Physical Standards For Scuba Divers

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Abstract: Scuba diving has become a popular aquatic sport during the past 2 decades, and family physicians are frequently involved in examining scuba divers and in the decision making that allows them to pursue their training or careers in this sport. The purpose of this article is to review the physiology and gas laws that are involved in diving and to provide guidelines for assessing each diving candidate. The clinical manifestations of decompression sickness are discussed as well as the medical problems that could cause severe morbidity or mortality if diving is attempted. (J Am Bd Fam Pract 1988; 1:194-200.)

Although scuba diving began in the early 1940s, it has become much more popular in the past 2 decades with the development of comfortable and relatively inexpensive underwater equipment. There are now about 3 million recreational or sports divers in the United States,[1] and more than 200,000 new divers are certified annually.

Scuba diving shops and clubs are found in almost all of the 50 states, and it is through these organizations that courses in diving are available to students. Even physicians who have practices far from the oceans may encounter individuals who are learning how to scuba dive.

The student diver is requested by a certifying agency to have a physical examination before undertaking a certification course; however, there are no state or federal laws regulating this sport, and physician approval is not required. Even though a physician cannot forbid candidates to dive, he or she should be aware of the health hazards and be able to advise students about health conditions that might compromise their safety in diving.

Basic Physiology

One must appreciate the clinical significance of the diving environment. For each 33 feet of descent into the sea, the diver is exposed to one additional atmosphere of pressure. It is increased pressure that makes medical problems under water of critical importance. Important concepts about pressure include:

- *Pressure.* The force applied per unit area. In the underwater environment, pressure is measured as atmospheres (ATM), pounds per square inch (PSI) and millimeters of mercury (mmHg).
- *Atmospheric Pressure.* The amount of pressure or force exerted by the earth's atmosphere, which at sea level is equal to 14.7 pounds per square inch or 760 mmHg.
- *Gauge Pressure.* Gauges normally read zero at sea level; therefore, gauge pressure is read as an increase above atmospheric pressure.
- *Absolute Pressure.* Gauge pressure plus atmospheric pressure.
- *Ambient Pressure.* Absolute pressure surrounding an object (or diver). Seven hundred sixty mmHg can be expressed as 14.7 PSI, 33 feet of salt water, or 1 atmosphere. The absolute pressure (ATA) at 33 feet of sea water is 2 atmospheres.
- *Hydrostatic Pressure.* The pressure exerted by a liquid at rest on any body immersed within it, with the pressure exerted both around the body and all axes.

Water in the liquid form is virtually incompressible, and because it does not change significantly in volume or in other characteristics due to changes in pressure, people can work comfortably at depths in the sea. The human body is largely liquid, and the ambient hydrostatic pressure is immediately reflected evenly to all body liquids. Pressure in the air spaces is rapidly equalized via respiratory and circulatory processes; the lungs, middle ear, and sinuses are equalized through air in the respiratory system, and the tissues are equalized by absorbing gases under pressure from the blood stream through the lungs.[2]

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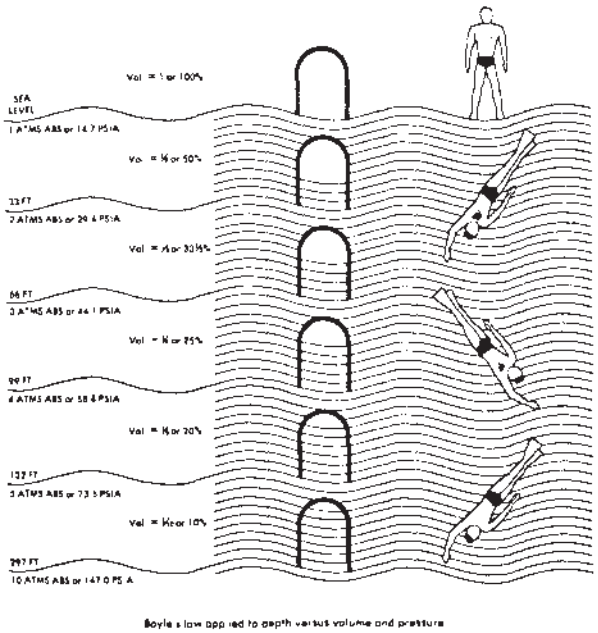

Figure 1. Boyle's law and lung volume changes with depth. Used with permission from *NOAA Diving Manual*, 2nd ed, Dec. 1979.

