Review

Ear Disorders in Scuba Divers

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Abstract

History of underwater diving dates back to antiquity. Breath-hold technique in diving was known to the ancient nations. However, deep diving progressed only in the early decades of the 19th century as the result of advancements in efficient underwater technologies which subsequently led to invention of sophisticated sets of scuba diving in the 20th century.

Currently, diving is performed for various purposes including commercial, recreational, military, underwater construction, oil industry, underwater archeology and scientific assessment of marine life. By increasing popularity of underwater diving, dive-related medical conditions gradually became more evident and created a new challenge for the health care professionals, so that eventually, a specialty the so-called "diving medicine" was established.

Most of the diving-associated disorders appear in the head and neck. The most common of all occupational disorders associated with diving are otologic diseases. External otitis has been reported as the most common otolaryngologic problem in underwater divers. Exostosis of the external ear canal may be formed in divers as the result of prolonged diving in cold waters. Other disorders of the ear and paranasal sinuses in underwater divers are caused by barometric pressure change (*i.e.*, barotraumas), and to a lesser extent by decompression sickness. Barotrauma of the middle ear is the most prevalent barotrauma in divers. The inner ear barotraumas, though important, is less common.

The present paper is a brief overview of diving-related ear disorders particularly in scuba divers.

Keywords: Scuba diving; external otitis; exostosis; ear barotrauma

Introduction

History of breath-hold underwater diving dates back to antiquity and as Edmond, *et al*, stated "by 4500 BC, it had advanced from the first timid dive into an industry supplying the community with shells, food and pearls." Pearl as a jewelry was highly valued for ancient Iranians from the *Achaemenids* period (700–330 BC) and accordingly, based on the historical documents, pearl hunting was a recognized activity in the first century BC in the Persian Gulf, southern Iran.[1] Afterward, a military activity has been added to the professional divers' duties. It has been reported that in the Trojan War (1194–1184 BC) divers were employed to destroy the enemy navy.[2]

The real progress in underwater diving started in the 19th century, when a barrel-like outfit with sleeves and observation port was invented in England; later on a hard-hat outfit supplied with compressed air from a pump was made. In due course, during the 20th century, by technologic development of underwater diving instrument, several sets of scuba (acronym for self-contained underwater breathing apparatus) were invented.[3] Presently, so-

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phisticated scuba sets are available and they are used in deep diving for commercial, recreational, military, industrial, underwater construction and scientific purposes including underwater archeology and studying marine life. The recreational scuba divers use only compressed air composed of oxygen and nitrogen—like ordinary air. However, for very deep diving, a mixture of helium and oxygen is used.

In Iran, underwater diving, especially in the Persian Gulf (with an average depth of 35 m to a maximum of almost 100 m),[4] southern Iran, became more prevalent in the past few decades. Nowadays, recreational diving is considered as a relatively widespread water sport in Kish Island located in Persian Gulf. In addition, professional diving is also performed for commercial, navy staff training, underwater construction and oil industry as well as scientific investigations such as underwater archeology and rescue missions.[5,6]

Mysterious underwater world is very attractive. Over 15 million people are internationally engaged in recreational diving and it is estimated that each year around 250 million dives are performed.[7] Annually, about 250 000 new divers receive diving license[8] and more than seven million people participate in scuba diving.[9]

Health Aspects of Underwater Diving

Despite its attractiveness, underwater milieu is potentially an aggressive environment for humans. As Sykes wrote, in the underwater world "pressure increases with depth, visibility is often poor, and temperatures are commonly low."[10] In addition, human body lacks the necessary adaptive mechanisms found in marine mammals to cope with increased underwater pressure,[11] thus, in deep-sea scuba diving, divers may develop various medical disorders some of which could lead to death. The most important diving-related disorders are due to changes in pressure—barotraumas;[12] The middle ear cavity is commonly affected in divers.[13]

Major disorders of diving can be classified as a) barotrauma which is due to expansion or compression of gas-filled spaces in the body including the middle ear cavity and paranasal sinuses;[13] and b) decompression sickness (caisson disease or colloquially known as divers' disease, or the bends) which is resulted from release of dissolved nitrogen gas into the blood and tissues on rapid ascent when ambient pressure is suddenly decreased; the disease is presented as body pain especially in the limbs and joints but may also involve the inner ear.[13] Deafness and vertigo may occur in those with inner ear involvement.[14]

