Modelling the risk factors for accidents in recreational divers: results from a cross-sectional evaluation in Belgium

Kurt G Tournoy[1,2], Martijn Vandebotermet[3], Philippe Neuville[4], Peter Germonpré[5]

[1] *Ghent University, Faculty of Medicine and Life Sciences, Ghent, Belgium*
[2] *Department of Respiratory Medicine, Onze-Lieve-Vrouw Hospital Aalst, Belgium*
[3] *Department of Respiratory Medicine, General Hospital Groeninge, Kortrijk, Belgium*
[4] *General Physician, Ostend, Belgium*
[5] *Centre for Hyperbaric Oxygen Therapy, Military Hospital, Brussels, Belgium*

Corresponding author: *Kurt Tournoy, OLV-Aalst, Moorselbaan 164, 9300 Aalst, Belgium*
ORCiD: *0000-0003-4943-3782*
kurt.tournoy@ugent.be

Keywords
Diving incidents; Diving medicine; Diving research; ENT; Epidemiology; Fitness to dive; Health surveys

Abstract
(Tournoy KG, Vandebotermet M, Neuville P, Germonpré P. Modelling the risk factors for accidents in recreational divers: results from a cross-sectional evaluation in Belgium. Diving and Hyperbaric Medicine. 2024 20 December;54(4):287–295. doi: 10.28920/dhm54.4.287-295. PMID: 39675736.)
Introduction: Characterisation of the recreational diving community could help to identify scuba divers at risk for accidents.
Methods: We performed a cross-sectional evaluation in a federation for recreational scuba divers in Belgium (Duiken. Vlaanderen). Using binary logistic regression, factors predictive for accidents leading to hospitalisation were identified.
Results: Of the 710 members, 210 (29.6%) participated in the survey, representing 140,133 dives. Age was > 50 years in 55% and the median (interquartile range [IQR]) number of dives was 380 (IQR 140–935). Cardiac (9.5%), orthopaedic (11.0%), ear-nose-throat (ENT, 10.5%) and allergic diseases (30.5%) were the top four morbidities. Twenty percent reported taking cardiovascular medication. Decompression accidents, barotrauma of the ear and musculoskeletal injuries were reported in 11.0, 11.9 and 11.0%. Fifty-five divers (26.2%) reported incidents not necessitating a medical intervention. For 36 divers (17.1%), medical interventions were necessary. Among these, 13 divers (6.2%) were hospitalised at least once and 12 (5.7%) of these needed hyperbaric oxygen therapy (HBOT). The absolute risk for hospitalisation or HBOT was 0.01% per dive. Age, advanced diving qualification, more dives annually, cardiac or ENT pathology and cardiac medication were significantly associated with an increased likelihood of hospitalisation resulting from diving accidents. In a multivariate risk model, ENT comorbidity (odds ratio [OR] 9.3; $P = 0.006$) and cardiac medication (OR 5.6; $P = 0.05$) predicted hospitalisation due to a diving accident.
Conclusions: One in six recreational scuba divers required a medical intervention at least once during their career, while 6.2% were hospitalised or received HBOT. Ear nose and throat comorbidity and cardiac medication were strong predictors for accidents. These should be given sufficient weight in dive medical examination.

Introduction

Balancing with its appeal to explore underwater environments, scuba diving poses inherent risks, ranging from minor discomforts to life-threatening accidents.[1,2] Minor diving incidents to major accidents can result from various factors, including equipment failure and diver-related issues such as health status and experience level. In addition, environmental conditions such as colder waters, strong currents or poor visibility impose additional challenges to the diver.[3] Few studies exist that document diving-related injuries and individual risk factors within particular divers populations.[4–8] Understanding the characteristics of the diving community and the factors contributing to these risks is crucial for enhancing diver safety and guiding medical practitioners in their assessments and interventions.

Data on the risks of the recreational diving community in Belgium which is exposed to a specific blend of dive types, is lacking. Dives in the tidal North Sea and the Eastern Scheldt Estuary complement popular (fresh water) quarry explorations. Additionally, many engage in more classical 'holiday dives', often in tropical waters abroad. The literature is devoid of multivariate risk models weighing the relative importance of risk features in divers with or without a history of accidents. Fitness-to-dive assessments in Belgium are done primarily by general physicians, who most often lack formal diving medicine qualifications. Although guidelines and questionnaires to assess the fitness-to-dive do exist there is no information available on their adherence.[9] In addition, these guidelines do not necessarily account for particular risk factors that may be important for certain diver populations.

The aim of the current study was to identify predictors of serious diving-related outcomes, such as hospitalisation and the need for hyperbaric oxygen treatment (HBOT), by assessing divers' profiles, comorbidities, and accident reports in Flanders, Belgium. We wanted to measure the past and current adherence to questionnaire-based medical examinations when fitness to dive is evaluated. By aligning medical examination protocols with newly identified risks, we hope to support both divers and healthcare providers in promoting a safer diving environment.

