Exploring Diver Health: An epidemiological study investigating health and self-reported symptoms while diving in divers with pre-existing cardiovascular diseases

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GRADUATION THESIS

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1. Prof. dr. sc. Alen Protić
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3. Doc. dr. sc. Tomislav Jakljević

The graduation thesis contains 28 pages, 6 figures, 4 tables, 28 references.

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1. List of abbreviations and acronyms

SCUBA	Self-contained underwater breathing apparatus
CVD	Cardiovascular diseases
CV	Cardiovascular
IPE	Immersion pulmonary edema
P	Pressure
V	Volume
n	Number of Moles of a gas
R	Universal Gas Constant
DCS	Decompression sickness
ANS	Autonomic Nervous System
FEV1	Forced Expiratory Volume in one second
BMI	Body Mass Index

2. Introduction

For most of humanity, underwater excursions were limited by breath-hold time or exclusive to military operations. It wasn´t until the invention of the aqualung, the first SCUBA (self-contained underwater breathing apparatus) unit, by Émile Gagnan and Jacques-Yves Cousteau in 1943 that scuba diving was recreationally possible (1). Nowadays, in America alone, 3.145 million Americans participate in scuba diving activities at least once per year, and 893.000 participate in scuba diving activities at least eight times per year (2).
While the popularity of scuba diving is growing, the average age of scuba divers is also increasing (3). An array of health conditions accompanies increasing age. The most common of those health conditions are cardiovascular diseases (CVD). They are the leading cause of death and morbidity in the world, with nearly 523 million people suffering from them (4).

Despite advancements in technology and safe diving practices, the frequency of recreational scuba diving fatalities remains constant at two per 100,000 (5). The Divers Alert Network (DAN) continues to register over 1000 diving-related injuries yearly, with over 10% being fatal (5). DAN has grouped these diving-related injuries into four main categories: equipment problems, changing environments, procedural errors and pre-existing medical conditions of divers (5). In 2020, DAN reported that out of 25 autopsy cases, four deaths were attributed directly to cardiac-related causes, while in a further twelve cases, a disabling injury that proved fatal was the result of a cardiac-related issue (6).
While some diving-related injuries prove fatal, others, such as immersion pulmonary oedema (IPE), have been found at higher rates in divers with pre-existing CVD (7).

The underwater environment imposes stress on the cardiovascular system, potentially exacerbating CVD in divers and increasing symptoms during or after diving (8,9). Cardiac arrhythmias, stress-induced cardiomyopathy, beta-blocker use, and hypertension can all contribute to diving-related injuries (7).
Despite all this, courses conducted by scuba diving training agencies make little to no mention of diving with cardiovascular diseases and the risks this may pose.

As the number of scuba divers with cardiovascular diseases continues to grow, it becomes increasingly crucial to understand the relationship between CVD and diving-related injuries, as well as divers' awareness and attitudes toward this issue.

3. Aims and objectives

The primary aim of this study is to investigate the relationship between cardiovascular health and diving safety among divers with pre-existing cardiovascular diseases (CVD). Specifically, this research seeks to understand the symptoms experienced during or after diving, the impact cardiovascular medications have on diving performance and investigate the awareness of risks by divers with CVD.

The first objective is to assess self-reported symptoms in divers with CVD. This involves conducting an online survey to determine the type and frequency of symptoms divers with CVD experience.

The second objective is to evaluate the demographics of divers with CVD, such as age, experience/ certification level and BMI.

The third objective is to identify factors influencing divers' decision-making regarding diving with CVD. This involves assessing their awareness of the risks and examining the influence of diving certification level and experience.

4. Participants and study design (Materials and methods)

This study employs a quantitative approach to investigate diver health and CVD-related implications related to diving activities.

An online survey was designed to collect data about diver demographics, diving experience, CVD history, medication use, symptoms during or after diving, and awareness of cardiovascular risks. Participants in this study were divers of all ages. A convenience sampling method was used, and the survey was distributed via diving clubs, online forums, and social media groups dedicated to diving, with a two-month response period. The complete questionnaire is available in the appendix.

Confidentiality and anonymity were ensured throughout the study.

The data was analysed using Microsoft Excel, including descriptive statistics (means, medians, standard deviations) and visualisations (histograms and bar charts).

5. Physiological changes while diving

Exploration of the underwater world dates back thousands of years, but only in the last 200 years have scientists started to understand the physiological impact of diving on the human body (10). Some of these physiological changes have profound effects on the cardiovascular system and have the potential to exacerbate or cause CVD.

5.1. Pressure

Arguably, the most significant impact on human physiology is caused by the increase in ambient pressure. Humans have evolved to live at an ambient pressure of one bar. Every 10m a diver descends adds an extra one bar of ambient pressure (11). The biological effects of pressure directly are mild and occur at 40-60 bars of pressure (equivalent to depths of approximately 400-600 meters) (12). These include a slight reduction in the sedative properties of propofol and a slight increase in the affinity of haemoglobin to oxygen (12,13). Within the depths of modern scuba diving pressure changes primarily affect human physiology through changing gas properties (12). Derivatives of the ideal gas law (PV = nRT) are used to explain the effects of pressure on gasses and tissues (i.e. Boyle´s law, Henry´s law, Dalton´s law) (14).
Boyle's Law asserts that at a constant temperature, the volume of a given mass of gas is inversely proportional to the pressure applied to it (15).
Henry's law is a gas law that states that the amount of a gas that dissolves in a liquid is directly proportional to the partial pressure of that gas above the surface of the solution. This means that at a constant temperature, the concentration of a gas in a liquid is directly proportional to the partial pressure of that gas in the atmosphere (15).
Dalton's law of partial pressures states that in a mixture of non-reacting gases, the total pressure exerted is the sum of the partial pressures of the individual gases, assuming ideal gas behaviour (15).
These laws explain most diving-specific injuries, such as decompression sickness (DCS) and barotrauma. Diving training agencies usually discuss them thoroughly.

5.2. Density

Water has an approximately 830 times higher density than air (16). The increased density of water reduces human efficiency in water and increases the energy cost of locomotion, thus requiring more work for propulsion (12). The higher workload needed increases the demands of the cardiovascular system.

During a dive using a SCUBA system, air (or any other mixture of gases) is supplied to the diver at their ambient pressure. As the pressure increases, the gases' density increases proportionally, leading to the diver breathing denser air. This corresponds to an increased work of breathing, further increasing the strain on the cardiovascular system and increasing energy expenditure (12).

