Chain of events analysis in diving accidents treated by the Royal Netherlands Navy 1966–2023

Benjamin L Turner[1], Pieter-Jan AM van Ooij[1,2], Thijs T Wingelaar[1,3], Rob A van Hulst[3], Edwin L Endert[1], Paul Clarijs[1], Rigo Hoencamp[4,5,6]

[1] *Royal Netherlands Navy Diving and Submarine Medical Centre, Den Helder, The Netherlands*
[2] *Department of Respiratory Medicine, Amsterdam UMC, Location AMC, University of Amsterdam, Amsterdam, The Netherlands*
[3] *Department of Anesthesiology, Amsterdam UMC, Location AMC, University of Amsterdam, Amsterdam, The Netherlands*
[4] *Department of Surgery, Alrijne Hospital, Leiderdorp, the Netherlands*
[5] *Trauma Research Unit, Department of Trauma Surgery, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands*
[6] *Defence Healthcare Organization, Ministry of Defence, Utrecht, the Netherlands*

Corresponding author: *Mr Benjamin L Turner, Royal Netherlands Navy Diving and Submarine Medical Centre, Den Helder, The Netherlands*
ORCiD: *0009-0004-6606-9788*
b.l.turner@student.vu.nl

Keywords
Arterial gas embolism; Decompression sickness; Incidents; Risk factors; Safety; Underwater hazards

Abstract
(Turner BL, van Ooij P-JAM, Wingelaar TT, van Hulst RA, Endert EL, Clarijs P, Hoencamp R. Chain of events analysis in diving accidents treated by the Royal Netherlands Navy 1966-2023. Diving and Hyperbaric Medicine. 2024 31 March;54(1):39–46. doi: 10.28920/dhm54.1.39-46. PMID: 38507908.)
Introduction: Diving injuries are influenced by a multitude of factors. Literature analysing the full chain of events in diving accidents influencing the occurrence of diving injuries is limited. A previously published 'chain of events analysis' (CEA) framework consists of five steps that may sequentially lead to a diving fatality. This study applied four of these steps to predominately non-lethal diving injuries and aims to determine the causes of diving injuries sustained by divers treated by the Diving Medical Centre of the Royal Netherlands Navy.
Methods: This retrospective cohort study was performed on diving injuries treated by the Diving Medical Centre between 1966 and 2023. Baseline characteristics and information pertinent to all four steps of the reduced CEA model were extracted and recorded in a database.
Results: A total of 288 cases met the inclusion criteria. In 111 cases, all four steps of the CEA model could be applied. Predisposing factors were identified in 261 (90%) cases, triggers in 142 (49%), disabling agents in 195 (68%), and 228 (79%) contained a (possible-) disabling condition. The sustained diving injury led to a fatality in seven cases (2%). The most frequent predisposing factor was health conditions (58%). Exertion (19%), primary diver errors (18%), and faulty equipment (17%) were the most frequently identified triggers. The ascent was the most frequent disabling agent (52%).
Conclusions: The CEA framework was found to be a valuable tool in this analysis. Health factors present before diving were identified as the most frequent predisposing factors. Arterial gas emboli were the most lethal injury mechanism.

