Revisiting the Hazards of Smoking and Diving

Doing It Wrong: Smoking and Diving

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The CDC reports that more deaths are caused each year by tobacco use than by all deaths from HIV, illegal drug use, alcohol use, motor vehicle injuries, suicides, and murders combined.

Introduction

One of the things that impressed me the most in my GUE training is the "evidence-based practice" approach that they take. Everything that I learned had a reason behind it. GUE applies sound physiologic rationales and mechanical principles in all of their methods, which is fantastic for someone like me who tends to question everything.

Another aspect of GUE that I genuinely appreciate is that they choose safety over hurting someone's feelings. In particular, I am referring to their overt references to the importance of good physical fitness and their anti-smoking stance. Although the two are closely related, the purpose of this writing is to focus on smoking.

The very first publication of *Quest* has a wonderful article on the dangers of mixing smoking and diving (Ranz, 1999). It is definitely time to revisit this topic. I would also encourage the readers to look at Ranz's article, as it is an excellent review.

With all the adverse effects of cigarette smoking clearly documented, there can no longer be any question that smoking is a high-risk activity. (Courtesy of Dan Piraro)

In addition to lugging around heavy equipment, swimming in strong current, surge, or flow, and, perhaps, performing physically demanding work underwater, several studies have shown that regular physical activity may protect against DCS. This is believed to be attributed to reduced bubble formation associated with exercise (Pontier et al., 2009).

According to Cresp et al. (2000), current medical screening is not efficacious at determining which individuals are medically unfit for diving. The authors also advocate the promotion of continued health surveillance in divers, seeing as most certifying agencies are not engaging in this practice. Although some organizations do require "dive physicals," these are largely self-reporting instruments.

Commercial divers routinely undergo more rigorous medical screening. In Japan, they have a health examination every six months, including spirometry, which is the most common form of pulmonary function tests (PFTs) (Suzuki, 1997). Suzuki also conducted a study to compare the PFTs in smoking versus non-smoking commercial divers, which will be subsequently discussed.

How Smoking Affects Divers

A basic review of the scientific literature using key words such as "smoking and diving" and "smoking and hyperbaric" yielded three overall categories: physical fitness/determination of fitness for diving; retrospective analyses of diving accidents, namely DCI/DCS; and lastly, experimentation. Experiments included pulmonary function tests (PFTs) in smokers and non-smokers and physiologic functioning/wound healing in hyperbaric chambers. The negative consequences of smoking are described in all of the literature, with a special focus on these effects in the hyperbaric environment. These effects are summarized in the table at the end of the article and will be described throughout the rest of the article.

Diving Fitness

The need for divers to be in good physical condition and to have solid exercise tolerance is already well established. What seems to be lacking is a more thorough physical exam that includes more than a swim test, as well as ongoing maintenance of physical health.

Experimentation: Hyperbaric O_2 Therapy

The heart and lungs are truly one unit—one cannot function without the other. In order for our bodies to efficaciously eliminate N_2 and CO_2, as well as deliver life-sustaining O_2, our cardiovascular system must be in tip-top shape. Smoking has direct negative impacts on the very mechanisms that we depend on not only for maintaining life at the surface, but for surviving in the hyperbaric environment.

There is an abundance of studies that describe hyperbaric oxygen therapy and wound healing (i.e., diabetic ulcers, bone fractures, spine fusions, reconstructive tissue flaps), comparing smokers versus non-smokers. While the details are beyond the scope of this article, their findings are predictable. Smokers consistently exhibit delayed healing due to their compromised microvasculature (the smallest blood vessels). Smoking not only damages the lungs but the cardiovascular system as well. Some classic predicted pathology includes damaged endothelium (lining) of microvasculature and larger vessels and platelet aggregation (clumping), as well as acute changes in heart rate and systemic vascular resistance (vasoconstriction). These effects are summarized in the table at the end of the article.