5.3. Mammalian dive reflex

The mammalian dive reflex or diving response is a multifaceted and protective response that occurs in mammals, including humans, when submerged in water (17). When the face and nose become wet, it triggers bradycardia and apnea and increases peripheral vascular resistance; collectively, this is termed the mammalian diving reflex (17). The cause of these responses is thought to be partly due to the activation of the autonomic nervous system (ANS) (18). However, there are complex and sometimes conflicting ANS responses in SCUBA dives (18). As the vagal response elicited by the mammalian diving reflex is primarily parasympathetic, the peripheral vasoconstriction is driven by a sympathetic response (9). Exposure to cold water and mental stress while diving furthermore increases sympathetic activity (18).

The decrease in heart rate, mediated by the vagus nerve, reduces the heart's oxygen consumption and conserves oxygen for vital organs. In divers with CVD, however, bradycardia can lead to ventricular arrhythmias, potentially leading to dangerous reductions in cardiac output (19).
Peripheral vasoconstriction occurs due to the activation of the sympathetic nervous system. Blood vessels in the extremities constrict, redirecting blood flow to the core organs (heart, brain, and lungs) (17). This centralisation of blood flow helps to maintain oxygen supply to critical organs but also increases the volume of blood returning to the heart, increasing preload (20,21).
Preload refers to the degree of ventricular stretch before contraction, which is directly related to the volume of blood returning to the heart. The mammalian diving reflex increases preload due to the augmented return of blood from the periphery (20). For healthy divers, this can increase cardiac output by the Frank-Starling mechanism, which states that an increased blood volume in the heart results in a stronger contraction. However, for individuals with CVD, especially those with compromised cardiac function, the increased preload can

overload the heart, leading to pulmonary congestion or exacerbation of heart failure symptoms, such as breathlessness (21).
Excessive stretching of the myocardial fibres due to the increased volume of blood in the heart can also lead to electrical instability (22). This instability can lead to arrhythmias, particularly in individuals with underlying cardiac conditions (22).
The confluence of bradycardia, increased preload, and myocardial stretching creates a susceptible environment for the initiation of arrhythmic events, which can have life-threatening implications during a dive.

Peripheral vasoconstriction also leads to an increased afterload, which refers to the resistance the heart must overcome to eject blood. The increased afterload requires the heart to work harder to pump blood, thus increasing myocardial oxygen demand (17). In healthy divers, this mechanism might be well-tolerated. However, in those with conditions such as hypertension or left ventricular hypertrophy, the elevated afterload can precipitate ischemic events or worsen existing cardiac conditions (23).

The mammalian diving reflex is not dependent on depth, meaning that the risk of adverse cardiovascular events caused by it is also not influenced by depth and thus can occur even during shallow dives.

5.4. Temperature

Water has a higher thermal conductivity than air; thus, heat is conducted approximately 22-24 times faster in water (24). One physiological response to cold is peripheral vasoconstriction, which causes the centralisation of blood to vital organs (24). This, in turn, causes the previously mentioned potential problems, including inducing arrythmias.
A meta-analysis conducted in 2023 concluded that every 1°C decrease in temperature increases cardiovascular disease-related mortality by 1.6% and morbidity by 1.2% (25). The most pronounced effects are observed in the mortality of coronary artery disease and morbidity of aortic aneurysms and dissection (25).

6. Diving and Hypertension

Hypertension is one of the most common CVDs, affecting approximately 40% of the general population, with an increase related to age (26). As a consequence, hypertension has a high prevalence amongst divers with a rising tendency (26).

Diving is likely to aggravate hypertension through several mechanisms:

- Immersion, which leads to a centralisation of blood, usually amounts to 600-700ml.
- Peripheral vasoconstriction is caused by cold and the mammalian diving reflex, as discussed previously. This increases centralisation and central blood pressure.
- Exercise, which leads to an increase in blood pressure.
- Activity-related stress (psychological), particularly in novice divers.

For sports in general, European Society of Cardiology guidelines recommend a blood pressure below 160/100 mmHg (27). Pre-dive elevated blood pressure in hypertensive divers, in combination with the previously mentioned blood pressure-increasing aspects of diving, may accumulate to a cardiovascular strain, which may lead to adverse cardiovascular events (26).
There is credible evidence that suggests that hypertensive divers are more susceptible to developing immersion pulmonary oedema (IPO) (28).

In animal models, hypertension led rats to develop DCS twice as often as in the control group, which indicated that hypertension may be a risk factor for DCS (26). However, further research is required to confirm this.
As hypertension is a risk factor for cardiovascular incidents, the risk of scuba diving-related cardiovascular incidents is also likely to increase in hypertensive divers (26).

7. Diving and CVD medication

With the rising incidence of CVD, the incidence of medication usage has also increased. Some medications may have diving-related safety concerns. However, very little research exists on taking CVD medication while diving and most of it is categorised as level C evidence (21).

7.1. Angiotensin-converting enzyme inhibitors (ACE inhibitors) and angiotensin II receptor blockers (ARB)

ACE inhibitors and ARBs are well tolerated by divers, and no diving-related risks have yet been identified (21,26). One common side effect of ACE-I is a dry cough, which should be evaluated (26).

7.2. Calcium antagonists

Due to the vascular selectivity of dihydropyridine calcium channel blockers compared to non-dihydropyridine calcium channel blockers, divers who are taking these medications are at risk of experiencing orthostatic hypertension upon exiting the water (21). Otherwise, no diving-related risks are known.

Non-dihydropyridine calcium channel blockers are known for their higher selectivity for the myocardium and their ability to negatively affect dromotropism and chronotropism. Caution is advised when using these blockers due to the potential development of bradycardia as a result of the mammalian diving reflex (21).

7.3. Diuretics

Dehydration is believed to be a contributing factor to DCS. While there is a strong theoretical basis for this, there is minimal scientific evidence to support it (21). However, it still raises concerns that plasma volume reduction caused by diuretics may theoretically increase the risk of DCS.