Introduction

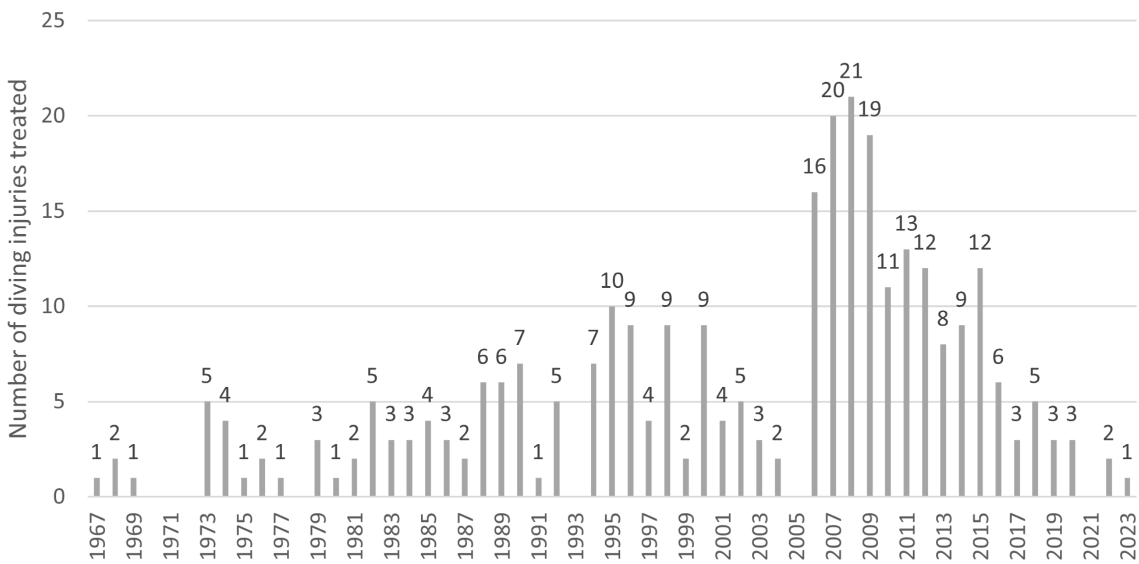
Scuba diving is a popular, growing sport practiced by more than six million divers worldwide.[1] Due to the physiological changes induced by water immersion and submersion, exercise, and the usage of specialised equipment, every dive contains inherent risks, albeit small, for the diver's health and safety.[2] Other factors influencing the safety of a dive are, for example, human factors (e.g., mistakes made due to a lack of training), a diver's medical history and environmental factors (e.g., water conditions including temperature). In addition, injuries sustained while diving can occur due to various mechanisms, such as sudden pressure changes and insufficient decompression.

Due to the complex interplay between the aforementioned factors influencing the risk of incidents, determining a single causal factor for a diving injury is rarely possible. There are several studies available presenting data on diving injuries.[3–7] However, literature often focusses on specific aspects or outcomes of diving accidents.[3–6,8–10] Data on the full spectrum of factors influencing the occurrence of a diving injury are limited.

Table 1
Definitions of the phases contained within the chain of events analysis, adapted from Lippmann[9]

Step	Definition	Example
Predisposing factor	A relevant factor that was present prior to the dive, and/or prior to the trigger occurring, and which is believed to have predisposed to the incident and/or to key components in the accident chain (e.g., the trigger or disabling agent)	A diver with acute rhinitis and limited training
Trigger	The earliest identifiable event that appeared to transform an unremarkable dive into an emergency	A malfunctioning communication system
Disabling agent	An action or circumstance (associated with the trigger) that caused injury or illness. It may be an action of the diver or other persons, reaction of the equipment, effect of a medical condition or a force of nature	A rapid ascent
Disabling condition	An injury caused by the diving accident	Decompression sickness

Figure 1
The distribution of included cases per year



The ‘chain of events analysis’ (CEA) was first introduced by Denoble and further developed by Lippmann.[6,9] It allows for consideration of the entire accident sequence of a diving fatality. The CEA framework consists of five steps: (1) predisposing factors, (2) triggers, (3) disabling agents, (4) disabling conditions and (5) cause of death. In non-fatal incidents the final phase is not applicable, so the CEA is reduced to the initial four steps (Table 1). Older studies using CEA contain data discrepancies due to the use of varying categorisation and terminology.[6,7] The root cause analysis method used by other studies does not allow for including predisposing factors.[7,11] Human factors, which have been shown to be a significant factor in the occurrence of diving accidents, can also be taken into account in the CEA framework.[9,12]

Applying the CEA framework on a large dataset could generate meaningful insights for the diving medical community due to its structured approach and inclusion of human factors. For example, frequently identified predisposing factors could help dive medical physicians to screen more effectively, and frequently identified triggers could show diving instructors important focus points for training.