A recent study by Hart and Strauss (2010) analyzed gas tensions in skeletal muscle and subcutaneous tissues in smokers and non-smokers, comparing them at room air and under hyperbaric O_2 conditions (HBO_2). This article also includes an excellent overview and explanation of how smoking affects gas exchange, and I highly recommend reading it. The researchers' most relevant finding was the significant delay in N_2 off-loading from skeletal muscle in the smoking group when exposed to both protocols (room air and HBO_2). They concluded that this was due to the chronic destruction of the microvasculature's epithelium (lining of the tiny blood vessels) rather than the transient effects of nicotine. These changes were already evident in young smokers in their 30s.

Since this study protocol used a PO_2 of 2.0 (subjects at 2 ATA breathing pure O_2 from a scuba regulator), these findings cannot necessarily be generalized to the typical hyperbaric conditions a scuba diver is exposed to, for example, with a PO_2 of 1.2. If anything, a study that mimics a scuba dive would show even more detriment in the smoking group. This is because HBO_2 has been shown to improve tissue oxygenation even with endothelial damage. It would be fascinating to replicate this study in a hyperbaric environment minus the benefits of a 2.0 PO_2.

Tobacco advertising often trades on sexually charged images to promote identification and sell its product. The sad irony, however, is that the end result of the activity of smoking is not what is represented in the ad.

Pulmonary Function Tests

In short, PFTs (also called "spirometry") are a method of assessing a variety of lung volumes (i.e., flow over time). There are volumes and capacities, with a capacity being the sum of one or more volumes. Here is one example that you can try on yourself; it is called functional residual capacity or FRC. After a normal tidal exhalation, there is still a lot of volume left in your lungs, but you would not be aware of this unless you "forced" it out. Take a normal breath, in then out. After you have exhaled normally, gently force yourself to exhale every last drop of air. This "leftover" volume is called the FRC, and it can be measured. Another measurement is the DLco, or diffusing capacity of the lung for carbon monoxide. Typically, obstructive lung disease (as seen with smoking) will cause a decrease in the lung's diffusing capacity. Please see Figure A for classic flow-volume loops that clearly depict the differences between normal and pathological patterns.

Experimentation: Lung Function

The following two studies analyze PFTs in commercial divers, comparing smokers versus non-smokers. These findings might not necessarily be able to be generalized to the "normal" diving population since the majority of participants of the studies were young and in otherwise good health.

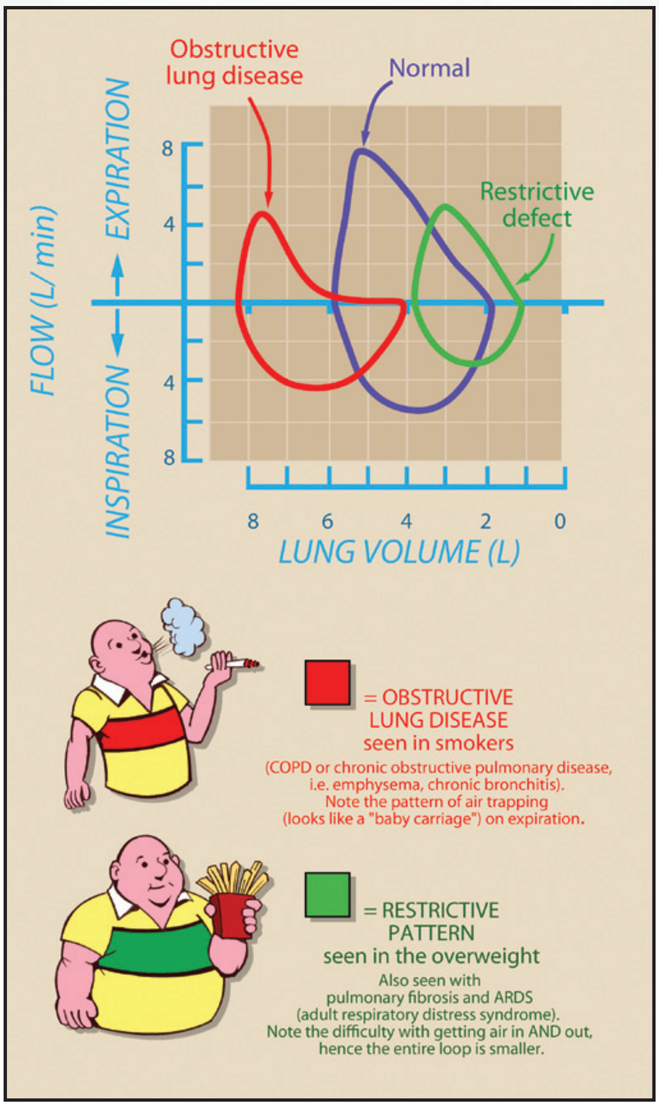
Suzuki's study (1997) used seventy-one male participants who were divers with the Japan Maritime Self-Defense Force (JMSDF); forty-six were smokers and twenty-five non-smokers. She analyzed static lung volumes, dynamic lung volumes and flows, and DLco. Overall lung volumes were larger than those seen in the general population. As to be expected, there was a decrease in DLco seen with smoking, suggesting emphysema (which the author reports is a contraindication for diving). It is worth mentioning that a drop in DLco is seen with normal aging, even in non-smokers. So, these seemingly healthy young divers were actually performing with aging lung function.