7.4. Beta Blockers

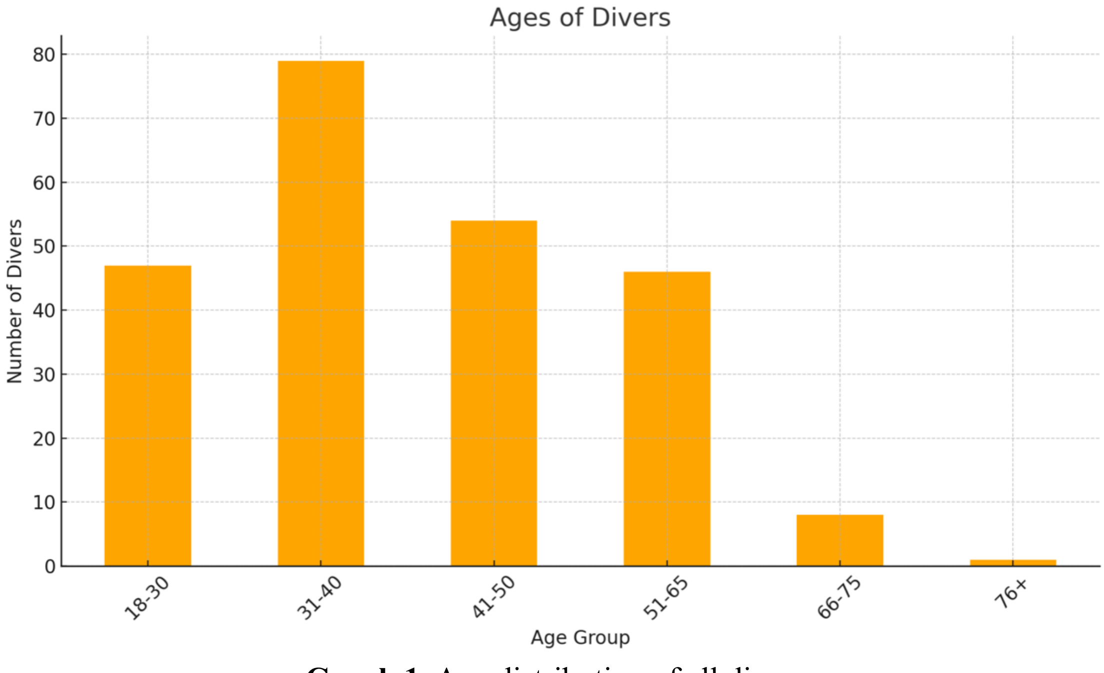
Beta-blockers cause several concerns while diving. First, they might cause chronotropic impedance of the heart by limiting heart rate adjustment during exercise, which limits exercise capacity (23). Second, they can potentially reduce FEV1 in susceptible individuals by acting on beta-2 receptors (23). However, this side effect diminishes with prolonged use (23). Finally, beta-blockers have been linked to multiple cases of immersion pulmonary oedema (26). However, there are no systematic studies investigating this.

8. Results of the survey

While the main focus was on divers with CVD, a significant number of respondents did not have a diagnosed CVD. This will be addressed in a subsequent section.

8.1. Demographics and Diving Activities

After a two-month period, 236 divers responded to the questionnaire: 174 men (74%), 61 women (26%) and one participant preferred not to specify their gender. The gender split is in accordance with the diving industry as a whole. Out of 236 divers, the largest group, comprising 79 individuals (33%), fell within the 31 to 40 age range. 54 divers (23%) were aged 41 to 50, 47 (19%) were between 18 and 30, and another 46 (19%) were aged 51 to 65. The remaining divers were distributed among other age groups, with eight individuals (3%) falling within the 61 to 75 range, one diver under 18, and one diver over 75 years old.

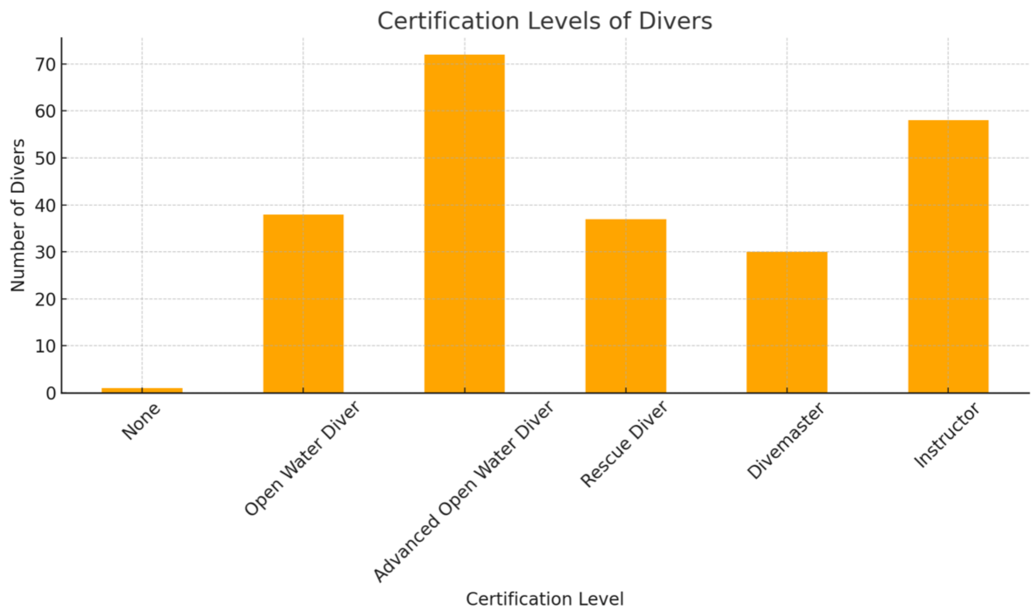


Graph 1: Age distribution of all divers

The average BMI of all divers was 28.27. The female average was 27.97, and the male average was 28.39.

The survey revealed that the majority of divers held advanced open water level certification, with 72 respondents (30%) indicating this. Following that, 58 respondents (24%) were certified to instructor level, 38 (16%) were certified as Open Water Divers, 37 (15%) as

Rescue Divers, and 30 (12%) as Divemasters. One participant indicated that they were not certified at all.



Graph 2: Certification level of all divers

The most significant proportion of divers, 56 (24%), had accumulated 1-3 years of diving experience, while 41 (17%) had been diving for over 20 years. Furthermore, 39 (16%) had between 11 and 15 years of experience, 27 (11%) had between 16 and 20 years, 25 (10%) had been diving for 6 to 10 years, another 24 (10%) for 4 to 5 years, and 24 (10%) for less than one year.

In terms of the total number of dives, the data shows that 63 (26%) divers had completed between 101 and 500 dives, 50 (21%) over 1000 dives, 44 (19%) between 31 and 100 dives, 43 (18%) had less than 30 dives, and 36 (15%) had between 501 and 1000 dives.
Most participants engage in diving activities more than 50 times yearly, with 69 (29%) divers reporting this frequency. This is followed by 45 (19%) participants who dive between 16 and 30 times yearly, 42 (17%) diving between 31 and 50 times per year, and 40 (16%) dive 6 to 15 times yearly. Moreover, 33 (13%) participants reported diving between 1 and 5 times per year, and 7 (2%) reported diving less than once yearly.