Methods

An online questionnaire (Forms, Office 365 – Microsoft Corporation, Redmond, WA, USA) was presented to all members of the scuba dive clubs affiliated with 'Duiken. Vlaanderen', one of the diving federations in Belgium. Members had to provide informed consent before access was be given to the separate and anonymised questionnaire. The study was supervised by the independent juridical and ethical committee of the federation 'Duiken.Vlaanderen'. The invitation was sent three times to the divers between January and March 2024.

The questionnaire was developed by the medical committee of the federation to meet the objectives of this research project. The questionnaire comprised 86 questions. There were four parts to be completed: (i) general biometrics and diving history, (ii) general medical information with inquiries for comorbidities and medication, (iii) diving incidents and accidents and (iv) data on the fitness-to-dive medical examination. Participants were instructed to document their situation from the start of their diving career until the cut-off date of 1 January 2024. A 'diving incident' was defined as an unexpected or unusual event that occurs during a dive resulting in harm or injury to the diver, but without the necessity of a formal medical intervention and solved by the diver or his buddy. A 'diving accident' specifically refers to a situation resulting in harm ranging in severity from minor injuries to more serious situations such as decompression sickness or barotrauma, but always requiring professional medical intervention. The full questionnaire (available in Dutch due to the specific diving population) is available upon simple request to the corresponding author.

The anonymised data matrix was transferred as an Excel file to SPSS 28.0 (IBM Corp. Released 2021. IBM SPSS Statistics for Windows, Version 28.0. Armonk, NY: IBM Corp) for statistical analysis. Data are presented as medians (range and interquartile range [IQR]) for continuous variables and as numbers (frequencies) for categorical variables. To compare the frequencies and medians of selected variables in subgroups, Fisher's exact and Mann-Whitney U tests were used. To identify risk factors for diving accidents and hospitalisations due to diving accidents, a binary logistic regression model was constructed using those variables identified as significant in the univariate analysis. The model included a constant value, and the variables were included using the enter method. The Nagelkerke R square values were calculated to adjust the Cox and Snell measures providing a more interpretable metric of model fit (data not shown). Odds ratios (OR) with 95% confidence intervals (95% CI) were calculated. A significance level of $P < 0.05$ was adopted for all analyses.

Results

POPULATION CHARACTERISTICS

The recreational scuba federation 'Duiken.Vlaanderen' member count was 710 in January 2024 – date of the survey. Two-hundred fourteen members gave consent to participate to the survey (30.1%), but four (1.9%) had no diving experience other than in a pool. The clinical characteristics of the 210 divers are shown in Table 1. Age was over 50 in 55.2%, and 83.8% were males. A history of tobacco smoke exposure (either active, passive or former smoker, with the latter defined as having quit at least one year ago) was present in 41.9%. Among the respondents, 35.7% were diving instructors with a significant proportion engaging in more technical profiles: 53.8% were qualified for decompression or deep dives and 76.7% were trained for Nitrox diving. The median years of diving experience was 18 (IQR 8–28), the number of dives was 380 (IQR 140–935), with 23 (IQR 15–44) dives annually. A total of 140,133 logged scuba dives were reported in this survey.

COMORBIDITY AND MEDICATION USE

There were 80 divers (38.1%) reporting no morbidities. In Table 2, the self-reported morbidities of the other divers are listed, many having multiple comorbidities. Nine and a half percent of the respondents indicated they had been hospitalised or that they are receiving medical care or follow-up for cardiac diseases (mainly hypertension and cardiac arrhythmias). This was 10.5% for ear-nose-throat (ENT) problems and 30.5% for allergies. Musculoskeletal and rheumatic m respectively. Pulmonary diseases were reported in 3.3% (mainly asthma). There were no divers with a history of primary pneumothorax, but two reported a secondary pneumothorax. Of note, 98.1% of divers reported to have been vaccinated at least twice for COVID-19. Table 3 summarises the active medication profiles. The most frequent medications taken were cardiovascular in 20.0%, anti-allergic in 15.2% or pulmonary in 4.8%. Four divers (1.9%) were on anticancer drugs.

DIVING INCIDENTS AND ACCIDENTS

Fifty-five divers (26.2%) reported a total of 116 incidents related to scuba diving, not necessitating the intervention of a medical doctor. This translates into an absolute risk of 0.08% per dive (Table 4). One or more diving accidents necessitating medical interventions were reported by 36 (17.1%). There were 13 divers (6.2%) who reported at least one hospital admission because of a diving accident.