The Gas Laws

Air and other gases with a lower density than liquids are compressible. The gas laws define the relationship of gases to pressure, temperature, and volume.

Boyle's law illustrates the relationship of pressure to volume and is of fundamental importance to underwater physiology. If the temperature of a gas is constant, the volume of the gas varies inversely with the pressure. If the pressure of the gas is doubled, its volume must be halved and vice versa.[1]

If a diver breathes a lungful of air at a depth of 99 feet, the volume is only one fourth that at surface level. As a diver ascends, the air will expand fourfold, and the diver must get rid of three volumes of air through expiration.[2]

Failure to understand and use this concept of air elimination is probably the most common cause of death in scuba diving. If a diver holds his/her breath on ascent, or if any airway pathology traps air, the expanding alveoli will rupture, releasing air either into the circulation, the pleural cavity, or the surrounding soft tissue. The major catastrophic problem would be air embolism, which is frequently fatal.[2]

Henry's law is the gas law that accounts for decompression sickness. Henry's law states that at a constant temperature, the amount of gas dissolved in a liquid with which it is in contact is proportional to the partial pressure of the gas. For example, with increasing pressure as a diver descends, the solubility of nitrogen that is held in the tissue increases.

The term "squeezes" connotes a condition that occurs when a diver cannot equalize the pressure differential between an air-containing space and the ambient water upon descent. Most often this occurs within the ears, but sinus squeezes, face mask squeezes, and dry suit squeezes can occur.

Barotrauma or ear squeezes occur when pressure in the middle ear (surface pressure) cannot equalize with the increasing ambient pressure because of eustachian tube blockage from an upper respiratory infection or severe nasal allergy. Similarly, sinuses cannot equalize if a diver is suffering from sinusitis or sinus polyps.

Decompression Sickness

Decompression sickness is a multisystem disorder resulting from the liberation of inert gas from so-

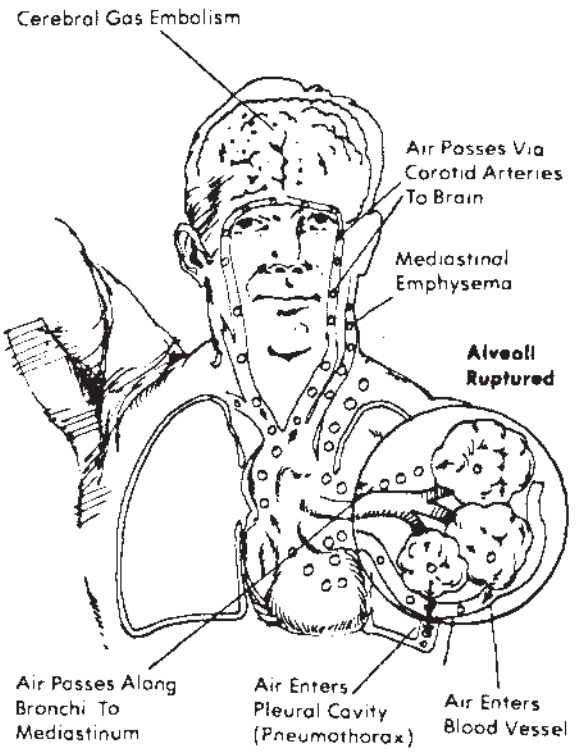

Figure 2. Complications from expansion of air in the lungs during ascent. Used with permission from *NOAA Diving Manual*, 2nd ed, Dec. 1979.

lution and the resultant formation of gas bubbles in blood and body tissue when ambient pressure is decreased.[1] In scuba diving, the inert gas is nitrogen, and the critical factor in the pathogenesis of decompression sickness is the increased interstitial tissue absorption of nitrogen as governed by Henry's law.

While the diver is breathing compressed air under increased pressure, the partial pressure of respirable nitrogen rises, and an increased flow of nitrogen from the alveoli to the blood stream to the tissue occurs. After a period of time at depth, the tissue continues to absorb nitrogen until a new equilibrium is achieved. The rate at which this occurs is an exponential function of the diffusion and the perfusion characteristics of the different tissue.