8.2. Dive-related incidents

Of the 236 respondents, 186 (78%) reported never having had any dive-related incident, while 50 (22%) experienced at least one.
The most frequently reported incidents comprised barotrauma affecting the ears, sinuses, or lungs, with 20 documented cases (as depicted in Table 1). There were 17 reported instances of equipment failure, 12 cases of decompression sickness (DCS), 11 reports of panic or anxiety-related incidents, eight injuries related to marine life, three cases of loss of consciousness, three cases of exacerbation of previous health issues (e.g., cardiovascular diseases, respiratory diseases), and two incidents related to cold exposure.

Table 1
Diving-related incidents reported by 236 divers. More than one incident may be reported.

Diving-related incident	Number (%)
Barotrauma (ears, sinuses, lungs)	20 (8.5%)
Equipment failure	17 (7%)
Decompression sickness	12 (5%)
Panic or anxiety-related incidents	11(4.6%)
Marine life-related incidence	8 (3.3%)
Loss of consciousness	3 (1.2%)
Exacerbation of previous health issues	3 (1.2%)
Cold exposure incident	2 (0.8%)
None	176 (78%)

8.3. Self-reported symptoms while or after diving

Among the 236 divers surveyed, 80 (34%) reported experiencing symptoms, including breathlessness, fatigue, and dizziness, while or after engaging in diving activities.
The predominant symptom was ear pain or pressure, affecting 62 (26%) divers. This was closely followed by fatigue, reported by 59 (25%) divers. Furthermore, 46 (19%) divers reported experiencing headaches, 36 (15%) reported breathlessness, 19 (8%) reported nausea and vomiting, 12 (5%) reported rapid or irregular heartbeat, and five (2.1%) reported chest pain.

Table 2

Self-reported symptoms experienced by 236 divers. More than one symptom may be reported.

Self-reported symptoms while or after diving	Number (%)
Ear pain or pressure	62 (26%)
Fatigue	59 (25%)
Headache	46 (19%)
Breathlessness	36 (15%)
Nausea and vomiting	19 (8%)
Rapid or irregular heartbeat	12 (5%)
Chest pain	5 (2.1%)
Other	10 (2.3%)
None	156 (66%)

8.4. Divers with previous cardiovascular diseases

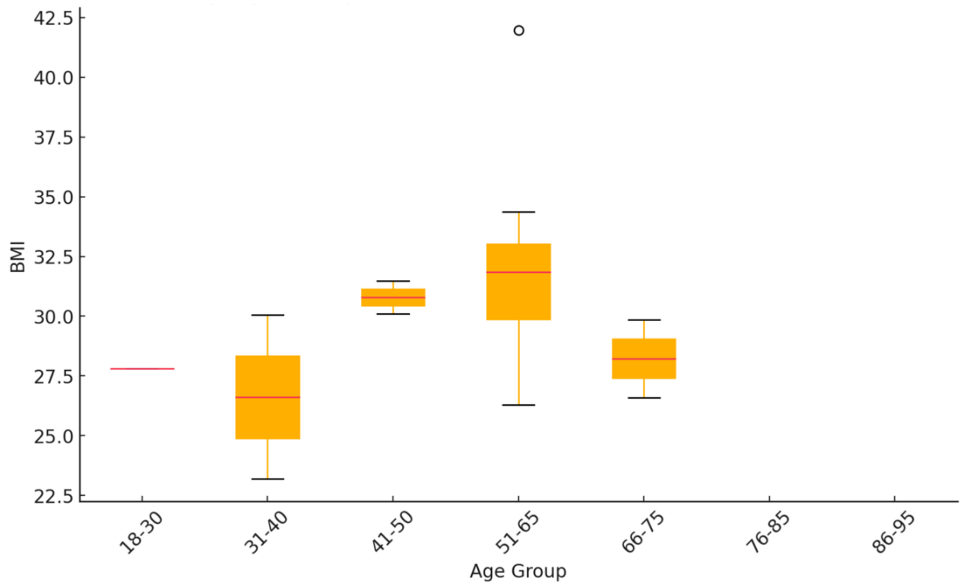
Nineteen divers reported having at least one CVD. Among the reported divers diagnosed with CVD, hypertension was the most common, with 18 out of the 19 divers being diagnosed with it. Two divers were diagnosed with arrhythmias, one with peripheral artery disease, and one had a stent.

Table 3

Cardiovascular diseases reported by 19 divers. More than one disease may be reported.

Cardiovascular disease	Number
Hypertension	18 (95%)
Arrythmias	2 (10.5%)
Peripheral artery disease	1 (5.2%)
Stent implantation	1 (5.2%)

Out of the 19 divers with CVD, 18 were male, and one was female. The average BMI of divers with CVD was 30.62. Graph 3 shows the distribution of BMI by age group.



Graph 3: BMI By Age Group (Participants with Cardiovascular Diseases)

Out of the 19 divers diagnosed with a CVD, 13 were aware of guidelines and recommendations regarding diving with their CVD, and six were not aware of any.

Most divers with CVD held instructor (8 divers, 42%) or divemaster (5 divers, 26%) certification levels. Three divers (15%) possessed advanced open water diver qualifications, two (10%) held rescue diver certifications, and one (5%) had an open water diver certification.

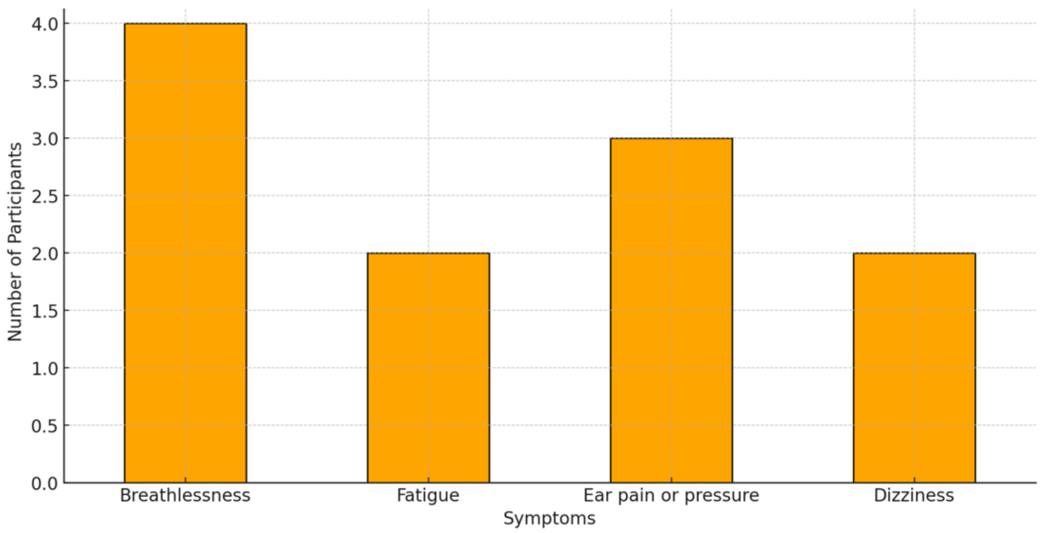
Among the 19 divers diagnosed with cardiovascular diseases (CVD), 18 were prescribed medication for their condition (as shown in Table 4). Ten divers were administered calcium channel blockers, six were prescribed angiotensin II receptor blockers (ARBs), four were taking diuretics, three were on angiotensin-converting enzyme (ACE) inhibitors, three were using beta-blockers, two were prescribed statins, and one was receiving an antiplatelet agent. All divers who were prescribed medication reported taking it regularly.

