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Diving and long-term cardiovascular health

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Background Short-term cardiovascular effects from ambient pressure exposure are known. However, long-term cardiovascular effects from diving in humans have been less studied.

Aims To examine possible long-term cardiovascular health effects from occupational diving.

Methods We compared the prevalence of cardiovascular disease in former divers to non-divers. We obtained data on male former divers with a certificate valid for professional diving after 1980, from the Norwegian Diver 2011 project, and matched data on the general male population from the HUNT3 Survey. We also compared former divers with high and low grades of diving exposure.

Results Data were available on 768 former divers. The prevalence of self-reported high blood pressure in former divers who often omitted a dive-free day after 3 days of strenuous diving was 28% compared with 18% in those who rarely violated these regulations [relative risk (RR) 1.47, confidence interval (CI) 1.01–2.15]. Also, the prevalence of myocardial infarction/angina pectoris was 11% in divers with >150 professional dives/year compared with 4% in divers with ≤50 professional dives/year [RR adj. 2.91 (CI 1.23–6.87)] and 16% in divers with >2000 air dives in total relative to 3% in divers with ≤2000 dives [RR adj. 3.05 (CI 1.47–6.34)].

Conclusions The prevalence of some cardiovascular symptoms and diseases may be higher in male former divers than in the general population. Diving might have adverse long-term cardiovascular effects. Whether this is associated with diving per se or strenuous physical activity requires further studies.

Key words Cardiovascular disease; dive-free day; diving; long-term effects; the HUNT3 Survey; the Norwegian Diver 2011 project.

Introduction

Commercial divers do important underwater work in the offshore and inshore industry. Diving operations are technically complex, and the underwater environment poses a high risk of fatal or near miss accidents. Divers are exposed to increased ambient pressure, variable depths up to >150 m of sea water, sea states from calm to several metres high waves, gale force winds, currents and a wide range of temperatures. Short-term adverse cardiovascular effects of diving in humans have been shown [1], but there are no studies on the long-term effects.

Increased ambient pressure is associated with negative effects on endothelial function, possibly due to exposure to hyperoxia and the formation of vascular bubbles. In sea dives, this effect could be increased by the physiological stress of immersion [1]. Immersion alone leads to central blood pooling and increased cardiac preload, aggravated by cold water [2], an effect seen in humans at only 1–2°C below normal core temperature. This might explain the mechanism of pulmonary oedema in some 'self-contained underwater breathing apparatus' (SCUBA) divers [3].

Long-term cardiovascular effects are less studied. A study of 35–45-year-old divers and policemen did not show any differences in heart function [4]. Another study showed slightly increased right ventricular cavities in SCUBA divers compared with controls [5]. A study of rats showed necrotic areas in the left ventricle, including higher left ventricular mass and indications of subvalvular aortic stenosis, after multiple pressure exposures [6].

A Norwegian register-based study showed a lower mortality in professional divers compared with the general population. However, the mortality of highly exposed divers was similar to the general population. This is considered a notable result, as divers are thought to have better health than the general population [7]. However, a Swedish cohort study showed a higher mortality in professional divers compared with the general population, with ischaemic heart disease causing most of the excess mortality rate. The study drew no conclusions about the explanation for this finding [8].

The aim of this study was to explore possible long-term cardiovascular health effects from diving in former occupational (FO) divers, by comparing prevalences of several cardiovascular symptoms and diseases, in FO divers to the general population, and in FO divers with different grades of diving exposure.

Methods

We used existing questionnaires from the Norwegian Diver 2011 project [9] and the HUNT3 Survey [10–12]. All participants gave written consent. Both studies, and this one, received ethical approval from regional committees for medical and health research ethics in Norway (REK) [9,13].

We used data on divers with a certificate valid for professional diving after 1980, from the Norwegian Diver 2011 project by the Norwegian Centre for Diving Medicine [9], and participants from the HUNT3 Survey (a longitudinal population health study in Norway) as controls (non-divers) (93 860 were invited to the study) [10].