When the ambient pressure is then decreased, the inert gas is reabsorbed into the blood and expired through the lungs. If the diver has remained too long at depth causing too great an absorption of nitrogen, or if the pressure is relieved too rapidly, then the supersaturated gas will form bubbles, because the excess gas cannot be removed rapidly enough. The bubbles cause vascular occlusions, as well as biophysical effects resulting in ischemic tissue damage (Figure 3).[1]

The clinical manifestations of decompression sickness are categorized as Type I and Type II. Type I (minor decompression sickness) affects mainly the joints and produces pain. Skin "bends" with urticarial rashes are also classified as Type I. Type II (serious or major decompression sickness) usually affects the spinal cord, causing paresthesias, sensory deficits, weakness, and other insidious neurological findings. Cerebral symptoms include diplopia, scotomata, blurred vision, headaches, and very frequently personality changes. Disturbances of labyrinthine and vestibular function are sufficiently common in decompression sickness to be described as "the staggers." Type II symptoms can also include "chokes" from nitrogen bubbles in the pulmonary vasculature. Although this is not commonly seen, the symptoms are fairly characteristic with sharp retrosternal pain, cough, and tachypnea. A rare manifestation of Type II decompression sickness is hypovolemic shock.

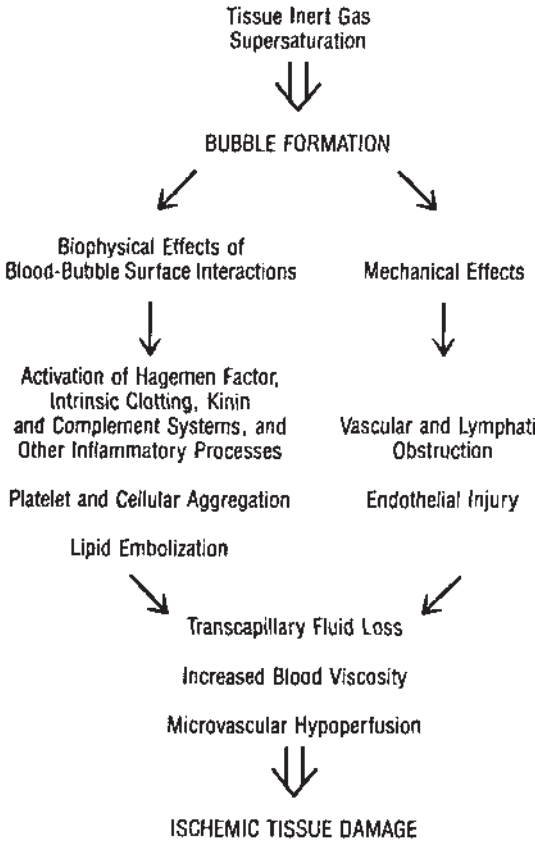

Figure 3. The pathogenesis of decompression sickness schematically represented. Used with permission from Kizer KW. Management of dysbaric diving casualties. Emerg Med Clin North Am 1983; 1:665.

History and Physical Examination

A thorough medical history should ascertain the candidate's reason for diving, whether sport, commercial, or research diving. Is the prospective diver new or experienced? How often and where will the diving occur? Is there a history of air embolism, decompression sickness, barotrauma, vertigo, near drowning, oxygen toxicity, or prior disqualifications?[3]

Divers more than 30 years of age have an increased frequency of decompression sickness, and many have decreased levels of fitness. If the candidate is unfit, an exercise program considering both aerobic exercise and muscle toning is warranted.

Obesity is a factor because fatty tissue absorbs nitrogen more slowly than most tissue and will release more gas on decompression. An obese candidate is more at risk for decompression sickness, and appropriate dietary counseling should be done.

Young divers must be physically mature to make use of the heavy equipment involved in the diving and also strong enough to be able to handle

Table 1. *Medications to Avoid in Scuba Diving.*

1. Sedatives and tranquilizers	10. Thyroid drugs
2. Antidepressants	11. Antihypertensives
3. Antihistamines and decongestants	12. Coronary vasodilators
4. Hypoglycemic agents	13. Narcotics
5. Andrenergic blocking agents	14. Antituberculous agents
6. Steroids	15. Chemotherapeutic agents
7. Anticonvulsants	16. Antipsychotic agents
8. Alcohol	17. CNS stimulants (anorexiants)
9. Hallucinogens	18. Antigout agents

treacherous surf or heavy currents. They should be emotionally mature to understand and make use of the diving tables and to evaluate the conditions at the dive site. Some experts recommend that 16 years be the cutoff age for diving, but each person should be evaluated on individual merit.

Is the diver a smoker? Smoking, of course, leads to increased air trapping, decreased pulmonary reserves, and increased upper airway congestion, all of which increase the chances of air embolisms and decompression sickness. The candidate should be counseled about the increased risk associated with smoking but not necessarily disqualified from diving.