Table 4
Cardiovascular disease medication use reported by 19 divers with CVD. More than one medication may be used.

Cardiovascular disease medication	Number (%)
Calcium Channel Blocker	10 (52.3%)
Angiotensin II receptor blocker	6 (31.5%)
Diuretics	4 (21%)
Angiotensin-converting enzyme inhibitor	3 (15.7%)
Beta-blockers	3 (15.7%)
Statins	2 (10.5%)
Antiplatelet Agent	1 (5.2%)

Eight (44%) out of the 18 dives taking prescription medication reported receiving guidance or counselling about diving with their medication, while 10 (56%) reported never having received any guidance or counselling on the matter.
One diver reported adjusting or skipping their medication due to diving.

Four of the divers with CVD reported experiencing symptoms while or after diving. These symptoms included breathlessness (four counts), ear pain or pressure (three counts), dizziness (two counts), and fatigue (two counts).



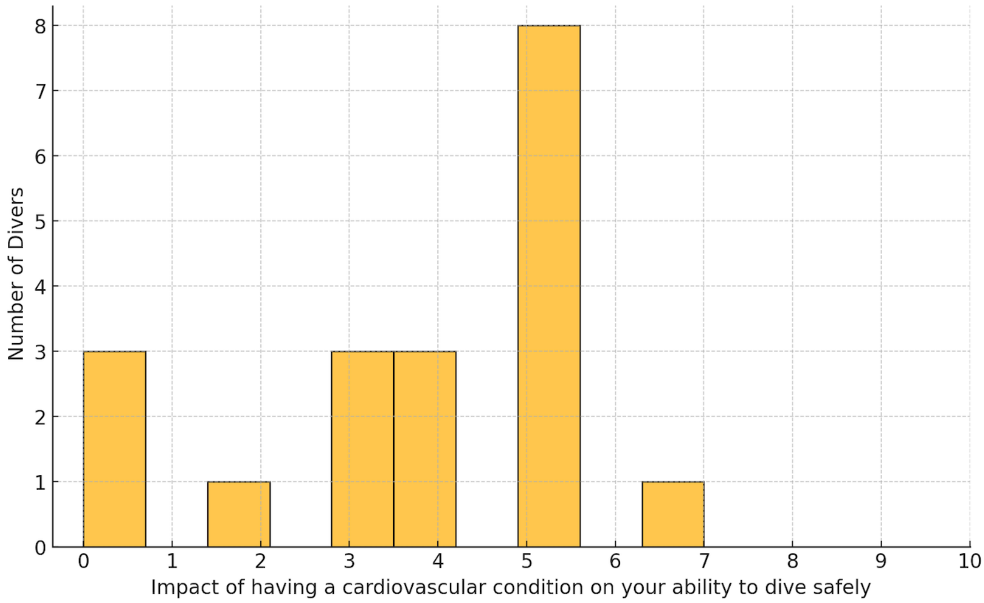
Graph 4: Symptoms Experienced by Divers with Cardiovascular Diseases

8.5. Risk awareness of divers with CVD

Divers were asked about their perception of the impact of CVD on their ability to safely engage in diving activities, as well as their level of awareness concerning the interaction of their medications with diving.

8.5.1 Impact of CVD on Diving Ability

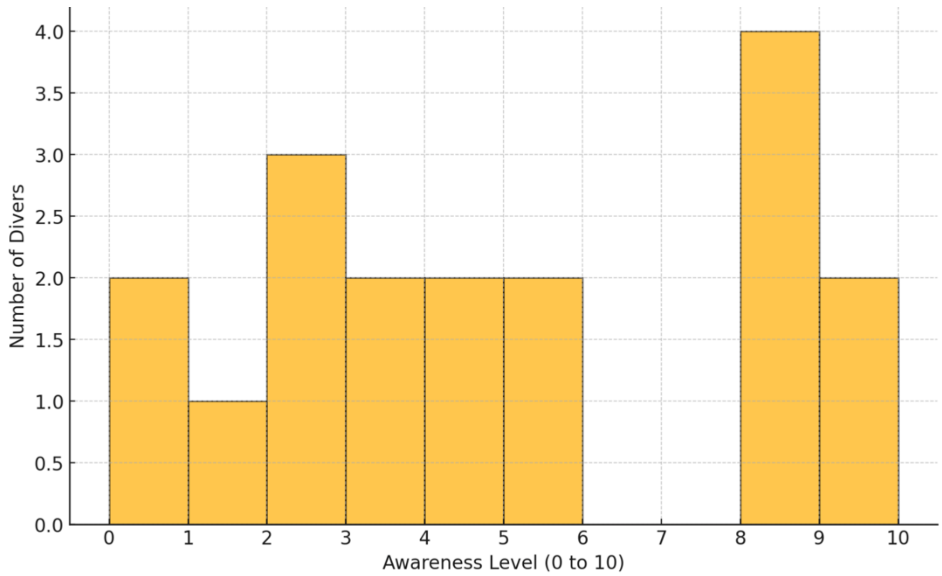
The mean score for the perceived impact of their CVD on their ability to dive safely was 3.68 on a scale of 0 (no impact) to 10 (extreme impact). The responses varied, with a standard deviation of 1.97.



Graph 5*:* From 1 (no impact) to 10 (extreme impact), how significant do you believe the impact of having a cardiovascular condition is on your ability to dive safely?

8.5.2 Awareness of Medication Interactions

The study also examined how well divers with CVD feel informed about the interactions between their medications and diving on a scale of 0 (not informed at all) to 10 (Extremely informed). The mean score for feeling informed was 4.61 out of 10, with a standard deviation of 3.31.