Table 1
Population characteristics of the study cohort; AOW – advanced open water; IQR – interquartile range; * vocational or higher education

Characteristic	*n* = 210
Age category, *n* (%)	
< 20 yr	5 (2.3)
21–30 yr	13 (6.2)
31–40 yr	25 (11.9)
41–50 yr	51 (24.3)
51–60 yr	72 (34.3)
61–70 yr	38 (18.1)
71–80 yr	6 (2.9)
Male, *n* (%)	176 (83.8)
Body mass index, kg·m^{-2} median (range; IQR)	27 (15–42; 24–30)
Education, *n* (%)	
Primary	2 (1.0)
Secondary	67 (31.9)
Postsecondary*	141 (67.1)
Smoking, *n* (%)	
Never	122 (58.1)
Passive	11 (5.2)
Active	17 (8.1)
Ex-smoker	60 (28.6)
Diver qualification, *n* (%)	
Candidate	4 (1.9)
D1 (Open water)	14 (6.7)
D2 (AOW)	41 (19.5)
D3 (Master diver)	50 (23.8)
D4 (Rescue diver)	26 (12.4)
Instructor	75 (35.7)
Years of diving median (range; IQR)	18 (1–54; 8–28)
Outdoor dives median (range; IQR)	380 (1–4,386; 140–935)
Dives per year median (range; IQR)	23 (1–186; 15–44)
Specialties, *n* (%)	
Dry suit	108 (54.4)
Deep / decompression	113 (53.8)
Nitrox diving	161 (76.7)

Table 3
Medications used by subjects in the study cohort; *includes blood pressure medication, anticoagulants and antiplatelet agents including low dose aspirin, lipid lowering drugs, anti-arrythmia medication; **inhalers

Medications in 210 subjects	*n* (%)
Cardiac medication*	42 (20.0)
Anti-allergy medication	32 (15.2)
Pulmonary medication**	10 (4.8)
Diabetes medication	6 (2.9)
Neuropsychiatric medication	5 (2.4)
Cancer therapy	4 (1.9)

Table 2
Comorbidity burden among subjects in the study cohort; COPD – chronic obstructive pulmonary disease; * with or without stent or prior coronary bypass grafting

Comorbidities in 210 subjects	*n* (%)
Cardiac diseases	20 (9.5)
High blood pressure	10 (4.8)
Cardiac arrythmia	8 (3.8)
Pacemaker or defibrillator	0 (0)
Myocardial infarction*	0 (0)
Valvular disease	2 (1.0)
Other cardiac diseases	4 (1.9)
Pulmonary diseases	7 (3.3)
Asthma	5 (2.4)
COPD	0 (0)
Thoracic surgery	1 (0.5)
Other pulmonary diseases	1 (0.5)
ENT diseases	22 (10.5)
Kidney diseases	2 (1.0)
Gastro-intestinal disease	6 (2.9)
Diabetes	6 (2.9)
Rheumatic diseases	17 (8.1)
Neurologic diseases	4 (1.9)
Psychiatric diseases	4 (1.9)
Oncologic diseases	10 (4.8)
Orthopaedic diseases	23 (11.0)
Lower back problems	9 (4.3)
Back surgery	8 (3.8)
Arthrosis	9 (4.3)
Prosthesis	7 (3.3)
Allergies	64 (30.5)
Claustrophobia	5 (2.4)
COVID	
Vaccinated (at least 2 vaccines)	206 (98.1)
At least one positive COVID test	140 (66.7)
Hospitalised due to COVID	1 (0.5)
Other pathologies	31 (14.8)

Twelve of these were treated with HBOT. There were 24 divers (11.4%) who sought emergency medical help, but without subsequent HBOT or hospitalisation (one of these divers also reported hospitalisation on another occasion). Decompression sickness, middle ear barotrauma and orthopaedic events were reported in 11.0, 11.9 and 11.0% respectively. The absolute risk for hospitalisation due to diving accidents in this cohort was 0.01% per dive. Two divers suffered from severe permanent health issues resulting from their diving accident (1.0% of the divers' population).

RISK ASSESSMENT FOR DIVING ACCIDENTS WITH HOSPITALISATION

We conducted a risk assessment for the divers reporting to have been hospitalised due to a diving accident, regardless of the need for HBOT. There were 13 divers reporting a total of 18 hospitalisations (Table 4).

Table 4

Diving incidents and accidents among subjects in the study cohort; MD – medical doctor; * twelve divers had accidents necessitating hyperbaric oxygen treatment (HBOT). A total of 15 accidents necessitating HBOT were recorded (some divers had more than one accident); ** there were 24 divers seeking medical help without hospitalisation, three of them had two medical contacts, and one of these divers also reported being hospitalised because of a diving accident on separate occasions explaining why the total number of divers with at least one accident was 36; # 15/140,133 equals an absolute risk of 10.7/100,000 dives for requiring HBOT (see discussion)

Scuba diving events	210 divers *n* (%)	140,133 dives *n* (%)
Diving incidents (without MD consult)	55 (26.2)	116 (0.08)
Diving accidents (with MD consult)		
Hospitalisation (with or without HBOT)*	13 (6.2)	18 (0.01)#
No hospitalisation**	24 (11.4)	27 (0.02)
Diving incidents and accidents		
Decompression event	23 (11.0)	–
Barotrauma ear	25 (11.9)	–
Orthopaedic events	23 (11.0)	–
Recovery characteristics		
Major health issues remaining	2 (1.0)	–
Minor health issues remaining	5 (2.4)	–