Risk Factors

Diving injuries were investigated in a recent survey on 682 divers. Around 80% of divers had diving license, 32.7% of whom reported different medical problems such as hypertension, asthma, diabetes mellitus, and epilepsy. The researchers concluded that there were no significant differences among those with diving license in terms of dive frequency, medical conditions, smoking, and alcohol or illicit substance use.[15] In another study, the investigators reported that the risk of decompression sickness may be somewhat more in women divers, which was probably due to the different fat distribution in their bodies.[16] Based on the evaluation of pre-dive and follow-up records of 46 healthy sport scuba divers, no relationship has been observed between barotrauma of the paranasal sinuses and gender, alcohol consumption, smoking, use of decongestants, mild nasal septal deviation, and inability to perform the Valsalva or Toynbee maneuvers. However, the author added that

TAKE-HOME MESSAGE

- Underwater milieu is potentially an aggressive environment for humans.
- In deep-sea scuba diving, divers may develop various medical disorders such as barotrauma and decompression sickness.
- Barotrauma, decompression sickness and noise are among the main etiologies of hearing loss in different diving groups.
- Dive-related otologic disorders include external otitis, exostosis of the ear canal, middle ear barotrauma and Inner ear barotrauma.

divers with a positive history of sinusitis or barotrauma of the middle-ear may be at higher risk for developing paranasal sinus barotrauma.[17]

Diving-Associated Ear Problems

A significant number of scuba divers experience dive-related otolaryngologic (ENT) disorders.[15] Barotrauma, decompression sickness and noise are considered as the main etiologies of hearing loss among different diving groups.[18]

External otitis

A study of 429 active experienced divers showed that the most frequent disorder was external otitis(43.6%).[16,17] The authors also reported the predisposing factors of external otitis in these divers including local trauma, removal of lipid from the skin, prolonged exposure to high humidity and temperature as well as the most common responsible microorganism, *Pseudomonas aeruginosa*.[19] It has also been shown that proliferation of Gram-negative bacterial species in the external ear canals of divers was related to the conditions of helium saturation diving (which allows professional divers work at depths more than 50 m) but within 48 hours after returning to normal atmospheric conditions, the normal flora of the external ear canal returned to Gram-positive bacteriae which became again the predominant microorganisms.[20-22]

Exostosis of the ear canal

The prevalence and severity of exostoses of the external auditory canal in a group of experienced breath-hold divers were studied and the findings were compared to the same parameters among surfing and scuba divers. In this research, 76 male and 35 female breath-hold divers were studied. Then, those who completed the questionnaire (111 of 154 attendees) were examined by otoscope for any evidence of exostoses in the external auditory canals. It was found that exostoses were evident in 87.7% of the 204 ears. The severity of exostoses in breath-hold divers was significantly lesser than surfing divers, but greater than scuba divers. The most important predictor of the prevalence and severity of external auditory exostoses in breath-hold divers was the sea surface temperature at the location of open-water exposure.[23] In a similar study in Japan, 97 military divers from two districts, Mutsu (a cold area, northern Japan) and Yokosuka (a warm region, Central Japan) were evaluated for the presence of exostosis in their external ear canals. The average sea water temperature of the two mentioned districts was different because of their altitude, but the two groups of divers had similar diving activity. The prevalence of exostosis in the cold area group showed a significant increase as their diving career progressed, but the same pattern was not observed among the warm region group. In addition, the Mutsu group also had a

higher rate of grade two exostosis formation than the Yokosuka divers. The authors concluded that these findings may confirm the popular hypothesis of cold water as a factor in development of ear canal exostosis in divers.[24] In another investigation, 87 US Navy divers have been compared to an age-matched control group of 42 non-divers. The authors reported that the ear canal exostoses were found in 23 (26%) of divers but in none of controls. In this study, the majority (70%) of the exostoses were minor causing between 10% and 20% stenosis of the ear canal. The largest exostoses were observed in the external ear canal of those divers with an extensive history of aquatic activities. The difference in total hours of diving, and total time of all water activities, was statistically significant between divers with or without exostoses. The authors concluded that these results support the relatively common incidence of exostoses in the ear canal of professional divers.[25]

In another study, a group of 31 professional divers who had experienced frequent underwater pressure change, were evaluated; it was found that more than 40% of divers had exostosis in their external auditory canal, but no correlation was detected between the incidence of the exostosis and the length of their occupational career as a diver.[26]

Middle ear barotrauma

The body of a diver with its gas-filled cavities including the middle ear cavity, is exposed to high underwater pressure.[27] Underwater barotraumas (called colloquially ear squeeze) may damage all parts of the ear of divers which is the result of inability to equalize the pressures across the tympanic membrane (TM) during underwater descent. At sea level, the pressure is one atmosphere (760 mm Hg). For each 10 meters, the underwater pressure increases by one atmosphere.[28]

Underwater world though beautiful, is potentially an aggressive environment for humans.