Graph 6: How well-informed do you feel about the interaction between your cardiovascular medications and diving? From 0 (not informed at all) to 10 (Extremely informed)

9. Discussion

This study aimed to investigate the health and self-reported symptoms of divers with pre-existing CVD and analyse the risk assessment of those with CVD.

Although divers with diagnosed CVD were targeted, 217 divers without a diagnosis of CVD responded to the survey. 34% of divers who responded to the questionnaire stated they experienced symptoms while diving or after diving. This high number of respondents without diagnosed CVD but with symptoms indicates a significant interest in diving health and safety. It suggests that divers without diagnosed CVD might still experience considerable health concerns and are keen to share their experiences and learn about potential risks associated with diving. It could also be attributed to a broader interest among divers in the possible health impacts of diving and a desire to participate in studies that might improve safety guidelines and recommendations for the diving community.

Moreover, it is possible that some divers who reported experiencing symptoms while diving may have undiagnosed cardiovascular diseases. These individuals might be unaware of their condition, which poses a significant risk during diving activities. This underscores the importance of regular medical check-ups and comprehensive health screenings for divers to identify any underlying health issues that could affect their safety.

9.1. Key findings

The study included 236 divers, 19 of which were diagnosed with CVD. Most divers were male (74%) and aged between 31 and 50. This demographic profile aligns with existing research indicating that the diving population is predominantly male and middle-aged (3). The average BMI of all divers was 28.27, with males averaging 28.39 and females 27.97. The 19 divers with CVD had a higher average BMI of 30.62. This suggests that obesity, a known risk factor for CVD, is prevalent among divers with these conditions. The high BMI values in this group are consistent with global trends, showing a strong correlation between obesity and cardiovascular conditions (4).
Divers with CVD often held higher levels of diving certification and had extensive experience, with many having over 20 years of diving history. The extensive diving experience of participants indicates that diving is a long-term recreational activity for many, necessitating continuous health monitoring.
Most of the divers with CVD held instructor (42%) or divemaster (26%) certification levels, suggesting a certain level of knowledge about diving-related activities. Most of the divers with CVD were aged 51 and over. Achieving a higher level of scuba certification, such as instructor or divemaster, requires significant time and experience. Consequently, individuals holding these certifications tend to be older. With advancing age, the prevalence of cardiovascular diseases increases, explaining the higher incidence of CVD among divers with more advanced certifications.
Diving instructors and divemasters with CVD have additional responsibilities, not only for their health and safety but also for the well-being of their students. Instructors are role models and safety officers during dives, and any health issue they experience can directly impact the safety of their students.
It is crucial for instructors and divemasters with CVD to maintain optimal health and regularly evaluate their fitness to dive to ensure they are not putting themselves or others at risk. This includes staying informed about the interactions between their medications and diving and seeking guidance from healthcare professionals on safe diving practices tailored to their health conditions.

Most CVD divers engage in frequent diving activities, with 47% diving more than 50 times a year. However, it is also crucial to monitor divers with CVD who only dive occasionally. Irregular CVD divers may face additional risks due to a lack of continuous diving practice, which could affect their overall fitness and familiarity with diving procedures. Therefore, these divers also need frequent health monitoring and regular medical check-ups to ensure they can safely dive and effectively manage their cardiovascular conditions.

A third of all divers reported experiencing symptoms such as breathlessness, fatigue, and dizziness while or after diving. Specifically, divers with CVD reported symptoms like breathlessness (four counts), ear pain or pressure (three counts), dizziness (two counts), and fatigue (two counts). The prevalence of symptoms among divers with CVD indicates a potential danger to their diving safety.
As mentioned previously, some of these symptoms, particularly breathlessness, may result from the combined effects of the mammalian diving reflex and pre-existing cardiovascular diseases, whether they are diagnosed or not. This underscores the critical need for targeted interventions and screening to manage the risks associated with diving in individuals with CVD.

9.2. Perceived Impact of CVD on Diving Ability

The study also examined how divers with cardiovascular diseases (CVD) perceive the impact of their condition on their ability to dive safely.
The scores ranged from 0 (no impact) to 10 (extreme impact), with the majority of responses clustered around the moderate range and none rating it as extreme (8-10). The mean score for the perceived impact was 3.68 out of 10, suggesting a moderate impact on average. These findings indicate that while most divers feel their CVD has little to no impact on their diving ability, others perceive a more noticeable effect.
This result suggests divers may not be fully aware of the risks associated with diving with CVD. The lack of perceived impact among some divers points to a need for increased education and awareness about the potential dangers and necessary precautions when diving with a CVD.
Training agencies provide comprehensive training on various aspects of diving safety and an extensive overview of DCS symptoms. Yet, there is a notable deficiency in topics related to diving with CVD. Most training manuals do not mention CVD.

The importance of this education and screening is underscored by the findings from the Divers Alert Network (DAN) report, which highlighted that a significant number of diving-

related fatalities were attributed to cardiovascular-related issues. Out of 25 autopsy cases reported in 2020, four deaths were directly linked to cardiac causes, and in an additional 12 cases, a disabling injury leading to death was the result of a cardiac-related issue.
Improving education about CVD in diving courses will not only enhance safety for divers with pre-existing conditions but also contribute to broader health awareness and proactive risk management in the diving community.

9.3. Awareness of Medication Interactions

The study also sought to assess the level of awareness among divers with cardiovascular diseases (CVD) regarding the potential interactions between their medications and diving. On average, divers rated their level of being informed as 4.61, indicating a moderate level of awareness, with responses ranging from 0 (not informed at all) to 10 (very well-informed). However, the standard deviation of 3.31 suggests a wide variation in how informed divers feel. This variation suggests that while some divers feel well-informed about the interactions between their CVD medications and diving, many do not. Over half of CVD divers (56%) had never received any guidance on diving with their CVD or medication.
This lack of awareness among divers suggests that more comprehensive information and resources should be available to ensure divers with CVD can make informed decisions about their diving activities and manage their medications safely. More information and resources should also be made available to healthcare professionals so that they can make evidence-guided decisions when prescribing medications to divers.

9.4. Implications for Diving Safety and Health Management

There is a clear need for personalised health interventions and regular medical check-ups for divers with CVD. This includes medication management and guidelines. Healthcare professionals should work closely with divers to monitor their cardiovascular health and adjust their diving practices while educating divers about the potential risks.
Divers with CVD should be encouraged to engage in cardiovascular fitness programs to improve their overall health and reduce the risk of diving-related incidents. Regular medical evaluations can help detect any changes in health status that might affect diving safety.
Certain CVD medications should be avoided while diving and diving activities need to be considered when choosing medications. In addition, more research should be done to better understand the effects of CVD medications while diving.