Table 5

Characteristics of the study cohort stratified by those hospitalised and not hospitalised; IQR – interquartile range; * vocational or higher education; ** see Table 1 for diver qualification classifications

Characteristic	Not hospitalised *n* = 197	Hospitalised *n* = 13	*P*-value
Age category, *n* (%)			
< 50 years	92 (46.7)	2 (15.4)	0.04
≥ 50 years	105 (53.3)	11 (84.6)	
Sex, *n* (%)			
Male	165 (83.8)	11 (84.6)	ns
Female	32 (16.2)	2 (15.4)	
Body mass index, $kg \cdot m^{-2}$	27	28	ns
median (range; IQR)	(15–42; 24–29)	(19–35; 25–32)	
Education, *n* (%)			
Primary or secondary	63 (32.0)	6 (46.2)	ns
Postsecondary*	134 (68.0)	7 (53.8)	
Smoking, *n* (%)			
Never	117 (59.4)	5 (38.5)	ns
Active, passive or ex	80 (40.6)	8 (61.5)	
Diver qualification, *n* (%)			
Candidate D3**	108 (54.8)	1 (7.7)	< 0.001
D4 → Instructor	89 (45.2)	12 (92.3)	
Dives per year,	21	48	< 0.001
median (range; IQR)	(1–122; 14–42)	(41–186; 43–77)	
Specialties, *n* (%)			
Dry suit	97 (49.2)	11 (84.6)	0.02
Deep / decompression	101 (51.3)	12 (92.3)	0.004
Nitrox diving	148 (75.1)	13 (100)	0.04

Hospital admissions were predominantly for HBOT. In Tables 5–7, the characteristics of these divers are compared to those divers that were never hospitalised due to diving accidents. As shown in Table 5, divers with accidents necessitating hospitalisation were older (> 50 years, $P = 0.04$), had a higher-level diver qualification ($P < 0.001$) and in addition did more dives per year (48 versus 21, $P < 0.001$). In Table 6, the burden of comorbidities is compared. Divers with accidents necessitating hospitalisation had significantly more cardiac diseases (30.8% vs 8.1%, $P = 0.03$) or ENT pathology (38.5% vs 8.6%, $P = 0.006$). The medication use of the divers with

Table 6
Comorbidities among the study cohort stratified by those hospitalised and not hospitalised; ENT – ear nose and throat conditions; * if total count of patients with a comorbidity was ≤ five, the factor was not tested

Comorbidity	Not hospitalised, *n* = 197 *n* (%)	Hospitalised, *n* = 13 *n* (%)	*P*-value*
Cardiac diseases, High blood pressure	16 (8.1) 6 (3.0)	4 (30.8) 4 (30.8)	0.03 0.002
Pulmonary diseases Asthma	6 (3.0) 4 (2.0)	1 (7.7) 1 (7.7)	ns ns
ENT diseases	17 (8.6)	5 (38.5)	0.006
Gastro-intestinal diseases	6 (3.0)	0 (0)	ns
Diabetes	6 (3.0)	0 (0)	ns
Rheumatic diseases	14 (7.1)	3 (23.1)	ns
Cancer	9 (4.6)	1 (7.7)	ns
Orthopedic diseases Lower back problems Back surgery Arthrosis Prosthesis	22 (11.2) 8 (4.1) 7 (3.6) 8 (4.1) 6 (3.0)	1 (7.7) 1 (7.7) 1 (7.7) 1 (7.7) 1 (7.7)	ns ns ns ns ns
Allergies	60 (30.5)	4 (30.8)	ns
Claustrophobia	5 (2.5)	0 (0)	ns

Table 7
Use of medications among the study cohort stratified by those hospitalised and not hospitalised; * if total count of patients with a comorbidity was ≤ five, the factor was not tested; ** includes blood pressure medication, anticoagulants and antiplatelet agents including low dose aspirin, lipid lowering drugs, anti-arrythmia medication; *** inhalers

Medications	Not hospitalised, *n* = 197 *n* (%)	Hospitalised, *n* = 13 *n* (%)	*P*-value*
Cardiac medication**	35 (17.8)	7 (53.8)	0.005
Pulmonary medication***	9 (4.6)	1 (7.7)	ns
Diabetes medication	6 (3.0)	0 (0)	ns
Anti-allergy medication	30 (15.2)	2 (15.4)	ns
Neuropsychiatric medication	5 (2.5)	0 (0)	ns