The primary aim of this study was to analyse the frequency and causes of diving injuries sustained by divers seen or treated by the Diving Medical Centre of the Royal Netherlands Navy (DMC) using the standardised CEA method. The secondary aim was to assess the value of the CEA method in determining mechanisms of diving injuries for future research and documentation.

Methods

This retrospective cohort study was performed by applying CEA on pseudonymised medical records and related documents at the DMC. The study was conducted in accordance with the recommendations of the surgeon general of the Ministry of Defence (reference: DGO20230511). The data collected during this study was stored and analysed in compliance with national privacy legislation and European Data Protection Regulations (GDPR).

INCLUSION AND EXCLUSION CRITERIA

Injury reports and medical files of potentially eligible diving injuries between 1966 (the year of inception of the DMC) up to August 2023 were screened. The population consisted of civilian and military divers treated or examined by a dive medical physician. A record was included if both the description of the diving incident and the medical files of the diver were available and the dive medical physician at the time of the incident deemed the injury to be related to a diving accident. Records were excluded if the description of the diving incident was not available or the injury was not sustained through diving.

DATA EXTRACTION AND OUTCOMES OF INTEREST

Aside from baseline characteristics, such as age, sex, and weight, data on dive profiles, treatment, and recovery of the divers were collected as well. Furthermore, the categories for each step in the CEA, as defined by Lippmann, were compared to the information described in the record. Except for sex, all baseline characteristics were assessed for normality using a Jarque-Bera test.

ANALYSIS

The records were analysed and encoded by author BT. Additionally, cases were cross-checked by two senior dive medical physicians (RH and PJvO), and, if necessary, discussed until a consensus was reached.

The definition provided for each step of the CEA is described in Table 1. Because most cases seen by the DMC are non-fatal, it was decided to extend Lippmann's framework by utilising the 'Disabling condition' category for non-fatal diving injuries as well as fatal diving injuries. The symptoms and diagnoses were encoded using ICD-10 Version 2019 codes.[13]

Descriptive statistics were obtained from the assembled dataset using SPSS Statistics for Windows software (2020, version 27.0; IBM Corp; Armonk, NY).

Results

In total, 288 cases met the inclusion criteria for the period 1966–2023. The distribution of the cases per year is shown in Figure 1.

Height was normally distributed, while body mass index BMI, weight, and age showed a non-normal distribution. The median age of the casualties was 34 (IQR 28.0–43.3), and 76.7% were male. Males had a slightly higher median BMI than females, respectively 24.5 (IQR 24.5–25.3) and 23.8 (IQR 21.6–26.7). Baseline characteristics are presented in Table 2. In total, 81.3% of cases concerned civilians and 17.0% military divers. Of these military divers, 18.4% were part of the Royal Netherlands Army, 79.6% were part of the Royal Netherlands Navy, and one diver's military branch was not specified. Furthermore, in three cases (1.0%) the divers were part of the fire brigade.

In 38.5% of cases (111/288) one or more risk categories in each of the four steps within the CEA model could be identified. All 288 cases were included in the final analysis, including the 61.5% (177/288) of cases in which not all steps were identified. In some cases, multiple relevant categories were identified per step, especially the predisposing factors. Table 3 presents the distribution of the identified categories within each step.

