water must be just below scalding, approximately 113-114°F for it to be of any use. Often this either is not available on the dive boat or is too dangerous to be safe. Weakness, vomiting, shortness of breath, or loss of consciousness may require immediate stabilizing measures. More extensive blistering wounds will require topical antiseptics such as silver sulfadiazine, bacitracin, or mupirocin ointment, along with dressing changes. Large wounds from a lionfish may require months to heal.

For those interested in pursuing a career in diving medicine, it is best to start with a strong foundation in your chosen medical field. Internal medicine or family medicine are excellent choices, but there is no one approved pathway. For dive medical training, start with a four-day introductory course. Several of these are available from well-known providers, variously called either "fitness for diving" or "fitness to dive." The best (most comprehensive) civilian course is actually a 2-week training course called Physician Training in Diving and Hyperbaric Medicine, held every year by NOAA. The Navy has a pathway for the Diving Medical Officer in the Submarine Service for those so inclined. Ongoing physician education is crucial, as the pace of scientific advances in the field is often mind boggling. For this, the Undersea and Hyperbaric Medical Society (UHMS) offers a yearly scientific meeting where exchange of ideas flows freely. Duke University offers a fellowship in hyperbaric medicine, which is highly desirable for a physician who is just starting out in his or her professional career. This combination of a solid scientific foundation in diving medicine coupled with regular updates when new science is available makes this field challenging and rewarding. The UHMS website (UHMS.org) has all the information a provider might need in terms of educational opportunities.

FURTHER READING

Anderson, B., Farmer, J.C., 1978. Hyperoxic myopia. Trans. Am. Ophthalmol. Soc. 76, 116–124.
Recommended as the original reference describing the effects of high partial pressure oxygen on the eye.

Bennett, M.H., Lehm, J.P., Mitchell, S.J., et al., 2012. Recompression and adjunctive therapy for decompression illness. Cochrane Database Syst. Rev. 5, CD005277.
Recommended state-of-the-art evidence-based review of treatment options for decompression sickness.

Brubakk, A.O., Neuman, T., Bennett, P., et al., 2003. Physiology and Medicine of Diving, fifth ed. Saunders, Edinburgh.
Highly recommended as the preferred desktop reference manual for dive-related medical issues.

Brubakk, A.O., Ross, J.A.S., Thom, S.R., 2014. Saturation diving; physiology and pathophysiology. Compr. Physiol. 4, 1229–1272.
Recommended as an excellent in-depth review of diving physiology.

Chandy, D., Weinhouse, G.L., 2015. Complications of Scuba Diving. Available at <UpToDate.com>.
Recommended as a description of the state-of-the-art approach to the complications of SCUBA diving.

Delonca, G., 1980. Prévention des accidents: La plongée santé-sécurité, FRUCTUS (X) / SCIARLI (R), Edité par Editions Maritimes et d'Outremer, 1980, Translated to English: Health and Safety of Diving, FRUCTUS (X) / SCIARLI (R), Publisher: Atlantic Publishing 1980 [Prevention of Accidents: Diving Safety and Health], 116–118.
In French. Recommended as the original description of the French method of equalizing middle-ear pressure while diving, béance tubaire volontaire (voluntary tubal opening).

Farmer, J.C. Jr., 1985. Eustachian tube function and otologic barotrauma. Ann. Otol. Rhinol. Laryngol. 120, 45.
Recommended, as Dr. Farmer was the original physician who described and categorized middle-ear barotrauma.

Hardy, K.R., 1997. Diving-related emergencies. Emerg. Med. Clin. North Am. 15, 223–240.
Recommended for its comprehensive handling of the various emergencies that can present while diving.

Isbister, G.K., 2014. Marine envenomation from corals, sea urchins, fish, or stingrays. Available at <UpToDate.com>.
Recommended as a description of the state-of-the-art knowledge concerning marine envenomation.

Marcus, E.N., Isbister, G.K., 2014. Jellyfish stings. Available at <UpToDate.com>.
Recommended as a description of the state-of-the-art knowledge concerning jellyfish stings.

Moon, R.E., Vann, R.D., Bennett, P.B., 1995. The physiology of decompression illness. Sci. Am. 273, 70.
Recommended as an excellent review of the issues regarding the physiology of decompression sickness.

National Oceanic and Atmospheric Administration (NOAA), 2013. Diving Manual, fifth ed. US Department of Commerce, Best Publishing Company (Author), NOAA Diving Office (Editor), 5th edition.
Excellent resource for up-to-date technical issues regarding commercial and military diving. This is complementary to the US Navy Diving Manual.

Neblett, L.M., 1985. Otolaryngology and sport scuba diving. Update and guidelines. Ann. Otol. Rhinol. Laryngol. Suppl. 115, 1–12.
Recommended as an excellent reference for ear and sinus barotrauma.

Nevo, B., Breitstein, S., Psychological and Behavioral Aspects of Diving. Best Publishing Co 1999.
Recommended as a review of the psychological aspects pertinent to the diver's behavior in the water.

Pelizzari, U., Tovaglieri, S., 2004. Manual of Freediving: Underwater on a Single Breath. Idelson-Gnochi, Reddick, FL.
Recommended as a detailed and comprehensive guide for anyone who wants to understand breath-hold diving. Specific chapters outline valuable techniques that can be found nowhere else but in this manual.

Roydhouse, N., 1993. Underwater Ear and Nose Care. Best Publishing, Flagstaff, AZ.

Recommended as an excellent introduction to the various techniques a diver may use to equalize middle-ear pressure.

Tetzlaff, K., Muth, C.M., Waldhauser, L.K., 2002. A review of asthma and scuba diving. J. Asthma 39, 557–566.

Recommended for understanding the additional risks associated with diving with reversible airway disease (asthma).

Undercurrent Newsletter. <http://www.undercurrent.org/>.

Recommended as the highly acclaimed source of up-to-date information regarding dive hazards and fatality statistics. This newsletter often contains information that is not available anywhere else on the Internet regarding a diver's health and safety.

US Department of the Navy, 2011. U.S. Navy Diving Manual, Rev 6. Available at <http://www.supsalv.org/00c3_publications.asp>.

Recommended as the Bible of current military diving techniques, often used in commercial diving and often referred to as the gold standard of technical data.

Wienke, B., 2008. Diving Physics with Bubble Mechanics and Decompression Theory in Depth. Best Publishing, Flagstaff, AZ.

Recommended as an in-depth review of the physics and physical properties of decompression sickness.

Wurtman, R., 2013. Physiology and Clinical Use of Melatonin. Available at <UpToDate.com>.