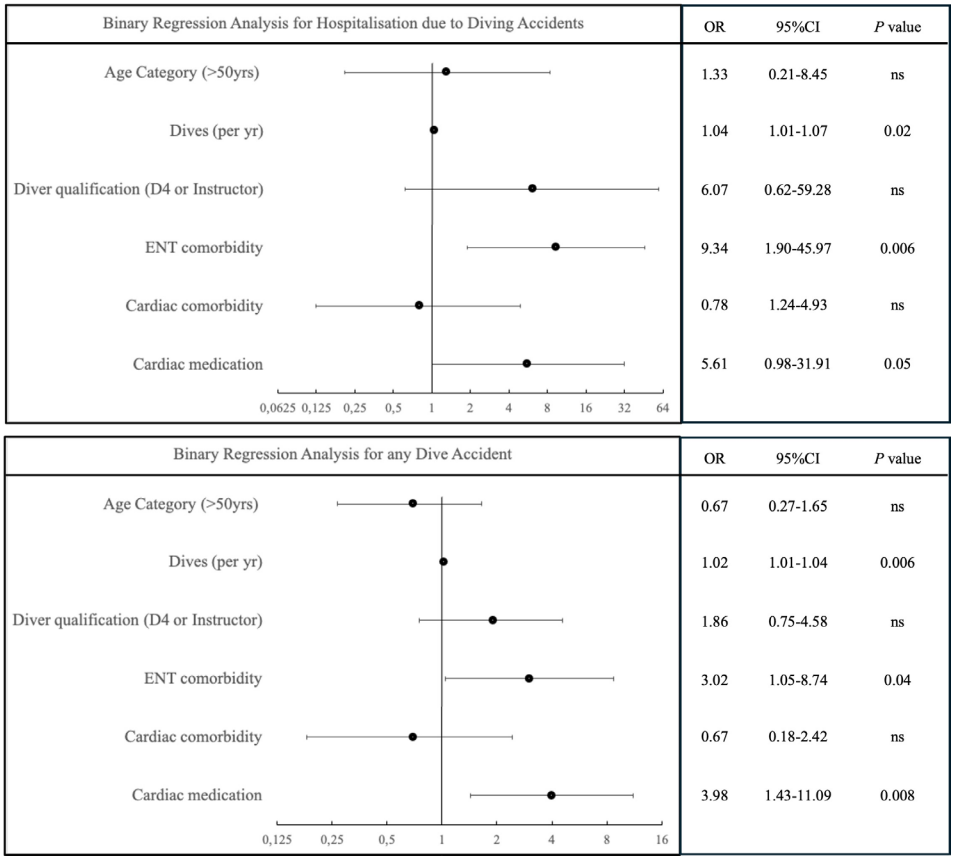
accidents necessitating hospitalisation is shown in Table 7. Those hospitalised for an accident were more likely to take cardiac medication (53.8% versus 17.8%, $P = 0.005$).

Based on the factors identified above, a binary multivariate logistic regression model was constructed to model the risk for a severe diving accident in the studied cohort. We selected age category, diving qualification (D4 or instructor vs all lower qualifications), number of dives per year, cardiac or ENT comorbidities and the regular use of cardiac medication as risk factors of interest. A forest plot is shown modelling the risk for 'any diving accident' (Figure 1 – lower panel) or a 'diving accident necessitating hospitalisation' (Figure 1 – upper panel). The OR for an accident leading to hospitalisation of the diver (with or without HBOT) was 9.34 (95% CI 1.90–45.97, $P = 0.006$) and 5.61 (95% CI 0.98–31.91, $P = 0.05$) if there was ENT comorbidity and if any cardiac medication was taken respectively. The OR for any dive accident leading to an urgent medical intervention was 3.02 (95% CI 1.05–8.74, $P = 0.04$) and 3.98 (1.43–11.09, $P = 0.008$) in case of ENT comorbidity or if cardiac medication was taken respectively. The number of dives per year is also significantly correlated (although the OR is close to 1) while age and diver qualifications are not.

DIVING MEDICAL EXAMINATIONS: EXPERIENCES AND PREFERENCES

Table 8 shows the medical examinations the scuba divers underwent. During the initial diving medical examination, targeted questionnaires were frequently used (58.1%), along with ECG (53.8%), ergometry (29.0%), thoracic imaging (9.0%), and spirometry (52.4%). In subsequent consultations, there is a trend towards less use of questionnaires and technical investigations. In 52.6% of those older than 50 years, an ergometry was performed in the last three years. In at least 76.7%, the diver estimated the knowledge of the medical doctor as appropriate; but at least 12.9% did not think their medical examiner was competent for diving medicine. Gauging the preference of divers about the way

Figure 1
Risk model for dive accidents; the lower panel pertains to 'any diving accident' and the upper panel pertains to a 'diving accident necessitating hospitalisation'



a medical examination should be performed, a minority (5.7%) indicated that systematic medical screening is not useful. The majority (61.4%) believed the combination of a questionnaire plus a doctors' visit, and ergometry in those aged at least 45 years, is appropriate. Two thirds prefered to have a yearly medical examination, while one in four indicated a two-yearly medical examination would be sufficient.