Divers should be able to increase their middle ear pressure by performing the Valsalva maneuver during diving, otherwise barotrauma may occur. In mild cases with barotrauma of the middle-ear, the congestion of the TM is seen due to vascular engorgement, but the TM may perforate at only 3–5 meter depth without clearance, or at even shallower depth in those with either thin or scarred TMs. The resultant relatively negative pressure of the middle ear cavity may lead to conductive hearing loss which is the result of transudate accumulation leaked from the capillaries in the middle ear walls.[28]

Barotrauma of the middle-ear may happen during the descent or ascent phases of the dive, although the barotrauma during descent is more common and may accompany ear bleeding and rupture of the TM; acute onset ear pain and conductive hearing loss are the main symptoms. In severe cases, usually during ascent, increased pressure of inside the middle ear cavity may produce reversible weakness of the facial nerve, a condition known as facial baroparesis.[29] The Eustachian tube dysfunction increases the risk of barotrauma

of the middle-ear.

Postmortem histopathologic examinations of two recently deceased divers showed the rupture of the TM and blood accumulation in the middle ear cavity in one, and new bone growth in the lateral semicircular canal of the inner ear following the inner ear decompression sickness in the second case. These changes were the result of high underwater pressure which was exerted on the middle and inner ears of the victims during diving.[30]

Inner ear barotrauma

Animal studies showed that degeneration of the organ of Corti of the inner ear as well as perilymphatic hemorrhage may occur as the result of direct effect of repeated compression and decompression in high pressure exposed individuals.[19] Transient vestibular symptoms are common in diving, however, the vestibular end organs of the inner ear may develop permanent injuries due to decompression sickness or barotrauma and cause distressing long-term dizziness and imbalance. Diving-associated vestibular disorders were probably the result of a single event such as inner ear barotrauma or inner ear decompression sickness.[31]

In one study, 230 offshore divers (mean age of 52 years) and 166 age-matched non-diving controls were evaluated for the symptoms related to the vestibular system. It was found that the prevalence rates of dizziness (28%), spinning vertigo (14%), and unsteady gait (25%) were significantly higher in divers than controls. The high exposure to underwater pressure was considered an important factor in developing the vestibular symptoms.[32]

In a study carried out between January 2002 and November 2005, 44 divers with symptoms of acute inner ear disorder were investigated; only one (2%) patient had bilateral manifestations of inner ear decompression sickness. The authors added that both decompression sickness and inner ear barotrauma may result in residual cochleovestibular damage.[33]

Inner ear barotrauma may also cause rupture of the round window membrane of the inner ear and result in deafness.[34] In one study, in seven divers with presumptive diagnosis of rupture of the round window membrane, tympanotomy was performed. None of the patients had the classical triad of deafness, tinnitus, and vertigo, simultaneously. Their major symptom was hearing loss and only two had vertigo. Tinnitus was found in half of the patients. Intra-operatively, the rupture of the round window membrane was presumed in five divers. The authors then recommended that in all cases of concurrent occurrence of the inner ear dysfunction accompanied by diving, the possibility of rupture of the round window membrane must strongly be considered and after an accurate otologic examination and exclusion of other possibilities, a tympanotomy should be done to cover the round window membrane, provided that the patient's symptoms continued for more than 24 hours.[35]

In a study, eight patients with inner ear barotrauma were evaluated by computed tomography. The causes of the inner ear barotrauma were diving in four, flying in an airplane in three, and climbing in one patient. The authors suggested the probable association between the inner ear barotrauma and poor development of the jugular fossa.[36]

For inner ear decompression sickness, hyperbaric oxygen therapy is considered as the treatment of choice, but it is contraindicated in inner ear barotraumas. As inner ear decompression sickness cannot be easily excluded, according to Klingmann, hyperbaric oxygen therapy should be used only after performing bilateral TM paracentesis.[37]

Ear Problems and Fitness to Dive

According to experts' recommendations fitness to dive after the inner ear barotrauma depends on the hearing ability restoration of the involved ear.[38] After inner ear decompression sickness, the possibility of right-to-left vascular shunt should be investigated before diving can be recommenced.[38] Diving can be restarted three months after the middle ear surgery, especially after tympanoplasty, provided that the middle ear normal ventilation without atrophic scars on the TM is achieved.[38] After sinus surgery, performing a test dive under supervision is suggested before certifying fitness to dive.[38] After aural surgery to improve hearing, implantation of the middle ear amplifiers or cochlear implants, paranasal sinus operation, skull base surgery and even after the canal wall down mastoidectomy, diving is possible provided that certain necessities are fulfilled.[38] After stapes surgery in the middle ear, scuba diving is controversial because of possible risk of inner ear barotrauma, but according to House, stapedectomy does not appear to increase the risk of inner ear barotrauma in scuba and sky divers provided that adequate Eustachian tube function has been established.[39,40]

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