We constructed four variables to compare data on myocardial infarction and/or angina pectoris, self-reported high blood pressure, breathlessness or heart failure and stroke or brain haemorrhage in divers and non-divers. We tried to find question formulations as similar as possible from the Norwegian Diver 2011 project and the HUNT3 Survey. However, there are some differences concerning self-reported high blood pressure and breathlessness or heart failure: divers = self-reported treated and non-treated high blood pressure; non-divers = self-reported treated high blood pressure only. Divers = breathlessness while walking on flat ground, more breathlessness than people at the same age while walking on flat ground and/or more breathlessness than people at the same age while walking uphill; non-divers = heart failure. Because of these differences, we also compared breathlessness in divers to any kind of attack of wheezing or breathlessness during the last 12 months in non-divers.

Both females and former or active occupational divers from the HUNT3 Survey were excluded (male cohort). As there are strict health requirements for diving, we set additional exclusion criteria to make the group of divers from the Norwegian Diver 2011 project and non-divers from the HUNT3 Survey as similar as possible (contraindication cohort). We set age and smoking criteria as these could influence outcomes. We included divers and non-divers aged between 50 and 79 years. We excluded current and previous smokers; non-divers (based on contraindications for diving [14]) with angina pectoris before 30 years of age (no divers under 30 years had myocardial infarction or angina pectoris) and non-divers with asthma, chronic bronchitis, emphysema or chronic obstructive pulmonary disease, type 1 diabetes, epilepsy or body mass index (BMI) >30.

As diving is a physical activity, and all divers in this project have or have had a certificate for professional diving, for non-divers who were still working, we included only those with a physically active job (work that requires much walking and lifting or heavy physical labour [15]). For those who did not work, we included only those with a former job that required them to work very hard (often or sometimes [16]).

We also compared male FO divers with high and low grades of diving exposure (both groups from the Norwegian Diver 2011 project). High grade of diving exposure is defined as a high certificate class, a long time of exposure (a high number of years from start to cessation of diving), a high number of dives, a deep diving depth, strenuous diving (diving with variable depth, depth deeper than 30 m, bottom time leading to a decompression time >15 min, strenuous dives or being cold during decompression), often omitting a dive-free day after 3 days of strenuous diving and multiple dives after a strenuous dive.

For analysis, we used descriptive statistics and generalized linear models with binomial probability distribution and log as link function, providing relative risks (RRs) with 95% confidence intervals (CIs). We adjusted for smoking and age. We performed all statistical analyses with IBM SPSS version 21 [17].

Results

In the Norwegian Diver 2011 project [9], 2848 (49%) answered the questionnaire, 2663 (94%) of whom were male, 768 (29%) FO divers and 1669 (63%) still active occupational divers. Despite being qualified as occupational divers, some participants had mainly done recreational diving. In the Norwegian Diver 2011 project, 284 divers were excluded. A few returned an empty questionnaire since they did not consider themselves as occupational divers. For the rest, the right address could not be reached. As only 185 female divers (7%) returned the questionnaire, we excluded them.

In the HUNT3 Survey, 23 049 of 50 805 (50%) of respondents were male [10]. Of non-participants (female and male) who answered why they did not participate, 3790 did not have time, 1461 did not get the invitation, 252 said there were questions they did not want to answer, 250 were too ill to participate, 155 said they had no use of such studies, 82 said they did not believe in such studies and 1794 had other reasons not to participate [18].