PREDISPOSING FACTORS

Predisposing factors were identified in 90.6% (261/288) of cases. The most frequently identified categories were *'Health'* (n = 308, divided over 159 unique cases), '*Activity*' (n = 90), *'Planning'* (n = 47) and '*Training*' (n = 31). The category *'Health'* was comprised of multiple subcategories, including the most frequently identified subcategories

Table 2

Baseline characteristics; data depict median (interquartile range, and number of observations); BMI – body mass index

Parameter	Total (n = 288)	Male (n = 221)	Female (n = 67)
Age (years)	34.0 (28–43.3, n = 261)	34.0 (27–44, n = 197)	34.0 (28–40, n = 64)
Height (cm)	179.0 (171–186, n = 131)	183.0 (179–188, n = 89)	169.0 (167–174, n = 42)
Weight (kg)	78.0 (69–89, n = 131)	84.0 (76–91.5, n = 89)	65.0 (61–70.5, n = 42)
BMI (kg·m^{-2})	24.4 (22.4–27.1, n = 131)	24.5 (24.5–25.3, n = 88)	23.8 (21.6–26.7, n = 42)

Table 3

Distribution of the identified categories; *this subcategory contains decompression sickness type 1 (n = 41 for Diagnosis, n = 4 for Possible diagnosis), decompression sickness type 2 (n = 90 for Diagnosis, n = 15 for Possible diagnosis) and air embolism (n = 22 for Diagnosis, n = 8 for Possible diagnosis)

Step	Row Labels	Occurrence (% of total)	
Predisposing factors	Activity	90 (17.1%)	
	Communication	1 (0.2%)	
	Equipment	39 (7.4%)	
	Health	308 (58.6%)	
	Organization	9 (1.7%)	
	Other	1 (0.2%)	
	Planning	47 (8.9%)	
	Training	31 (5.9%)	
	Category total	**526**	
Triggers	Anxiety	14 (9.6%)	
	Buddy diver error	11 (7.5%)	
	Buoyancy	12 (8.2%)	
	Communication	4 (2.7%)	
	Environment	8 (5.5%)	
	Equipment	25 (17.1%)	
	Exertion	28 (19.2%)	
	Gas supply	17 (11.6%)	
	Health	1 (0.7%)	
	Primary diver error	26 (17.8%)	
	Category total	**146**	
Disabling agents	Anxiety	7 (3.4%)	
	Ascent	107 (51.9%)	
	Buoyancy	2 (1.0%)	
	Descent	1 (0.5%)	
	Environment	5 (2.4%)	
	Equipment	6 (2.9%)	
	Gas supply	4 (1.9%)	
	Medical	34 (16.5%)	
	Other	13 (6.3%)	
	Post-dive	27 (13.1%)	
	Category total	**206**	
Disabling conditions		Diagnosis (% of total)	Possible diagnosis (% of total)
	Congenital and chromosomal abnormalities	2 (0.7%)	2 (0.7%)
	Diseases of the circulatory system	2 (0.7%)	0
	Diseases of the digestive system	2 (0.7%)	0
	Diseases of the ear and mastoid process	6 (2.2%)	1 (0.4%)
	Diseases of the musculoskeletal system and connective tissue	5 (1.8%)	3 (1.1%)
	Diseases of the nervous system	0	5 (1.8%)
	Diseases of the respiratory system	14 (5.0%)	2 (0.7%)
	Endocrine, nutritional and metabolic diseases	4 (1.4%)	1 (0.4%)
	External causes of morbidity and mortality	9 (3.2%)	2 (0.7%)
	Injury, poisoning and certain other external causes*	168 (60.2%)	31 (11,1%)
	Mental and behavioural disorders	2 (0.7%)	1 (0.4%)
	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	14 (5.0%)	2 (0.7%)
	Diseases of the skin and subcutaneous tissue	1 (0.4%)	0
	Category total	**229**	**50**

'*diagnosis in medical history*' (*n* = 144), '*health problems present before dive*' (*n* = 60) and '*history of smoking*' (*n* = 39). Further analysing the '*diagnosis in medical history*' category for medically relevant diagnoses resulted in 83 remaining identifications.

TRIGGERS

Triggers were identified in 49.3% (142/288) of cases. '*Exertion'* (*n* = 28), '*Primary diver error'* (*n* = 26), and '*Equipment'* (*n* = 25) were the most frequently identified triggers.