Sekulic and Tocilj's study (2006) looked at PFTs in thirty-two male and twenty-seven female military divers in Croatia. The only statistically significant difference that they found between smokers and non-smokers was in the relative inspiratory vital capacity. They also concluded that smoking negatively affects pulmonary function in military divers, mainly with respect to large airway function. The authors speculate that regular physical fitness training (such as what military divers must endure) can decrease the harmful effects of smoking, which would explain the lack of more statistically significant differences between the two groups.

Retrospective Analyses of Diving Accidents

The next two papers were retrospective analyses of scuba diving accidents, including assessment of accident severity and possible contributing factors (i.e., diver characteristics). These articles also provide a thorough review of the physiologic mechanisms behind the etiology of DCI.

An overview of DCI is relevant at this juncture, to demonstrate its relationship with smoking. First, every dive is a decompression dive. Second, bubbles are commonly found in the venous circulation after diving but are usually asymptomatic because they are filtered by the pulmonary capillaries and are eliminated via the alveoli. If ambient pressure is reduced below the partial pressure of the gas dissolved in the tissues, then bubbles can form and cause DCS. Obstructive lung disease with air trapping (commonly seen with smoking) or failure to fully exhale during ascent can cause pulmonary barotrauma, leading to bubbles invading the pulmonary veins to become arterial gas embolism (AGE).



Courtesy of Tony Gleeson (www.tonygleeson.com)

Wilmhurst and Bryson (2000) published a unique study that analyzed one hundred consecutive divers who sustained neurological DCI and compared them to 123 historical "control" divers, whose dives were uneventful. Dr. Bryson regularly treats divers for DCI. The authors specifically looked at right-to-left shunts (also known as a patent foramen ovale or PFO), lung disease, and provocative dive profiles. We will focus on the lung disease.

Not surprisingly, there were significantly more smokers in the cases who did not have predisposing factors and with short latencies than in the rest of the divers (five out of twelve versus twelve out of eighty-eight). The authors define latency as the interval between surfacing and the onset of the first neurological symptom. Interestingly, their current practice is to carry out lung function tests in all cases of neurological decompression illness, including spirometry, flow volume loops, chest X-ray, and sometimes a chest CT (computerized tomography), which is more sensitive than a chest X-ray for detecting the presence of bullae (air-filled pockets due to alveolar damage). They also recommend a CT scan of the lungs if a diver wishes to resume diving after an episode of neurological DCI starting on the ascent or soon after surfacing, when other tests are negative. The authors describe many individual case reports of neurological DCI, the role of lung disease, and the need for proper diagnostics. For example, there was a case of a diver who smoked a pack and a half of cigarettes a day, then had quit for two years. Immediately upon surfacing after a dive, he showed signs of neurological DCI. His entire work-up was negative, except his chest CT showed multiple bullae.

Lastly, Buch et al. (2003) used data from the Divers Alert Network® (DAN) from 1989-1997, to retrospectively analyze a total of 4,350 cases of DCI. There were actually a total of 8,269 cases; however only cases that had complete data were analyzed. Additionally, diving-related deaths were not included in the study. Data was not analyzed after 1997 because the following year the instrument was changed, allowing for free text and not a "check list" of symptoms. As we know, there are many contributing factors for DCI but this article specifically looked at smoking.