FO divers who often omitted a dive-free day after 3 days of strenuous diving had a higher prevalence of self-reported high blood pressure than those who seldom violated these recommendations (Table 1). FO divers with a high relative to a low total number of professional dives or air dives had a higher prevalence of myocardial

Table 1. Prevalence of self-reported high blood pressure among male former divers (male cohort) (the Norwegian Diver 2011 project) by low and high grade of diving exposure, respectively

Diving exposure—self-reported high blood pressure					
Exposure	Low exposure, *n* (%)	High exposure, *n* (%)	Total number	RR (95% CI)	RR adj. (95% CI)
Certificate class (Low = I, high = II)	39 (21)	25 (25)	289	1.19 (0.77–1.85)	1.13 (0.73–1.74)
Total exposure time (years) (Low = 0–15, high = >30)	20 (17)	11 (36)	152	**2.15 (1.15–4.00)**	1.71 (0.90–3.26)
Professional dives (average number/year before 2005)	54 (24)	30 (28)	337	1.16 (0.79–1.71)	1.11 (0.76–1.61)
(Low = 0–50, high = >150)	13 (25)[a]	15 (33)[a]	99[a]		
Lowest regular depth (m)	48 (18)	52 (21)	524	1.16 (0.82–1.65)	1.18 (0.83–1.67)
(Low = 0–20, high = >20)	10 (19)[a]	16 (36)[a]	98[a]	1.96 (0.99–3.89)[a]	2.19 (0.89–5.41)[a]
Air dives (total number) (Low = 0–500, high = >500)	64 (17)	59 (23)	631	**1.39 (1.01–1.90)**	1.20 (0.87–1.65)
Nitrox dives (total number) (Low = 0–100, high = >100)	21 (18)	10 (21)	165	1.20 (0.61–2.34)	1.08 (0.55–2.12)
Gas mixture dives (total number) (Low = 0–100, high = >100)	14 (20)	16 (30)	124	1.48 (0.79–2.76)	1.55 (0.85–2.81)
Strenuous diving (before 2005) (Low = seldom, high = often)	61 (20)	34 (25)	435	1.25 (0.87–1.81)	1.09 (0.75–1.58)
No diving-free day after 3 days of strenuous diving (before 2005) (Low = seldom, high = often)	67 (18)	27 (28)	468	**1.58 (1.08–2.33)**	**1.47 (1.01–2.15)**
Multiple dives after a strenuous dive (before 2005) (Low = seldom, high = often)	70 (19)	14 (26)	415	1.31 (0.80–2.16)	1.08 (0.66–1.77)

Certification class I includes underwater work down to 50 m, and class II includes saturation diving in addition to underwater work down to 50 m. Strenuous diving is defined as diving with variable depths, depths deeper than 30 m, bottom time leading to a decompression time >15 min, strenuous dives or being cold during decompression. Bold values: significant results. RR adj. = RR adjusted for age and smoking.

[a]Contraindication cohort (male former divers ≥50 and <80 years, non-smokers) (the Norwegian Diver 2011 project). RR adj. = RR adjusted for age.

infarction/angina pectoris (Table 2). FO divers had a higher prevalence of self-reported high blood pressure (non-treated/treated versus treated) and breathlessness versus heart failure, than non-divers. However, the prevalence of stroke and/or brain haemorrhage, myocardial infarction and/or angina pectoris in FO divers was similar to non-divers (Table 3).

The prevalence of self-reported high blood pressure in FO divers with low diving exposure was 25% with a mean of 0–50 professional dives each year before 2005, 19% with a diving depth of 0–20 m and a mean of 19% in those who rarely had strenuous dives, who rarely omitted a dive-free day after 3 days of strenuous diving or who rarely had multiple dives after a strenuous dive. There was no difference for breathlessness versus heart failure between FO divers and active divers [RR adj. 2.04 (CI 1.00–4.17)] (Table 3).

Discussion

We found a higher prevalence of self-reported high blood pressure in FO divers who often omitted a dive-free day after 3 days of strenuous diving than those who seldom violated these recommendations, and a higher prevalence of myocardial infarction/angina pectoris in FO divers with a higher total number of dives. Our findings suggest a possible adverse impact on the cardiovascular system in FO divers. However, other subgroups of diving exposure did not seem to have any influence. FO divers had a higher prevalence of self-reported treated/non-treated high blood pressure than non-divers with self-reported treated high blood pressure (the HUNT3 Survey), which was similar to the prevalence of self-reported high blood pressure (both treated and non-treated) in FO divers with low grades of diving exposure (the Norwegian Diver 2011 project). We found no such difference between FO divers and non-divers in prevalence of myocardial infarction and/or angina pectoris nor stroke and/or brain haemorrhage.