Each overarching trigger category contains multiple subcategories. The most frequently identified subcategories were '*out of air*' (*n* = 9, belonging to *Gas supply*), '*mask filled with water*' (*n* = 8, belonging to *Equipment*), '*accidental ascent*' (*n* = 7, belonging to *Buoyancy*) and '*ignoring diving computer*', '*ascending too fast*' (*n* = 7, belonging to *Primary diver error*).

DISABLING AGENTS

Disabling Agents were identified in 67.7% (195/288) of cases. '*Ascent'* (*n* = 107), '*Medical'* (*n* = 34), and '*Post-dive'* (*n* = 27) were most frequently identified as disabling agents. Within the '*Other*' category, two frequently occurring subcategories, '*Ascent to altitude after diving'* (*n* = 11) and '*Exertion after dive'* (*n* = 10), were grouped under the new category '*Post-dive'*.

Two of the most frequently occurring subcategories are contained within '*Ascent*: *Ascending too fast'* (*n* = 63) and '*Staying at depth too long'* (*n* = 15). Another frequently occurring subcategory is contained within '*Medical'*: '*Volume depletion'* (*n* = 17), which represents cases where dehydration was considered a disabling agent.

DISABLING CONDITIONS

The disabling conditions were divided into '*Diagnosis'* (229/288 cases) and *Possible diagnosis* (50/288 cases) based on the information present in the case reports and medical charts. A disabling condition was only scored as a '*Diagnosis*' if the report specified it as such, otherwise, it was categorised as a '*Possible diagnosis*'. In the remaining cases, no (possible-) diagnosis was provided by the diving medicine physician.

The most frequently identified category was '*Injury, poisoning, and certain other consequences of external causes'* (*n* = 168 for *Diagnosis*, *n* = 31 for *Possible diagnosis*). This category contained the three most frequently occurring diagnoses and possible diagnoses: '*Decompression sickness type 1'* (*n* = 41 for *Diagnosis*, *n* = 4 for *Possible diagnosis*), '*Decompression sickness type 2'* (*n* = 90 for *Diagnosis*, *n* = 15 for *Possible diagnosis*) and '*Air embolism'* (*n* = 21 for *Diagnosis*, *n* = 8 for *Possible diagnosis*).

The second most frequently occurring category contained in *Diagnosis* was '*Diseases of the respiratory system'* (*n* = 14), containing, among other subcategories, '*Pneumothorax'* (*n* = 5) and '*Pulmonary oedema'* (*n* = 4). The third category, '*External causes of morbidity and mortality'* (*n* = 9), contained, among other things, the diagnosis '*Exposure to high and low air pressure and changes in air pressure'* (*n* = 6).

FATALITIES

In 2.4% (7/288) of cases, the diver died due to the sustained diving injury. Arterial gas emboli were the most frequent cause (*n* = 3), one resulted from a complication of immersion pulmonary oedema. Unspecified, either venous or arterial, gas emboli, drowning, and an allergic asthma attack were each the cause of one fatality. No data on the autopsies of the fatal injuries were available.

Discussion

This retrospective cohort study performed on the medical records of the Diving Medical Center of the Royal Netherlands Navy utilised the CEA method to analyse diving injuries. In our opinion, the CEA framework is valuable for diving medicine, due to the inclusion of predisposing factors that can directly translate to dive medical screenings performed by diving physicians, as well as the insights gained about the importance of training and planning.

Assessing the occurrence of categories identified in our application of the framework provides us with insights regarding risk factors influencing diving injuries. We identified a category for each step within the CEA model in 40% of cases. The '*health*' category represented over half of all identified predisposing factors. Both formally diagnosed medical conditions and health problems present before the dive started, as reported by the diver, were included in this category. However, the distinction must be made between relevant health factors and health factors of unknown clinical significance. Making this distinction in our analysis resulted in a reduction of 42.4% (from 144 to 83 diagnoses). The health category still remained the most frequently identified category, which seems to be in agreement with the literature, since underlying co-existing medical conditions have been shown to be a risk factor for diving fatalities and injuries.[11,14–16]

Interestingly, we have not identified cardiac events as disabling agents, which previous studies analysing diving fatalities have labelled as the most frequent disabling agent, albeit in cohorts of older recreational divers.[7,17,18] We did, however, observe cardiac conditions as predisposing factors. This difference could, therefore, be due to the use of our classification system and our data, which mainly consisted of diving injuries instead of diving fatalities.[7,17] The relatively young age, 34 years on average, of our cohort could further contribute to our lack of observed cardiac issues.

