Decompression Illness Reported in a Survey of 429 Recreational Divers

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Background: The purpose of this study was to investigate the influence of diving experience and diving techniques on the lifetime incidence of decompression illness (DCI). ***Methods:*** Attendants of three diving medical symposia voluntarily answered a questionnaire about their age, gender, medical history, diving experience, diving habits, diving certification levels, and diving associated incidents (cross-sectional survey). ***Results:*** Out of 650 divers, 429 completed the questionnaire. The study population consisted of experienced divers with an average of 670 dives. The majority of the divers were certified diving instructors (43%). There were 37 participants (8.7%) who were classified as technical divers with an average of 1193 logged dives. There was an overall lifetime incidence of DCI of 1 per 5463 dives. The complete study group showed an increased lifetime incidence of DCI with decreased diving experience (1.97-fold to 8.17-fold higher). Of the divers, 27% reported severe DCI with neurological symptoms. The lifetime incidence for severe DCI was 1 in 20,291 dives. Again, lifetime incidence for severe DCI was increased with decreased diving certification level (1.1-fold to 13.7-fold higher). Technical divers showed a DCI lifetime incidence of 1 to 8591 dives compared to the non-technical divers with a lifetime incidence of 1 to 5077 dives (not significant). ***Conclusion:*** In our study population, the lifetime incidence of DCI was increased in divers with less diving experience. If further studies confirm this finding, diving federations should be encouraged to intensify their efforts of educating divers and should limit diving time and depth in inexperienced divers.

Keywords: decompression sickness, altitude decompression sickness, decompression illness, diving accidents, arterial gas embolism, technical diving.

DIVING HAS BECOME an increasingly popular leisure time activity with more than one million certified divers in Germany (10) and more than nine million divers in the United States (12). Increasing numbers of divers raise the numbers of accidents, and thus physicians have to face diving associated accidents more frequently (1).

Decompression sickness (DCS) is a result of microbubbles forming in the tissue and blood vessels after having stayed in a hyperbaric environment (i.e., while diving) or when the ambient pressure is reduced in a saturated body (i.e., while flying—altitude DCS), leading to supersaturation of the body tissues with nitrogen. Decompression illness (DCI) comprises DCS and arterial gas embolism as a consequence of pulmonary barotrauma with air embolism during ascent. DCI can lead to permanent disability and long-term residual problems. Even though recreational diving has been performed for more than 40 yr now, only few studies have examined the lifetime incidence of DCI, gender differences, influence of experience, or the impact of technical diving.

DCI is a rare event with a reported lifetime incidence between 1 incident in 657 dives (6) to 1 incident in 6369 dives (14). Since divers usually perform less than 50 dives a year, prospective follow-up studies have to include a high number of participants over a longtime follow-up period. There is only one prospective analysis of diving behavior and diving incidence of DCI to date: Project Dive Exploration (PDE) started in 1995 which includes more than 1500 divers who have logged 105,135 dives so far. Although the data collection lasted for 9 yr, the number of DCI events was small. Divers Alert Network (DAN) found an incidence of DCI of 1:3003, but an evaluation of the impact of diving experience on DCI has not yet been performed (2).

PDE does not offer information about the influence of diving experience on the rate of DCI. Also, the available retrospective analyses did not examine the impact of diving experience nor showed controversial results, so that we were encouraged to perform the current study to retrieve more data about differences in lifetime incidence of DCI between diving novices and experienced divers. The study was performed as a cross-sectional, questionnaire-based study.

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METHODS

The data were obtained at three diving medical symposia taking place in Germany from 2003 to 2005, addressing divers, diving instructors, and diving physicians. There were 650 participants who were asked to complete a modification of a previously published questionnaire (7–9). The questionnaire consisted of 47 questions on a variety of topics including previous medical history, otorhinological history, diving history, diving medical problems, and questions to specify the occurrence of DCI (i.e., type of symptoms, onset of symptoms after diving, number of DCI events). It took about 30 min to complete. For this study we used only the 33 questions that were relevant to DCI, excluding other items that specifically addressed otolaryngological issues. Divers had the possibility to answer the questionnaire anonymously. Divers who had answered the previous questionnaires had to state this, and the previous questionnaires were excluded. The study was approved by the ethical committee of the University of Heidelberg.

The questionnaire was not randomized and the data were collected retrospectively. Divers were asked for their medical and diving history, diving associated problems in the otorhinolaryngological field, disorders of the temporomandibular joint (11), and the occurrence of DCI as defined by the diving accident treatment guidelines of the German diving and hyperbaric medical society (16). Diving accidents are also called "decompression accident" or "decompression illness" (DCI). These accidents are caused by rapid reduction of ambient pressure and are characterized by formation of gas bubbles in the blood and the tissues. Symptoms comprise skin troubles, pain, tingling, unusual weakness, motor weakness, numbness, paralysis, breathing troubles, visual, hearing, and speech troubles, vertigo, nausea, impaired consciousness, and coma.

