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EDITORIAL

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Freediving – from Tradition to Modernity

Apnoetauchen – aus der Tradition in die Neuzeit

While SCUBA diving has been very popular for many years, apnea diving has only begun to be popular in the past few years. The physical changes elicited in apnea diving by pressure differences and physical exertion require a completely healthy person. Environmental changes which can't be planned (currents, rough seas, underwater animals) may require further physiological and emotional resources.

Although many colleagues in practice and/or clinic have and had contact with SCUBA diving, the medical background knowledge on the topic of apnea diving is often more artificial. An expansion of the medical background knowledge is, however, important due to the growing popularity.

Apnea diving, also known as free diving, has a long and fascinating history. Originally, diving was made of necessity in order to harvest food and resources from the ocean. The Ama have been known for more than 2000 years for their capacity to dive down to 20 meters. The Bajau in Southeast Asia, too, often referred to as „Ocean Nomads", spend a large part of their lives on the water. The latest studies reveal noteworthy physiological and genetic adaptations, such as an enlarged spleen, to optimize their diving capacity (5). Both the Ama and the Ocean Nomads demonstrate the diversity and adaptation capability of human diving practices over centuries

Apart from military reports and isolated reports on free divers, apnea diving has only become popular in the western hemisphere in the past few years. When Jacques-Yves Cousteau and Émile Gagnan developed the modern breathing regulator, the Aqua lung, in 1943 and thus revolutionized diving, free diving lost public interest for a time. Apnea diving became emancipated only in the past 20 years and today is perceived as an independent sport. It differs from the material-intensive SCUBA diving especially in the esthetic and adventurous nature of the sport. Platforms like Instagram and YouTube are full of impressive videos and pictures of free divers, who explore breathtaking underwater landscapes. Visually attractive contents have inspired many people to take an interest in free diving.

Recent Developments in Apnea Diving

The improved availability of scientific research, access to new training methods via social media and the possibility of observing an initially enormous explosion in one's own performance have contributed to a marked increase in popularity. Rough differentiation must be made between static apnea diving on the surface., in which the breath must be held as long as possible, distance diving, in which the longest possible distance must be covered in shallow water, and deep diving. All three disciplines are further modified by regular and optional aids (fins, sinkers, etc.).

Improved imaging (MRT, ultrasonic techniques) and other examination methods (near infrared spectroscopy, EEG) along with molecular biological methods enable an "in-depth" view of the physiology these days (7). In this, there are certainly some parallels to diving mammals. In humans, the diving reflex is characterized by a synergistic sympathic and parasympathic activation, an increase in catecholamines, a redistribution of blood flow toward hypoxia-sensitive organs, and a reduction in heart rate (3, 4). Moreover, the human diving reflex can be influenced by physiological and emotional factors. Elite-apnea divers are able to attain a reduction in chemosensitivity to hypercapnia through repeated apnea training. A possible genetic predisposition is also under discussion (1). Recently, the spleen has come back into focus as a reservoir of erythrocytes in genetic studies on Ocean Nomads (5).

Limits of Deep Diving

The maximum diving depth is determined less by the absolute apnea time. The individual deep diving limit is multifactorial and among other things dependent on physiological factors like lung size and elasticity, cardiac fitness, blood redistribution, economizing diving movements, pressure equalization techniques and mental strength. The willingness of the athlete to take the risk of serious hypoxemia in surfacing also plays a role.

Earlier attempts at physiological explanation of the depth limits in apnea diving have meanwhile had to be greatly expanded. Originally, the ratio between residual volume (RV) and total lung capacity (TLC) was taken as the main limitation of the maximum attainable depth. According to the Boyle-Mariotte law, the product of pressure (p) and volume (V) of a gas is constant at constant temperature. Accordingly, in diving, the gas quantity held in the lung is compressed until underpressure and thus parenchymal tear occurs. Thus an elite apnea diver with TLC of 10 liters and RV of 1.7 liters could dive to a depth of 49 m based on the RV/TLC ratio.

In recent years, the understanding of the phy- ›

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siological adaptation mechanisms has been expanded. Considerably greater depths can be attained and physiologically explained by thoracic blood shifts and special breathing techniques like glossopharyngeal insufflation and exsufflation (techniques of forced in- and exhalation using a muscle pump). The following calculation example will demonstrate the effects of the individual factors described above on diving depth: In thoracic blood shift (1000 mL) the depth limit increases from 49 m to 134 m, since the RV of 1.7 liters would be reduced to 0.7 liter. By increasing the TLC to 13.2 l by glossopharyngeal insufflation, diving depths of 179 m are possible. By glossopharyngeal exsufflation, the pressure equalization would still be possible in diving depths to under 200 m, since air is actively drawn from the RV - an RV of 0.4 l can thus be attained (9) The Austrian free diver Herbert Nitsch reached the official world record in 2007 with a depth of 214 m, which makes the enormous adaptation capability of the whole human system clear. However, the techniques cited also have their limits. For example, the pulmonary pressure increases up to 80 cm/H2O in forced glossopharyngeal insufflation (9).

Cardiac Stress in Apnea Diving

Even before the onset of apnea, the glossopharyngeal insufflation required in maximal deep diving results in impaired cardiac filling, which initially causes a decrease in the mean arterial blood pressure (BD). Despite the reduced HF, the BD increases continuously in apnea diving. To explain this, BD, HF and cardiac output (CO, product of HF and stroke volume SV) were determined in dry apnea and during diving down to a depth of 30 m and the total peripheral resistance (TPR) in the systemic circulatory system estimated (10). The increasing BD in reduced HF could be ascribed to an elevated TPR. Increasing TPR promotes blood supply to the CNS and thus also its O2-supply. An elevated flow velocity of the blood in cerebral vessels, proven by MRT, can explain the improved O2 supply (6). In the final phase of apnea, the increase in pCO2 elicits a breathing reflex, which does not result in discontinuation of the dive in well-trained divers, but rather to involuntary breathing movements (IBM). The IBM elevate the HF in the inhalation movement and decrease the HF in the exhalation movement, just as observed in normal breathing (respiratory arrhythmia). Unlike in normal breathing, the IBM is performed with closed mouth. This induces great intrathoracic pressure differences between „in- and exhalation", which, in turn, supports the filling of the cardiac ventricles and produces an increased SV (3). High SV increases the BD (see above). Systolic blood pressures of up to 250 mmHg have been measured in exertion in the final phase of apnea dives.

Inert Gas Narcoses and Decompression Illnesses – Also possible in Apnea Diving?

Nitrogen narcoses may disrupt cognitive and physical functions starting at a depth of 10 m and become clinically apparent at depths of 30–40 m. Typical symptoms of a nitrogen narcosis are disorientation, memory problems, euphoria, hallucinations, mood swings, impaired coordination, psychomotoric and intellectual deficits and loss of consciousness.

The anesthetic potency of narcosis gases is often correlated with their lipid solubility (Meyer-Overton Theory). N2 and other inert gases bind to cell membranes and can make them swell to a more than critical volume, which causes narcotic effects (8). Since pressure has a linear influence on the narcotic potency and the effects of surfacing on the free diver do not disappear immediately, the effects on free divers are apparently more complex. The delayed decrease in N2-partial pressure in the CNS due to the rapid ascent speed and a disrupted cerebral autoregulation are under discussion (9).

For a long time, decompression illnesses and gas embolisms (inert gas embolisms) were considered extremely unlikely in apnea divers. More recent reviews, however, show an elevated risk in deep dives, repeated dives and in combination of apnea diving and SCUBA diving (2).

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