An important note is that not all health factors identified as predisposing factors may have had the same amount of causal influence on the diving injury. For example, a shoulder contusion may have had less influence on the occurrence of the diving injury than the dehydrated status of the diver, while both have been identified as predisposing factors.

Undertaking exertional activities while diving, such as moving heavy objects underwater and swimming for long distances, appeared to contribute to the triggering of a diving injury, which is in accordance with risk factors for diving injuries identified by other studies.[8,19] A possible causal relation could exist between the 'activity' and 'exertion' categories used as *predisposing factors* and *triggers* respectively. Underlying medical conditions and a lack of training can affect the level of exertion that a diver experiences. This illustrates the value of chain of events analysis, which enables us to take the influence of predisposing factors on factors occurring during the dive into account.

Triggers regarding equipment and gas supply were also frequently identified, which other studies have shown as well, underlining the importance of pre-dive checks and showing the influence of human factors when these checks are lacking.[6,17,20]

We identified a rapid ascent, a well-known risk factor for developing decompression sickness, as a frequent disabling agent, which is in agreement with other studies.[6,8,17,21,22]

In our application of the framework, we chose to include each case that contained at least one identifiable step in the CEA model in our dataset. Cases in which not all steps are identified, for example due to a lack of documentation, can still provide interesting information when analysing individual steps. For example, a case containing only predisposing factors and a disabling condition can be of value when researching risk factors. However, in our opinion the value of the CEA is in the connections made between each step. Therefore, we suggest future studies aiming to analyse the entire chain of events to only include cases without missing steps.

Further research utilising this framework should consider our findings of utilising a filter for relevant medical diagnoses as well as utilising ICD-10 coding for predisposing factors and disabling injuries. A limitation of ICD-10 coding is that the most frequent diagnoses and fatal injuries are all part of one overarching category. Therefore, we suggest explicitly distinguishing between arterial gas embolism and decompression sickness types 1 and 2 when using ICD-10 coding for other parts of CEA. A category within the '*Disabling agents*' step concerning '*Ascent to altitude after diving*' should be added, especially as this is a (risk) factor for developing decompression sickness. Further application of the framework will no doubt give rise to even more novel categories.

Furthermore, a way to analyse casual relations between categories, such as triggers causing diving injuries when specific predisposing factors are present, should be developed. This could result in valuable insights for diving injury prevention and treatment. These inter-categorical trends could be analysed by performing a multinomial regression analysis, keeping the risk of overfitting in mind and focusing on the relations between categories one step at a time.

A limitation of the CEA model is that the exact causal relationship between the predisposing factors and the diving injury sustained is not fully retraceable by only analysing the overview of identified categories but requires looking at each case in more detail. Furthermore, human factors, which have been shown to play a major role in the occurrence of diving injuries, are not fully incorporable in the analysed CEA model, especially detailed contextual factors such as psychological aspects.[23]

The strength of each CEA relies on the documentation of the diving injuries. Because of the potentially invaluable insights that could be gained by performing large-scale CEA, we suggest the application of a standardised format to document diving injuries that ensures the recording of essential information for future CEA applications. This format could be digitalised and should consist of a field for each step in the CEA model. Special attention should be paid to human factors that influenced the diving injury and medical factors. Of course, to ensure the usage of this format, it should not take the physicians a substantial amount of extra time to use this new documentation system.