The size and the wide range of information in the HUNT3 Survey data material makes a better matching control group possible (contraindication cohort), rather than the general population (male cohort). However, there may have been selection bias if some of the non-participants were too ill to participate. Also, FO divers could have quit due to health issues. Whether this would be related to diving is unclear. Small numbers could make the results in analysis of diving exposure

Table 2. The prevalence of myocardial infarction/angina pectoris among male former divers (male cohort) (the Norwegian Diver 2011 project) by low and high grade of diving exposure, respectively

Diving exposure—myocardial infarction/angina pectoris

Exposure	Low exposure, *n* (%)	High exposure, *n* (%)	Total number	RR (95% CI)	RR adj. (95% CI)
Certificate class (Low = I, high = II)	11 (6)	7 (7)	288	1.14 (0.46–2.86)	1.06 (0.43–2.65)
Total exposure time (years) (Low = 0–15, high = >15)	4 (3)	9 (7)	258	1.99 (0.63–6.29)	1.69 (0.55–5.21)
Professional dives (average number/year before 2005) (Low = 0–50, high = >150)	9 (4)	12 (11)	337	**2.79 (1.21–6.42)**	**2.91 (1.23–6.87)**
Lowest regular depth (m) (Low = 0–20, high = >20)	13 (5)	13 (5)	526	1.09 (0.51–2.30)	1.04 (0.50–2.16)
Air dives (total number) (Low = 0–2000, high = >2000)	19 (3)	10 (16)	632	**4.93 (2.40–10.11)**	**3.05 (1.47–6.34)**
Nitrox dives (total number) (Low = 0–100, high = >100)	4 (3)	5 (11)	164	Small numbers	Small numbers
Gas mixture dives (total number) (Low = 0–100, high = >100)	4 (6)	3 (6)	123	Small numbers	Small numbers
Strenuous diving (before 2005) (Low = seldom, high = sometimes/often)	10 (3)	25 (7)	676	2.02 (0.99–4.14)	1.71 (0.81–3.63)
No diving-free day after 3 days of strenuous diving (before 2005) (Low = seldom, high = sometimes/often)	15 (4)	16 (8)	579	1.93 (0.98–3.83)	1.58 (0.81–3.12)
Multiple dives after a strenuous dive (before 2005) (Low = seldom, high = sometimes/often)	15 (4)	17 (8)	581	1.86 (0.95–3.65)	1.50 (0.75–3.00)

Certification class I includes underwater work down to 50 m, and class II includes saturation diving in addition to underwater work down to 50 m. Strenuous diving is defined as diving with variable depths, depths deeper than 30 m, bottom time leading to a decompression time >15 min, strenuous dives or being cold during decompression. Bold values: significant results. RR adj. = RR adjusted for age and smoking.

Table 3. The prevalence of MI and/or AP among non-divers (the HUNT3 Survey)/former divers (the Norwegian Diver 2011 project); self-reported treated high BP among non-divers and self-reported treated/untreated high BP among former divers; MF among non-divers and breathlessness among former divers; breathlessness among active and former divers, respectively, and stroke and/or brain haemorrhage among non-divers/former divers

Cardiovascular disease

	MI/AP	BP	MF and breathlessness	Breathlessness	Stroke/brain haemorrhage
Active divers ref., *n* (%)				14 (8)	
Non-divers ref., *n* (%)	47 (5)	202 (21)	8 (1)		19 (2)
Former divers, *n* (%)	8 (6)	40 (30)	23 (17)	23 (17)	4 (3)
Total	1113	1113	1115	306	1113
RR (95% CI)	1.24 (0.60–2.57)	**1.44 (1.08–1.91)**	**20.70 (9.45–45.3)**	**2.05 (1.10–3.84)**	1.54 (0.53–4.45)
RR adj. (95% CI)	1.58 (0.77–3.25)	**1.68 (1.27–2.21)**	**22.87 (9.82–53.2)**	2.04 (1.00–4.17)	2.04 (0.71–5.88)