Discussion

The most important finding of our study is that one in six divers of the evaluated group reports to have needed professional medical help because of a diving related injury during their diving career. The presence of ENT comorbidities and the regular intake of cardiovascular medications were strongly associated with an increased risk of hospitalisation among Belgian divers.

Analyses of several recreational diving communities and their diving-related injuries is of utmost relevance to understanding and mitigating the risk factors. Not surprisingly, the identification of risk factors differs depending on the characteristics of the population, but also on the types of diving performed. These probably explain why risk factors for diving related injuries appear inconsistent across studies.[5,7,10,11] For example, age appears to be a risk factor for diving injuries in some studies[10] while it is a protective factor in others.[5–7]

Our study population can be considered 'old' (55% were aged 50 or older), 'male' (84%) with a considerable fraction (> 35%) of active smokers or former tobacco smoke exposure. They are apparently experienced divers (median 380 dives, 18 years of diving, and 36% were dive instructors). Only thirty-eight percent of respondents reported no comorbidities necessitating regular medical follow-up, which indicates comorbidities are prevalent in the studied population. We found that orthopaedic problems, cardiac diseases (mainly hypertension), ENT problems and allergies were the top four self-reported health issues for which the divers were followed-up regularly by a medical doctor. Lower back pain seems prevalent in divers and was related to higher weight belt loading.[12] In a recent review by Westerweel et al. it was reported that depending on the series, 12–33% of divers are reported to be hypertensive.[13] In our survey, we found that only 5% reported being followed-up by a medical specialist because of hypertension, however 20% did take medication related to the cardiovascular system. This was more than the 10% reported in a United Kingdom study[14] but lower than the 28% found in a Dutch study.[4] It has been suggested that the use of cardiac related medication in divers could be an

Table 8
Medical examinations undergone by the study cohort and related opinions and preferences; CT – computed tomography; ergo – ergometry; MD – medical doctor

Parameter	Initial examination *n* (%)	Last examination *n* (%)
Diving medical examination		
Consult with questionnaire	122 (58.1)	87 (41.4)
Consult without questionnaire	79 (37.6)	106 (50.5)
No consult	9 (4.3)	17 (8.1)
Tests administered during consult		
Clinical exam	192 (91.4)	177 (84.3)
Electrocardiogram	113 (53.8)	64 (30.5)
Ergometry	61 (29.0)	43 (20.5)
Spirometry	110 (52.4)	88 (41.9)
X-ray or CT scan of the chest	19 (9.0)	11 (5.2)
Ergometry in divers over 50 years	–	61/116 (52.6)
Appreciation of MD knowledge		
Good	79 (37.6)	–
Basic	82 (39.0)	–
Insufficient	27 (12.9)	–
Don't know / prefers not to tell	22 (10.5)	–
Divers' preferences initial medical exam		
Not necessary	1 (0.5)	–
Questionnaire + MD if abnormal	11 (5.2)	–
Questionnaire + MD always	59 (28.1)	–
Questionnaire + MD + ergo if ≥ 45 yr	129 (61.4)	–
None of the above	10 (4.8)	–
Divers' preferences follow-up exam		
Not necessary	–	5 (2.4)
Yearly	–	140 (66.7)
Two-yearly	–	52 (24.8)
Three-yearly	–	11 (5.2)
None of the above	–	2 (1.0)

argument for a more rigorous medical screening.[15] Problems with the upper airways and allergies necessitating regular medical contacts were quite prevalent in our population, a finding that was consistent with another report.[4]

The current survey evaluated self-reported diving-related incidents and accidents. Not surprisingly, the number of incidents largely exceeded that of accidents, the latter necessitating professional medical intervention. At the individual level, we found that one in six had needed at least one episode of professional medical help because of an acute diving-related injury. Although this seemed a very high number, it needs to be interpreted in the context of the high number of diving years (almost 4,000) or absolute number of dives (over 140,000) in our study population. In a Divers Alert Network (DAN) study there were 5.7 decompression accidents requiring HBOT per 100,000 dives.[5] In the current study, we found a higher figure: 10.7 per 100,000 dives. The absolute risk for permanent severe physical harm after a diving accident was 1% – a figure that compares to earlier reports describing severe residual symptoms in eight out of 799 divers.[7]

By identifying specific health conditions and behaviours that increase the risk of diving accidents, we can offer better recommendations for individual medical evaluations and interventions.[6] We presumed that the most accurate recordings would be those that caused hospitalisation (with or without HBOT). We therefore focused on those divers to construct a risk assessment model. In univariate analysis, we found that a higher age, a higher diver qualification and higher dive frequency as well as the presence of cardiac and ENT comorbidities and the regular use of cardiac medication all correlated with the risk for a diving accident with hospitalisation. Body mass index (BMI), sex or smoking behaviour did not. These findings differ with those of Ranapurwala et al. who found that greater age, more annual dives and higher certification levels were associated with less self-reported decompression symptoms.[5] Notably, their survey did not assess the risk of hospitalisation.