STRENGTHS AND LIMITATIONS

This study's main strength is that it is, to our knowledge, the first application of CEA on a dataset of this size and in predominantly non-fatal incidents. Furthermore, it could serve as a proof of concept of the proposed model, albeit with the addition of the ICD-10 classification.

There are also some limitations. The collection and analysis of data in a retrospective cohort using chart review is subject to certain limitations by default. The data quality is dependent on the information contained within the medical records and eyewitness accounts, which may be incomplete, speculative, and biased. This could have influenced the quality of our CEA. While from an academic perspective, this is a limitation, we feel it represents reality - not all information may be accessible in accident investigations.

We have utilised the medical records and additional material available in our archives, which did not contain all documentation of follow-ups. Therefore, some cases contained less information than others, which could have led to an underrepresentation of some categories. However, as the model has proven useful even with this limitation, we feel having all data would only increase its validity.

Moreover, not all (fatal) diving injuries in The Netherlands are treated at the DMC, which means our dataset contains a level of selection bias. Generalisation of our results to other populations should be done carefully.

Lastly, classifying cases into categories of the CEA, which is a simplified representation of reality, contains subjectivity. Therefore, misclassification could have occurred. This is, however, an inherent limitation of models utilising categories. We have tried to mitigate this bias by involving multiple researchers when doubt arose. Furthermore, we feel that simplification could perhaps contribute to grasping the complexity of reality and identifying valuable lessons, in contrast to trying to understand known and unknown factors and their multifactorial interactions and failing to reach a conclusion.[24]

Conclusions

We have found the CEA framework to be a valuable tool in analysing diving injuries and have made suggestions to improve the framework, including the application of filtering for relevant health factors and using standardised ICD coding.

In the cohort of diving accidents from 1966–2023, '*health problems'* was the most commonly identified predisposing factor for diving injuries (~58%). Furthermore, the '*activity'* undertaken by the diver seems to contribute to a diving injury occurring as well (~18%). '*Exertion'* (~19%), '*primary diver errors'* (~18%) and '*faulty equipment'* (~17%) were the most common diving injury triggers. The '*ascent of the diver'* was the most often occurring disabling agent (~52%).

The most frequently occurring diving injuries were decompression sickness type 1 (~15%) and type 2 (~32%) and arterial gas embolism (~8%). Arterial gas embolism was the most lethal injury (~43% of fatalities).

References

1 2023 Diving Fast Facts. [Internet]: Diving Equipment and Marketing Association; 2023. [cited 2023 Oct 4]. Available from: https://www.dema.org/store/download.aspx?id=7811B097-8882-4707-A160-F999B49614B6.

2 Bosco G, Rizzato A, Moon RE, Camporesi EM. Environmental physiology and diving medicine. Front Psychol. 2018;9:72. doi: 10.3389/fpsyg.2018.00072. PMID: 29456518. PMCID: PMC5801574.

3 Buzzacott P, Hornsby A, Shreeves K. Mortality rate during professionally guided scuba diving experiences for uncertified divers, 1992-2019. Diving Hyperb Med. 2021;51:147–51. doi: 10.28920/dhm51.2.147-151. PMID: 34157729. PMCID: PMC8426127.

4 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.

5 Kojima Y, Kojima A, Niizeki Y, Yagishita K. Recreational diving-related injury insurance claims among Divers Alert Network Japan members: Retrospective analysis of 321 cases from 2010 to 2014. Diving Hyperb Med. 2020;50:92–7. doi: 10.28920/dhm50.2.92-97. PMID: 32557409. PMCID: PMC7481107.

6 Denoble PJ, Caruso JL, Dear Gde L, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. Undersea Hyperb Med. 2008;35:393–406. PMID: 19175195.

7 Vinkel J, Bak P, Hyldegaard O. Danish diving-related fatalities 1999-2012. Diving Hyperb Med. 2016;46:142–9. PMID: 27723014. [cited 2023 Oct 4]. Available from: https://dhmjournal.com/images/IndividArticles/46Sept/Vinkel_dhm.46.3.142-149.pdf.