Increasing awareness about the risks associated with CVD in diving through training agencies might help mitigate some of the health risks.
Divers who completed their initial medical check-up for their certification at a younger age might not have been screened for conditions that develop later in life, such as hypertension, arrhythmias, or other cardiovascular issues. Therefore, periodic health assessments should be mandatory for divers, especially as they reach middle age and beyond.

It can also be assumed that more challenging dives, such as technical diving or cave diving, are typically performed by older divers. This is due to the extensive time and training required to acquire the necessary certifications and experience levels for these advanced diving activities. Consequently, the likelihood of divers undertaking challenging dives with CVD is notably higher.

9.5. Comparison with existing literature

The findings observed in this study corroborate existing research that highlights the prevalence of CVD and related symptoms among middle-aged and older adults. For example, Strauss et al. (2017) found that most divers are male and tend to be older, reflecting the growing trend of ageing divers who continue to participate in the sport despite potential health issues (3). Additionally, the high average BMI among divers with CVD aligns with global data, indicating a strong correlation between obesity and cardiovascular conditions (4).

Moreover, the physiological challenges of diving, such as increased pressure and cold exposure, have been documented to exacerbate cardiovascular conditions. Studies have highlighted the risks associated with diving for individuals with CVD, emphasising the need for specialised guidelines and interventions (8,9).
The Divers Alert Network (DAN) report has also highlighted that most of the autopsies performed on diving casualties concluded that cardiovascular-related events directly or indirectly caused the deaths (7).

9.6. Limitations of the Study

While this study provides valuable insights into the implications of CVD on diving safety and diver health, several limitations should be acknowledged. The sample size of 236 divers, including only 19 individuals with CVD, may limit the general applicability of the findings. Convenience sampling may have introduced selection bias, as participants who opted to respond might differ from those who did not. Reliance on self-reported data poses risks of recall and social desirability biases, potentially affecting the accuracy of reported symptoms and experiences. The cross-sectional design limits the ability to infer causality, as data were collected at a single point in time. Lastly, the absence of objective health measures, such as clinical assessments, could limit the reliability of health status data.

9.7. Recommendations for Future Research

Considering the findings and limitations of this study, several recommendations for future research are proposed. Firstly, there is a necessity for studies with larger sample sizes and more diverse populations to augment the generalizability of the results. Secondly, longitudinal studies could yield more profound insights into the long-term effects of CVD on diving safety. Thirdly, it would be advantageous to investigate the efficacy of various educational and intervention programs aimed at enhancing awareness and management of CVD among divers. Lastly, progress should be made in understanding the effects of CVD medications while diving.

10. Conclusion

Through an epidemiological study, the thesis investigated the health and self-reported symptoms of divers with pre-existing cardiovascular diseases (CVD). The growing popularity of scuba diving, combined with an ageing diver population, underscores the importance of comprehending the impact of CVD on diving safety and health.

Although divers with diagnosed CVD were targeted, a large proportion of divers without a diagnosis of CVD responded to the survey. Many of them had experienced symptoms while or after diving. This high number of respondents without diagnosed CVD but experiencing symptoms indicates a significant interest in diving health and safety. It could be attributed to divers' broader interest in the potential health impacts of ageing and diving.

The analysis revealed that divers with CVD often have a higher BMI and are typically more experienced. Many hold instructor-level certifications, implying that they have a degree of responsibility for other divers.
The divers with CVD reported symptoms such as breathlessness, fatigue, and dizziness during or after diving, suggesting that CVD can affect their diving experience and have severe and even fatal implications.

Additionally, this research showed that many divers with CVD are not fully aware of the risks of their condition in relation to diving and may also be unaware of any possible effects of their cardiovascular medications on their diving. The results highlight the necessity for personalised health interventions and regular medical evaluations for divers with CVD. Healthcare providers should work jointly with these divers to monitor their cardiovascular condition.
Furthermore, there is a crucial need for comprehensive education and guidance regarding the risks of diving with CVD and the safe use of medications while diving, with over half of CVD divers having never received any guidance on diving with their CVD.
Increasing awareness and education about the risks associated with CVD in diving through training agencies can significantly enhance safety and health outcomes.

The study encountered several limitations, including a relatively small sample size and the use of convenience sampling, which may restrict the generalizability of the findings. The reliance on self-reported data introduces potential biases, and the cross-sectional design limits the ability to infer causality.
To enhance the general applicability of the results, future studies should include larger and more diverse populations. Additionally, longitudinal studies could provide deeper insights into the long-term effects of CVD on diving safety.

In conclusion, this thesis has illuminated the significant health challenges and risks faced by divers with pre-existing cardiovascular diseases. By examining the self-reported symptoms, it has become evident that the unique physiological demands of diving can exacerbate cardiovascular conditions, leading to increased health risks. Due to a lack of awareness of risks, it is crucial to emphasise the necessity of education, regular health assessments, and tailored medical advice to ensure the safety and well-being of divers with pre-existing CVD.

As the popularity of scuba diving continues to grow and the average age of divers rises, it is crucial to address these health concerns through comprehensive research and the development of tailored safety guidelines.

These efforts might help promote a safer diving environment and enhance the overall diving experience for individuals with cardiovascular diseases, ultimately supporting the growth and sustainability of this popular recreational sport.

11. Summary

This study investigates the health and self-reported symptoms of divers with pre-existing cardiovascular diseases (CVD). With the increasing popularity of scuba diving and the aging population of divers, understanding the relationship between CVD and diving-related injuries is crucial. The research includes a survey of divers to assess symptoms experienced during or after diving, the impact of cardiovascular medications, and divers' awareness of associated risks. Findings reveal that divers with CVD face significant challenges, including breathlessness, fatigue, and dizziness, potentially exacerbated by the underwater environment. Despite the risks, many divers are not adequately informed about the interaction between their medications and diving. This highlights the need for comprehensive education and regular health assessments to ensure diving safety and health management for individuals with CVD.

Keywords: scuba diving, cardiovascular diseases, diver health, diving safety

References

1. National Geographic. Jacques Cousteau Centennial: What He Did, Why He Matters [Internet]. Washington, D.C.: National Geographic Society; 2024 [cited 2024 May 14]. Available from: https://web.archive.org/web/20100614064724/http://news.nationalgeographic.com/news/2010/06/100611-jacques-cousteau-100th-anniversary-birthday-legacy-google

2. Divers Alert Network. Participation in Recreational Scuba Diving [Internet]. Durham (NC): Divers Alert Network; 2024 [cited 2024 May 14]. Available from: https://dan.org/safety-prevention/diver-safety/divers-blog/participation-in-recreational-scuba-diving/

3. Strauss MB, Busch JA, Miller SS. Scuba in older-aged divers. Undersea Hyperb Med. 2017;44(1):45-55.

4. Roth GA, Mensah GA, Johnson CO, Addolorato G, Ammirati E, Baddour LM, et al. Global Burden of Cardiovascular Diseases and Risk Factors, 1990-2019: Update From the GBD 2019 Study. J Am Coll Cardiol. 2020 Dec 22;76(25):2982–3021.