Inclusion criteria of active/former divers (the Norwegian Diver 2011 Project): male divers ≥50 and <80 years, non-smokers; inclusion criteria of non-divers (the HUNT3 Survey): males ≥50 and <80 years, non-smokers, physical active job (workers) or former job where hard work is required; exclusion criteria: professional divers, angina pectoris before 30 years of age, asthma, chronic bronchitis, emphysema or chronic obstructive pulmonary disease, type 1 diabetes, epilepsy, BMI >30 (contraindication cohort). Bold values: significant results. RR adj. = RR adjusted for age. AP, angina pectoris; BP, blood pressure; MF, myocardial failure; MI, myocardial infarction.

unreliable, particularly for diving with nitrox and mixed gases. Different questions in the Norwegian Diver 2011 project and the HUNT3 Survey could explain some of the differences in prevalence of self-reported high blood pressure. However, divers probably have low prevalence of self-reported high blood pressure as hypertension is a relative contraindication for diving [14,19]. Different questions might also explain the differences in the prevalence of breathlessness in FO divers and heart failure in non-divers. The questions about myocardial infarction/

angina pectoris and stroke/brain haemorrhage were similar in the Norwegian Diver 2011 project and the HUNT3 Survey. However, as the numbers were small, particularly for stroke/brain haemorrhage, these results should be interpreted with caution.

As no divers below 30 years of age reported angina pectoris, we set the age limit of onset of angina pectoris in non-divers at 30 years. As most divers quit diving at an older age, a higher age limit might have been more suitable. However, this exclusion would have directly affected the results. Exclusion of those with type 1 diabetes might be a simplification as insulin-requiring diabetes is contraindicated for divers [14]. FO divers could have an increased BMI after they quit diving, in spite of previous requirements of BMI. A Swedish study implied an increased mortality due to ischaemic heart disease in professional divers [8], while a study of 20 active divers compared with 20 policemen (35–45 years old) did not show any differences in heart function [4]. We studied former rather than active divers, as health could be the reason to end a diving career. Also, long-term cardiovascular health effects might appear after the age of 45. However, as we relied on subjective reporting rather than objective measurements, recall bias may have occurred.

Our results underline the importance of a dive-free day after strenuous diving and avoiding strenuous diving. We could not conclude from our findings whether symptoms and diseases reported by divers were due to diving per se or strenuous physical work. In exercise physiology, there is a hypothesis that excessive endurance exercise training can induce adverse cardiovascular effects in some individuals [20]. Other studies show no protection against, or even a higher risk of cardiovascular disease after strenuous physical work [21,22]. About 30% of athletes develop acute dilation of right-side cardiac chambers and right ventricle and ventricular septum dysfunction following a marathon. These cardiac changes restore in the post-race period. However, one hypothesis is that the risk of sudden cardiac death in extreme endurance athletes is related to repeated stretching of cardiac chambers, and some athletes might be prone to more chronic structural changes [23]. One can speculate that since the professional divers experience recurrent stretching of cardiovascular dimensions due to the effect of immersion, some of them might be prone to more chronic effects of these dimensional and structural changes of the heart. However, as far as we know, this has not been investigated and remains to be explored. Although diving is considered a physical activity, the symptoms and diseases reported by divers in this study could also be life-style related. We can only speculate on the mechanisms of our findings.

Further research into diving as a risk factor for cardiovascular disease is needed. It might be useful to study the time of onset of cardiovascular disease in former divers. Understanding the mechanisms of the cardiovascular effects of diving also requires further research.

Key points

- Diving might have adverse long-term cardiovascular effects.
- In this study former divers with a high rather than a low number of dives had a higher prevalence of myocardial infarction and/or angina pectoris.
- A dive-free day after strenuous diving and avoiding strenuous diving might have preventive health effects.

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Conflicts of interest

None declared.

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