8 Casadesús JM, Aguirre F, Carrera A, Boadas-Vaello P, Serrando MT, Reina F. Diving-related fatalities: multidisciplinary, experience-based investigation. Forensic Sci Med Pathol. 2019;15:224–32. doi: 10.1007/s12024-019-00109-2. PMID: 30915609.

9 Lippmann J, Stevenson C, Taylor DMcD, Williams J, Mohebbi M. Chain of events analysis for a scuba diving fatality. Diving Hyperb Med. 2017;47:144–54. doi: 10.28920/dhm47.3.144-154. PMID: 28868594. PMCID: PMC6159623.

10 Svendsen Juhl C, Hedetoft M, Bidstrup D, Jansen EC, Hyldegaard O. Decompression illness treated in Denmark 1999-2013. Diving Hyperb Med. 2016;46:87–91. PMID: 27334996. [cited 2023 Oct 4]. Available from: https://dhmjournal.com/images/IndividArticles/46June/Juhl_dhm46.2.87-91.pdf.

11 Potts L, Buzzacott P, Denoble P. Thirty years of American cave diving fatalities. Diving Hyperb Med. 2016;46:150–4. PMID: 27723015. [cited 2023 Oct 4]. Available from: https://dhmjournal.com/images/IndividArticles/46Sept/Potts_dhm.46.3.150-154.pdf.

12 Febriyanto K, Rachman A, Rahman FF. The contribution of human error related to occupational accident among traditional divers. Gac Sanit. 2021;35(Supp 1):S27–9. doi: 10.1016/j.gaceta.2020.12.008. PMID: 33832619.

13 ICD-10 Version: 2019. [Internet]: World Health Organization; 2019. [cited 2023 Oct 4]. Available from: https://icd.who.int/browse10/2019/en#/.

14 Lippmann J, Tayor DMcD. Scuba diving fatalities in Australia 2001 to 2013: Chain of events. Diving Hyperb Med. 2020;50:220–9. doi: 10.28920/dhm50.3.220-229. PMID: 32957123. PMCID: PMC7819731.

15 Lippmann J, Stevenson C, Taylor DM. Scuba diving fatalities in Australia, 2001 to 2013: Diver demographics and characteristics. Diving Hyperb Med. 2020;50:105–14. doi: 10.28920/dhm50.2.105-114. PMID: 32557411. PMCID: PMC7481108.

16 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.

17 Tillmans F, editor. DAN Annual Diving Report 2020 Edition: A report on 2018 diving fatalities, injuries, and incidents. Durham (NC): Divers Alert Network; 2021.

18 Lippmann J. A review of snorkelling and scuba diving fatalities in Queensland, Australia, 2000 to 2019. Diving Hyperb Med. 2022;52:108–18. doi: 10.28920/dhm52.2.108-118. PMID: 35732283. PMCID: PMC9522589.

19 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.
20 Lippmann J, Lawrence C, Davis M. Scuba diving-related fatalities in New Zealand, 2007 to 2016. Diving Hyperb Med. 2021;51:345–54. doi: 10.28920/dhm51.4.345-354. PMID: 34897599. PMCID: PMC8920894.
21 Vann RD, Butler FK, Mitchell SJ, Moon RE. Decompression illness. Lancet. 2011;377(9760):153–64. doi: 10.1016/S0140-6736(10)61085-9. PMID: 21215883.
22 Jain KK. Textbook of hyperbaric medicine. 6th ed. Cham, Switzerland: Springer; 2017.
23 Lock G. Under Pressure: Diving Deeper with Human Factors. Great Britain: Vision Maker Press; 2019.
24 Kahneman D, Sibony O, Sunstein CR. Noise: A flaw in human judgment. London: Little, Brown Spark; 2022.

Acknowledgments

The authors acknowledge the Ministry of Defence for approving the protocol to perform this study.

Conflicts of interest and funding: nil

Submitted: 6 October 2023
Accepted after revision: 13 January 2024