Is the diver taking any drugs or medications? Any drug can affect the conscious state of the body, the response to stress, or potentiate nitrogen narcosis, oxygen toxicity, arrhythmias, fatigue, and hypothermia. A list of drugs that will cause either an unpredictable or deleterious effect on diving is provided in Table 1.

Contraindications to Diving (Table 2)

Eyes, Ears, Nose, and Throat

The physician needs to evaluate the candidate's successful performance of autoinflation. The Valsalva maneuver, swallowing, or jaw movement will demonstrate movement of the tympanic membrane. There should be evidence of eustachian tube patency, and the tympanic membrane must be intact.

Absolute contraindications include otosclerotic surgery, chronic serous otitis, Meniere's disease, inability to clear the middle ear due to any anatomical or permanent reason, chronic mastoiditis, and vestibular lesions.[3]

Relative contraindications include allergic rhinitis, dental caries, nasal polyps, deviated nasal septum, sinusitis, acute otitis externa or media, and any upper respiratory infection. An audiogram may be obtained to serve as a baseline for future problems and to ascertain a significant hearing loss. If the latter is discovered, the diver should be counseled about the need to avoid loud noise and to use ear protection. Repeated audiograms should be obtained when divers are reevaluated to monitor any hearing loss that may be occurring.

Contact lenses are permissible if either soft or fenestrated lenses are worn.

Cardiovascular System

The aquatic environment can impose severe stresses on the individual's cardiovascular system. Oxygen utilization in fit young Navy divers has been found to be within the range of "maximal" work.[4]

A 32 to 62 percent increase in cardiac output has been reported in subjects with headout immersion in thermoneutral water,[5] but most diving is done in hypothermic ocean water, which will stress the cardiovascular system. Many cold water drownings in middle-aged persons are probably due to premature ventricular contractions or other cardiac arrhythmias.[6]

Any heart murmurs that indicate potential right or left shunts should be evaluated further, and if a definite shunt is present, the candidate should not dive. Murmurs that indicate significant valvular disease also need further evaluation. Candidates with murmurs of mitral regurgitation may dive if they are asymptomatic with normal left ventricular function, no left ventricular hypertrophy, and minimal left ventricular dilatation by ECG and echocardiogram. Candidates with aortic insufficiency may dive if they are asymptomatic and the lesion is hemodynamically insignificant. Their ECG and echocardiogram must show no left ventricular hypertrophy, minimal left ventricular dilatation, and no left ventricular dysfunction. Any degree of aortic stenosis or mitral stenosis is considered disqualifying due to the impedance of the forward flow.[7]

Absolute contraindications include myocardial infarction within the last year, angina, coarctation of the aorta, prosthetic valves, intraventricular

Table 2. *Relative and Absolute Contraindications to Diving.*

System	Absolute Contraindications	Relative Contraindications
Eye, ear, nose, throat	Otosclerotic surgery, chronic serous otitis, Meniere's disease, anatomical or permanent inability to clear middle ear, chronic mastoiditis, vestibular lesions	Allergic rhinitis, dental caries, nasal polyps, deviated nasal septum, sinusitis, acute otitis externa or media, upper respiratory infection
Cardiovascular	Myocardial infarction within one year, angina, coarctation of the aorta, prosthetic valves, intraventricular conduction defects, Wolff-Parkinson-White syndrome, significant cardiac arrhythmias, history of Stokes-Adams attacks, significant peripheral vascular disease, anticoagulant drugs, some electronic pacemakers	
Respiratory	Pulmonary blebs, cystic or cavitary lesions, history of spontaneous pneumothorax, active asthma, emphysema, chronic obstructive pulmonary disease, recurrent thromboembolism or thrombophlebitis, pneumoconiosis or silicosis, lung tumors, sarcoidosis or granulomatous disease of lungs	Active infections, history of thorocotomy or traumatic pneumothorax
Gastrointestinal	Active Crohn's disease, ulcerative colitis or hepatitis	Inguinal or abdominal hernias
Genitourinary	Pregnancy	
Musculoskeletal	Muscular dystrophy, neurogenic muscular atrophy, active osteonecrotic lesions	Preexisting painful musculoskeletal pathology, healing fractures
Endocrine	Insulin-dependent diabetes mellitus	Diabetics taking oral hypoglycemic agents
Hematologic and immune	Sickle cell disease	
Neurological	Any demylenating process, brain tumor, history of cerebral vascular accidents or transient ischemic attacks, known intracranial aneurysms or arteriovenous malformations, narcolepsy, unexplained syncope, seizure disorders	Migraine headache, spasticity, weakness, paralysis of the extremities. (Commercial or military divers are disqualified by this; sport divers who are trained through certified Handicapped Scuba Association instructors may be qualified with proper instructions.)
Psychiatric	Claustrophobia, suicidal ideation, frank psychosis, drug use	Anxiety states, severe depression, alcoholism