In medical terminology, a "pack year" means that the individual has smoked a pack of cigarettes a day for a certain number of years. Therefore a "20-pack year smoker" is someone who has smoked a pack a day for 20 years. In this study, smoking history was quantified as heavy (>15 pack years), light (0-15 pack years), and never smoked. DCI symptoms were classified as severe (alteration in consciousness, balance or bladder/bowel control, motor weakness, visual symptoms, convulsions), moderate (other neurological symptoms), or mild (pain, skin, or nonspecific symptoms).

The authors found that the heavy smokers were 1.88 times more likely to have DCS than divers who never smoked, and 1.56 times more likely than light smokers. They also found that any smoker was more likely to have severe versus moderate symptoms than in non-smokers. Although a cause-and-effect relationship is not established with this data, there is an undeniable correlation. When categorized, the results clearly show that heavy smokers present the highest number of severe symptoms. The authors conclude that smoking is a risk factor for increased severity of symptoms.

Conclusions

It should be abundantly clear by now that smoking and diving do not mix. There is an impressive list of physiologic rationales, as well as sound medical research to support this statement. In addition to the obvious damage that smoking does to the lungs and conducting airways, there is a significant amount of occult pathophysiology that might not manifest until the least opportune moment (i.e., after surfacing from a dive). I am encouraging you to please not dive with smokers; they are putting themselves and their teammates at risk.

Effect of Smoking	Physiologic Impact; Relevance to Diving
Cardiac effects: ↑ heart rate; ↑ blood pressure; coronary vasoconstriction; hypoxia lasting up to one hour	Impaired N_2 offloading in skeletal muscle; accelerated when the diver is cold and exaggerated in "vessel-poor" tissue groups (i.e., joints and connective tissue), where DCI commonly occurs
Inhalation of tar-laden cigarette smoke, leading to decreased pulmonary function and airway obstruction	↑ bronchospasm, ↓ cilial activity, and ↑ mucus production; collectively contribute to air trapping and ascent pulmonary barotrauma
Decreased exercise tolerance and physical fitness	↑ heart rate, ↓ stroke volume (effectiveness of each heart beat), ↑ O_2 debt accumulation; ↑ risk for DCS (exercise reduces bubble formation), ↓ capacity to respond to the physical demands of an emergency and/or rescue
Vascular disease, affecting the circulation by destruction of the endothelium (blood vessels' lining; also, ↑ platelet aggregation and fibrinogen production	Same process that bubbles cause when stuck in blood vessels; ↓ body's ability to eliminate inert gases
Slower N_2 offloading in experimental hyperbaric O_2 exposure	↑ risk of DCI related to higher N_2 load
Chronic hypercarbia	↑ risk of narcosis related to ↑ CO_2
Centrilobular emphysema, leading to blebs (enlarged alveolar space due to alveolar wall destruction), as seen on chest X-rays	Blebs = an absolute contraindication for diving; dangerous if burst
Smoking-related pneumothorax (collapsed lung); most common in young, tall men	Another disqualifier for diving; has a known high risk of recurrence while diving, and if this happens during ascent, can lead to a fatal tension pneumothorax and AGE
Presence of CO (carbon monoxide) in the blood, resulting in the compound carboxyhemoglobin	↓ O_2 carrying capacity (O_2 not released to the tissues) by 250-300 times.
Presence of hydrogen cyanide and hydrogen sulfide in the blood	Direct toxins to the alveolus; interference with O_2 exchange; impairment of the body's natural "bubble filter"
Upper airway (nasopharyngeal) congestion	↑ risk of sinus and middle ear barotraumas
Air trapping/obstructive patterns on flow-volume loops; ↑ lung compliance	↑ risk of AGE and pulmonary barotrauma; ↑ risk of neurological symptoms
↑ hematocrit, or higher # of red blood cells per volume, making the blood more viscous	↑ atmospheric pressure causes tiny blood vessels to get clogged, leading to ↓ perfusion and ↑ risk of DCS; accelerated with more viscous blood
Acute nicotine withdrawal	Performance degradation, confusion, memory impairment, ↓ reaction time, impulsiveness

Summary of deleterious effects of smoking and diving

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