Multivariate risk models are however more relevant for estimating the risk for a diving accident. They account for the complexity and interplay of multiple factors simultaneously and provide a nuanced risk estimation. This leads to more

reliable and valid risk predictions, which are essential for making informed decisions and a more personalised risk management. Our binary logistic multivariate analysis reveals that the presence of ENT pathology and the use of cardiovascular medication indicate an increased risk for more severe diving accidents resulting in hospitalisation, while age or diver qualification no longer appear to be significant factors. Here, the question arises as to whether the influence of cardiovascular medication is explained by the role of beta-blockers and diuretics (commonly used antihypertensives) in the development of diving accidents such as decompression sickness and immersion pulmonary oedema.[13] A higher number of dives per year is also a significant factor, however, with a hazard ratio of 1.02 and 1.04 for any accident and for hospitalisation respectively, it cannot be seen as clinically relevant. To the best of our knowledge, this is the first integrated analysis of combined risk factors in a particular diver population and provides useful information to guide risk assessments and fitness of dive examinations.

We assessed how the current study population was evaluated for their first and last medical examinations. One in eight divers expressed concerns regarding the medical examiners' expertise during the fitness-to-dive evaluation, a concerning statistic. Standardised questionnaires as recommended by the Undersea and Hyperbaric Medical Society (UHMS) were used in less than 60%. This indicates there is room for teaching and standardisation.[9] It could be of help to indicate the websites where these questionnaires can be found on the medical cards issued by the dive federations. A wide range of medical tests was used with the majority of those done during the first-time medical exams. It is clear from the data that in daily practice, basic technical investigations such as electrocardiography or spirometry are not rigorously implemented.[16,17] The majority of participants endorsed the usefulness of a yearly medical investigation, preferably based on the use of a questionnaire, a clinical exam and an ergometry for those aged over 45 years. It has indeed been shown that the addition of a medical investigation on top of a questionnaire is more sensitive to detect those at risk for diving accidents.[18] A patient-centred approach, taking into account the risk-factors identified for the diving population the diver belongs to, and facilitating shared decision-making between divers and practitioners is always recommended to ensure an optimal assessment.[16]

The current analysis benefits from an adequate response rate to an online survey (30%) and the comprehensive evaluation of the participants' medical status, diving experience and accidents, enabling the development of a robust risk model. The fact that the analysis was done in one of the smaller diving federations in Belgium is subordinate. We argue the data are most probably of relevance for all recreational divers exposed to the blend of dives outlined in the methods. However, it is essential to emphasise certain issues that warrant cautious interpretation of the data. The diver sample exhibited selection bias, evidenced not only by a different distribution of dive qualifications compared to those who did not participate in the survey ($P < 0.001$, data not shown), but also by the fact that persons who terminated their membership after an accident were not considered. The impact of this bias on our conclusions is hard to estimate. The cross-sectional study design is subject to inherent limitations, including a notable risk of underreporting. The implication would be that the figures we report are even an underestimation of the reality. Comorbidities were defined as a medical problem that either led to hospitalisation or that still requires a regular medical follow-up. As a result, individual divers may incorrectly perceive some medical issues as not relevant. This may explain lower than expected values for cardiac comorbidities in comparison to the prevalence of cardiovascular medication use. An additional risk for underreporting, particularly for minor events, arises from considering a complete diving career spanning up to 54 years. Therefore, we focussed on severe accidents resulting in hospitalisation or HBOT, presuming that the likelihood of recall failure and underreporting would be reduced. However, this approach has the limitation of reducing the number of events available for risk factor analysis. Prospective data collection would effectively address these issues properly and appears to be a feasible approach.[11] Additionally, it could enable the evaluation of other potentially relevant variables, such as physical fitness, detailed diving profiles, geographical diving locations, and technical specifications of the diving equipment, which we didn't consider in this study.

Conclusions

By surveying a broad and diverse cohort of recreational divers in Belgium, we acquired valuable insights into common health issues and the frequency and characteristics of diving accidents. Our multivariate analysis identified cardiac medication and ENT disease as risk factors associated with dive accidents. These should require specific attention from healthcare professionals during medical evaluations. We suggest that similar studies be carried out in different settings as the identification of risk factors for dive accidents could improve fitness-to-dive assessments and contribute to overall dive safety.

References

1 Buzzacott PL. The epidemiology of injury in scuba diving. Med Sport Sci. 2012;58:57–79. doi:10.1159/000338582. PMID: 22824839.

2 Mitchell SJ, Bennett MH, Moon RE. Decompression sickness and arterial gas embolism. N Engl J Med. 2022;386:1254–64. doi: 10.1056/NEJMra2116554. PMID: 35353963.

3 Bove AA. Diving medicine. Am J Respir Crit Care Med. 2014;189:1479–86. doi: 10.1164/rccm.201309-1662CI. PMID: 24869752.