conduction defects, Wolff-Parkinson-White syndrome, significant cardiac arrhythmias, history of Stokes-Adams attacks, significant peripheral vascular disease, or anticoagulant drugs. Patients who wear permanent pacemakers are disqualified except for young individuals with congenital 3rd-degree atrioventricular (AV) block who have one of the new dual chamber, AV sequential pacemakers that allows the sinus rate to increase within certain ranges with exercise.[7]

If a diver has had myocardial infarction, he or she may safely dive if (1) more than 1 year has elapsed without angina or arrhythmias at maximal exercise, (2) there is a normal stress treadmill with thallium, and (3) the physical examination is normal. If there is any question after evaluation and the candidate is insistent on diving, a coronary angiogram should be performed to identify silent myocardial disease.

Respiratory System

Respiratory system pathology is the major cause of diver disqualification. Any lesions that predispose to air trapping can be fatal (Boyle's law).[3] The examination should include a posteroanterior chest roentgenogram in full inspiration along with pulmonary function studies to identify any evidence of air trapping.

Should the examination or history indicate any evidence of pulmonary blebs, cystic or cavitary lesions, or spontaneous pneumothorax, the candidate should not be permitted to dive.

Active asthma proscribes diving, but there is controversy in the literature whether a history of asthma is disqualifying. Some state that any history of asthma whatsoever should be a contraindication, while others say that if there has been no attack within 2 to 5 years, no medication is used, and there is normal chest roentgenogram and pulmonary function, a candidate may dive. Each physician will need to come to a conclusion about this controversy.[8,9]

Patients with emphysema, chronic obstructive pulmonary disease, recurrent thromboembolism or thrombophlebitis, pneumoconiosis or silicosis, benign or malignant lung tumors, or granulomatous disease of the lungs or sarcoidosis should be advised against diving.

A history of thoracotomy or traumatic pneumothorax is another controversial issue.[10,11] Some believe that the risk of undetectable air trapping from scars or adhesions is too great to allow diving, while others think that the diver who has normal pulmonary function and a normal chest roentgenogram and is willing to accept a slightly higher risk could be permitted to dive. If available, a hyperbaric chamber trial could be arranged for the candidate to be observed under controlled circumstances.

Any active infections such as pneumonia or bronchitis need to be treated before diving. Obviously, divers using bronchodilators are disqualified. The bronchodilator itself leads to increased risk of arrhythmias.

Gastrointestinal System

Abdominal pain from any cause can mimic decompression sickness, so diseases that predispose to gas trapping in a viscus are disqualifying.[3] Symptomatic gastrointestinal conditions such as Crohn's disease, ulcerative colitis, and liver disease constitute an absolute contraindication; however, patients in remission who have no obstructive lesions that could lead to perforation and who are physically fit would probably be able to dive. Patients should stay alert for signs of disease activity.

Inguinal or abdominal hernias contraindicate diving until repaired. Abdominal surgery rules out diving until complete healing has taken place.

Genitourinary System

There are numerous risks from diving for a pregnant woman. These include vomiting and morning sickness, decreased pulmonary function due to the enlarging uterus, unknown risk of high oxygen tensions on the human fetus, unknown risk of hyperbaric oxygen should treatment be needed for decompression sickness, and an increased air embolism risk.[3]

Musculoskeletal System

Type I or musculoskeletal decompression sickness presents as joint pain, so any preexisting musculoskeletal pathology that could confuse the diagnosis should be carefully evaluated and discussed with the candidate. If one is having active symptoms and pain, it would be better to postpone diving. Chronic low back pain presents special problems due to the extra stress placed upon the back while carrying equipment for diving and the difficulty in evaluating increased pain after diving. Patients with muscular dystrophy, neurogenic muscular atrophy, myasthenia gravis, or active osteonecrotic lesions should not dive.

Fractures should be totally healed and range of motion normal before diving is considered.