5. Penrice D, Cooper JS. Diving Casualties. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 May 14]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK459389/

6. Divers Alert Network. Annual Diving Report 2020 [Internet]. Durham (NC): Divers Alert Network; 2020 [cited 2024 May 14]. Available from: https://issuu.com/dansouthernafrica/docs/annualdivingreport2020

7. Buzzacott P, Denoble PJ, editors. DAN Annual Diving Report 2018 Edition: A Report on 2016 Diving Fatalities, Injuries, and Incidents [Internet]. Durham (NC): Divers Alert Network; 2018 [cited 2024 May 14]. (Divers Alert Network Annual Diving Reports). Available from: http://www.ncbi.nlm.nih.gov/books/NBK540490/

8. Tso JV, Powers JM, Kim JH. Cardiovascular considerations for scuba divers. Heart. 2022;108(14):1084-9.

9. Bove AA. Diving medicine. Am J Respir Crit Care Med. 2014 Jun 15;189(12):1479–86.

10. Raymond KA, Cooper JS. Scuba Diving Physiology. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 May 14]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK441837/

11. Human Kinetics. Understand the physics of SCUBA diving [Internet]. [cited 2024 May 14]. Available from: https://us.humankinetics.com/blogs/excerpt/understand-the-physics-of-scuba-diving

12. Bosco G, Rizzato A, Moon RE, Camporesi EM. Environmental Physiology and Diving Medicine. Front Psychol [Internet]. 2018 Feb 2 [cited 2024 May 14];9. Available from: https://www.frontiersin.org/articles/10.3389/fpsyg.2018.00072/full

13. Reeves RB, Morin RA. Pressure increases oxygen affinity of whole blood and erythrocyte suspensions. J Appl Physiol. 1986 Aug;61(2):486–94.

14. Pendergast DR, Moon RE, Krasney JJ, Held HE, Zamparo P. Human Physiology in an Aquatic Environment. In: Comprehensive Physiology [Internet]. John Wiley & Sons, Ltd; 2015 [cited 2024 May 14]. p. 1705–50. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/cphy.c140018

15. The Diver Clinic. Diving gas laws [Internet]. 2015 [cited 2024 May 14]. Available from: https://www.thediverclinic.com/diving-gas-laws.html/

16. U.S. Geological Survey. Water Density [Internet]. [cited 2024 May 14]. Available from: https://www.usgs.gov/special-topics/water-science-school/science/water-density

17. Godek D, Freeman AM. Physiology, Diving Reflex. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 [cited 2024 May 14]. Available from: http://www.ncbi.nlm.nih.gov/books/NBK538245/

18. Noh Y, Posada-Quintero HF, Bai Y, White J, Florian JP, Brink PR, et al. Effect of Shallow and Deep SCUBA Dives on Heart Rate Variability. Front Physiol [Internet]. 2018 Feb 27 [cited 2024 May 14];9. Available from: https://www.frontiersin.org/articles/10.3389/fphys.2018.00110/full

19. Shah M, Shah A. Bradycardia induced ventricular fibrillation with obstructive sleep apnea. J Am Coll Cardiol. 2019 Mar 12;73(9_Supplement_1):2661–2661.

20. Lindholm P, Lundgren CEG. The physiology and pathophysiology of human breath-hold diving. J Appl Physiol (1985). 2009;106(1):284-92.

21. Kauling RM, Rienks R, Cuypers JAAE, Jorstad HT, Roos-Hesselink JW. SCUBA Diving in Adult Congenital Heart Disease. J Cardiovasc Dev Dis. 2023 Jan;10(1):20.

22. Sideris DA, Pappas S, Siongas K, Grekas G, Argyri-Greka O, Koundouris E, et al. Effect of preload and afterload on ventricular arrhythmogenesis. J Electrocardiol. 1995 Apr;28(2):147–52.

23. Gooden BA. Mechanism of the human diving response. Integr Physiol Behav Sci. 1994;29(1):6-16.

24. Research I of M (US) C on MN, Marriott BM, Carlson SJ. Physiology of Cold Exposure. In: Nutritional Needs In Cold And In High-Altitude Environments: Applications for Military Personnel in Field Operations [Internet]. National Academies Press (US); 1996 [cited 2024 May 14]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK232852/

25. Fan JF, Xiao YC, Feng YF, Niu LY, Tan X, Sun JC, et al. A systematic review and meta-analysis of cold exposure and cardiovascular disease outcomes. Front Cardiovasc Med. 2023 Mar 27;10:1084611.

26. Westerweel PE, Rienks R, Sakr A, Taher A. Diving with hypertension and antihypertensive drugs. Diving Hyperb Med. 2020 Mar 31;50(1):49–53.

27. Kaplan NM, Gidding SS, Pickering TG, Wright JT. Task Force 5: systemic hypertension. J Am Coll Cardiol. 2005 Apr 19;45(8):1346–8.

28. Peacher DF, Martina SD, Otteni CE, Wester TE, Potter JF, Moon RE. Immersion pulmonary edema and comorbidities: case series and updated review. Med Sci Sports Exerc. 2015 Jun;47(6):1128–34.

Curriculum Vitae

Alistair George Powell was born in Hamburg, Germany, on November 26th, 1997. Alistair started diving at the age of eight and advanced up the certification ladder to Master Scuba Diver by the age of 14. After finishing his Abitur in 2016, Alistair pursued his passion for diving further by moving to Mexico and obtaining his instructor-level PADI Master Scuba Diver Trainer (MSDT) rating. After receiving his MSDT, he moved to the Maldives, where he worked as a managerial-level diving instructor at the St. Regis Vommuli resort for one year. After this, he followed his long-term goal of studying medicine and enrolled at the University of Rijeka, Faculty of Medicine, in 2018.

During his time at the faculty of medicine, he was part of the organising committee for Diving Medicine Summer School, was the president of the Student Section for Diving and Hyperbaric Medicine, received the scholarship for excellence five years in a row, and received the Dean's Award for Academic Excellence.

Alistair aspires to specialise in internal medicine, emergency medicine and intensive care medicine in his hometown of Hamburg.

Appendix

Survey used for collecting data.