4 Komdeur P, Wingelaar TT, van Hulst RA. A survey on the health status of Dutch scuba diving instructors. Diving Hyperb Med. 2021;51:18–24. doi: 10.28920/dhm51.1.18-24. PMID: 33761537. PMCID: PMC8313785.

5 Ranapurwala SI, Bird N, Vaithiyanathan P, Denoble PJ. Scuba diving injuries among Divers Alert Network members 2010–2011. Diving Hyperb Med. 2014;44:79–85. PMID: 24986725. [cited 2024 Jun 20]. Available from: https://dhmjournal.com/images/IndividArticles/44June/Ranapurwala_dhm44.2.79-85.pdf.
6 Beckett A, Kordick MF. Risk factors for dive injury: a survey study. Res Sports Med. 2007;15:201–11. doi: 10.1080/15438620701526779. PMID: 17987508.
7 Monnot D, Michot T, Dugrenot E, Guerrero F, Lafère P. A survey of scuba diving-related injuries and outcomes among French recreational divers. Diving Hyperb Med. 2019;49:96–106. doi: 10.28920/dhm49.2.96-106. PMID: 31177515. PMCID: PMC6704004.
8 Lippmann J, Taylor D McD, Stevenson C, Williams J, Mitchell SJ. Diving with pre-existing medical conditions. Diving Hyperb Med. 2017;47:180–90. doi: 10.28920/dhm47.3.180-190. PMID: 28868599. PMCID: PMC6159622.
9 UHMS Diver Medical Screen Committee (DMSC). Recreational diving medical screening system; 2020. [cited 2024 July 21]. Available from: https://www.uhms.org/resources/featured-resources/recreational-diving-medical-screening-system.html.
10 Cialoni D, Pieri M, Balestra C, Marroni A. Dive risk factors, gas bubble formation, and decompression illness in recreational SCUBA diving: analysis of DAN Europe DSL Data Base. Front Psychol. 2017;8:1587. doi: 10.3389/fpsyg.2017.01587. PMID: 28974936. PMCID: PMC5610843.
11 Tuominen LJ, Sokolowski S, Lundell RV, Räisänen-Sokolowski AK. Decompression illness in Finnish technical divers: a follow-up study on incidence and self-treatment. Diving Hyperb Med. 2022;52:78–84. doi: 10.28920/dhm52.2.74-84. PMID: 35732278. PMCID: PMC9527095.
12 Knaepen K, Cumps E, Zinzen E, Meeusen R. Low-back problems in recreational self-contained underwater breathing apparatus divers: prevalence and specific risk factors. Ergonomics. 2009;52:461–73. doi: 10.1080/00140130802707766. PMID: 19401898.
13 Westerweel PE, Rienks R, Sakr A, Taher A. Diving with hypertension and antihypertensive drugs. Diving Hyperb Med. 2020;50:49–53. doi: 10.28920/dhm50.1.49-53. PMID: 32187618. PMCID: PMC7276276.
14 St Leger Dowse M, Cridge C, Smerdon G. The use of drugs by UK recreational divers: prescribed and over-the-counter medications. Diving Hyperb Med. 2011;41:16–21. PMID: 21560980. [cited 2024 Jun 20]. Available from: https://dhmjournal.com/images/IndividArticles/41March/StLegerDowse_dhm.41.1.16-21.pdf.
15 St Leger Dowse M, Waterman MK, Penny CE, Smerdon GR. Does self-certification reflect the cardiac health of UK sport divers? Diving Hyperb Med. 2015;45:184–9. PMID: 26415070. [cited 2024 Jun 20]. Available from: https://dhmjournal.com/images/IndividArticles/45Sept/StLegerDowse_45.3.184-189.pdf.
16 Tso JV, Powers JM, Kim JH. Cardiovascular considerations for scuba divers. Heart. 2022;108:1084–9. doi: 10.1136/heartjnl-2021-319601. PMID: 34670825. PMCID: PMC9018859.
17 British Thoracic Society Fitness to Dive Group. British Thoracic Society guidelines on respiratory aspects of fitness for diving. Thorax. 2003;58:3–13. doi: 10.1136/thorax.58.1.3. PMID: 12511710. PMCID: PMC1746450.
18 Meehan C, Bennett M. Medical assessment of fitness to dive – comparing a questionnaire and a medical interview-based approach. Diving Hyperb Med. 2010;40:119–24. PMID: 23111909. [cited 2024 Jun 20]. Available from: https://dhmjournal.com/images/IndividArticles/40Sept/Meehan_dhm.40.3.119-124.pdf.

Acknowledgements

The authors would like to express their gratitude to all respondents of the dive federation 'Duiken.Vlaanderen' for taking the time to complete the questionnaire, thereby contributing to the promotion of dive safety in Belgium. Additionally, we thank Jan De Baerdemaeker for the ICT support in the setup of the online questionnaire tool, and the board members of 'Duiken.Vlaanderen' for their support of this initiative.

Conflicts of interest and funding: nil

Submitted: 22 June 2024
Accepted after revision: 24 August 2024