A diver who has suffered a recent Type I decompression sickness should not be permitted to dive until completing a 7-day recuperation period.[12]

Endocrine System

Most authorities consider insulin-dependent diabetes mellitus to be disqualifying. The chance of unconsciousness underwater is too great, plus the possible small vessel disease of diabetics may increase the risk of decompression sickness.

Data about patients taking oral hypoglycemic agents for diabetes are most controversial. Some authorities allow sports diving if the candidate is well controlled and others do not.[3,13]

Hematologic and Immune System

Candidates with sickle cell disease should not dive because sickling can be precipitated by cold.

Hemophilia increases one's susceptibility to Type I decompression sickness and to the trauma of diving. Other blood dyscrasia or anemias should be diagnosed and treated before diving is permissible.

Neurologic System

Type II (neurologic) decompression sickness as well as air embolism exhibits many subtle or gross neurologic deficits. The candidate's neurologic status should be determined before diving. Diminished reflexes or sensation should be recorded so there will be no confusion during evaluation at a later time of a possible diving accident.

Candidates who present with any demyelinating process such as multiple sclerosis should be barred from diving. Other contraindications include brain tumor, history of cerebral vascular accidents or transient ischemic attacks, known intracranial aneurysms or stenosis of major cranial arteries, narcolepsy, unexplained syncope, and seizure disorders.[3]

Severe motion sickness is considered a potential hazard in diving due to the fact that in most diving environments there will be some wave motion or surges. Antimotion sickness therapies can be tried.

Candidates with migraine headaches present another controversial issue. The symptoms of migraine are easily confused with those of decompression sickness or embolism. Migraines can provoke vertigo and vomiting, and diving can exacerbate migraines.

Any unusual neurologic symptoms or complaints should be resolved before the candidate is allowed to dive.

Paraplegics can participate in sports diving, but they should be encouraged to obtain special handicapped diving training.

Psychiatric System

Any candidate with severe claustrophobia, suicidal ideation, psychosis, severe anxiety, or severe depression should not dive. A diver needs to be mature, emotionally stable, and capable of good judgment.

Laboratory Examination

The U.S. Navy recommends a complete blood count, urinalysis, standard serum chemistries, and fasting blood sugar for divers more than 40 years of age. Sickle cell screening is recommended for black candidates.[3] Other laboratory tests already have been mentioned in reference to specific diseases.

Finally, should reason be found by means of the history or physical examination that would disqualify a candidate for diving, it is most important that the physician spend a sufficient amount of time explaining why it would be unsafe to dive. It is especially helpful to make use of diagrams or graphs explaining what could happen, especially if the candidate has not learned the gas laws. If the candidate is not adequately informed about the risks of morbidity or mortality, then permission from another physician who was not aware of the subtleties involved in diving might be obtained. Try to avoid the "Thou shalt not dive" syndrome and perhaps guide the candidate into another safer sport.

References

1. Kizer K. Diving medicine. Emerg Med Clin North Am 1984; 2:513-4,523-6.
2. Shilling CW. Hyperbaric and undersea medicine. San Antonio, TX: Medical Seminars Inc., 1981.
3. Hickey DD. Outline of medical standards for divers. Undersea Biomed Res 1984; 11:407-32.
4. Bennett PB, Elliott DH, eds. The physiology and medicine of diving and compressor air work. 2nd ed. Baltimore: Williams and Wilkins, 1975.
5. Arborelius M, Balldin VI, Lilja B, Lundgre CEG. Hemodynamic changes in man during immersion with head above water. Aerospace Medicine 1972; 43:592-8.
6. Eldridge L. Sudden unexplained death syndrome in cold water scuba diving. Undersea Biomed Res 1979; 6(Suppl):41.
7. Davis JC. Medical examination for sport scuba divers. 2nd ed. San Antonio, TX: Medical Seminars, Inc., 1986:32.
8. Linaweaver PG. Asthma and diving do not mix. Pressure 1982; June:6-11.
9. Edmonds C, Lowery C, Pennefather J. Diving and subaquatic medicine. 2nd ed. Mosman, Australia: Diving Medical Center Publication, 1981.
10. Strauss RH. State of the art: diving medicine. Am Rev Respir Dis 1979; 119:1001-23.
11. Bove AA. An approach to medical evaluation of the sport diver. SPUMS (South Pacific Underwater Medicine Society) Journal 1983; 2:3-17.
12. Return to active diving after decompression sickness. SPUMS (South Pacific Underwater Medicine Society) Journal 1985; 15:37-8.
13. Kizer K. Diabetes and diving. Diver 1984(April-May).