Divers were divided into four groups following the DIN-EN norms (German Industrial Standardization) 14153-1:2004, DIN-EN 14153-2:2004, DIN-EN 14153-3:2004, DIN-EN 14413-1:2004, and DIN-EN 14413-2:2004 (13). Group 1 consisted of divers without certificate or with a one-star certificate or an equivalent certification level (i.e., open water diver); group 2 comprised divers with a two-star certificate or an equivalent certification level (i.e., advanced open water divers); group 3 included three- and four-star divers or an equivalent certification level (i.e., divemasters); and group 4 consisted of diving instructors. Divers were classified as technical divers when they used an additional breathing gas, such as trimix, and performed diving with special training and equipment.

Statistical Analysis

The questionnaires were evaluated by two independent examiners. When both confirmed the self-reported symptoms to be consistent with DCI, the questionnaire was allocated to the group of divers with DCI. Questionnaires with unclear information, i.e., missing ticks or illegible information, were excluded. Statistical analyses were performed with SPSS® 14.0 for Windows (Chicago, IL) and SAS® 9.1 for Windows (Version 9.1; SAS Institute Inc., Cary, NC).

Nominal data are expressed in absolute (n) and relative (%) frequencies. Continuous data are expressed by mean, median, minimum, and maximum with confidence intervals (CI). Differences between groups were investigated using the Wilcoxon test, the Chi-square test, and Fisher's exact test. The influence of technical diving, maximum diving depth, diving experience, and diving certification level on the number of DCI incidents was investigated using Poisson regression models.

Statistical significance was accepted at $P < 0.05$. An adjustment for multiple testing was not performed because of the explorative nature of our study. Statistics were prepared by a professional statistician.

RESULTS

Sample Description

There were 435 questionnaires returned, of which 6 had to be excluded because of illegible handwriting. None of the excluded questionnaires belonged to the DCI group. The remaining 429 questionnaires were used for this study (return rate 66%). The mean age of the study population was 40 yr (range 17–70). The complete study group had an average of 670 dives and logged a total of 284,067 dives. Of the participants, 37 (8.7%) were classified as technical divers, logging an average of 1193 dives. Regarding the diving certification level, 56 divers (13%) were classified in group 1, 80 divers (19%) in group 2, 108 divers (25%) in group 3, and 184 divers (43%) in group 4. The majority of the study population consisted of diving instructors (group 4).

There were 29 divers who did not record their lifetime maximum diving depth. Including the technical divers, divers had logged a median maximum diving depth of 52 m (range 12–251 m). The isolated group of technical divers had a median diving depth of 84 m (range 45–251). Only 80 divers of the non-technical divers (22%) stated a maximum depth of 40 m and less. We divided the collective into three groups according to their diving experience: low experience with < 200 dives (105 divers); average experience with 200–400 logged dives (92 divers); and high experience with < 400 dives (201 divers).

Decompression Illness

DCI in the complete study group: An incident of DCI in their history was reported by 43 divers. In 40 divers, 1 incident occurred, whereas 1 diver experienced 2 episodes of DCI, 1 diver 3, and 1 diver 7 episodes of DCI. The complete study group experienced a total of 52 episodes of DCI and performed 284,067 dives, leading to an overall risk of 1:5463 (DCI cases:number of dives).

Effect of maximum diving depth on lifetime incidence of DCI: Deep diving is associated with an increased risk for the development of DCI. We, therefore, investigated whether a lifetime maximum diving depth had an influence on the lifetime incidence of DCI. A maximum diving depth of 40 m or less was indicated by 79 divers,

whereas 319 divers dove deeper than 40 m. The lifetime incidence of DCI in the first group was 1:2365 and was 2.51-fold higher than in the deep diving group (1:5999) and was statistically significant ($P = 0.03$, Poisson regression model).

Effect of diving experience on lifetime incidence of DCI: To study the influence of diving experience on the lifetime incidence of DCI, the study population was divided into three groups with low, average, and high diving experience. Divers with 200 or less logged dives had the highest lifetime incidence of DCI followed by divers with average and high experience (see **Table I**). The influence of diving experience was only significant between divers with low and high experience (relative risk of low diving experience vs. high diving experience = 3.90, 95% CI: 1.73–8.67, $P < 0.001$, Poisson regression model). Therefore, less experienced divers with 200 or fewer dives appear to have an especially higher risk of DCI.

Severe DCI with inner ear, neurological, cardiovascular, and pulmonary symptoms is of special importance because it often results in long-term and irreversible damage. Therefore, we examined the lifetime incidence of severe DCI. Of 52 cases of DCI, 14 (27%) could be classified as severe DCI. The distribution of the symptoms can be seen in **Table II**. Again, divers with 200 or less logged dives had the highest lifetime incidence of severe DCI followed by divers with high and average experience. The influence of diving experience between divers with low and high experience (relative risk of low diving experience vs. high diving experience = 4.06, 95% CI: 0.90–18.17, $P < 0.0694$, Poisson regression model) and between divers with average and high diving experience (relative risk of average diving experience vs. high diving experience = 0.8, 95% CI: 0.10–6.18, $P < 0.8281$, Poisson regression model) was not significant. Even though there was a statistical trend that less experienced divers with 200 or fewer dives seemed to have a higher risk of suffering from severe DCI, the difference was not statistically different in our population.

To investigate the influence of certification level on the lifetime incidence of DCI, divers were divided into four groups according to international diving certification levels. A strong influence of certification levels on the lifetime incidence of DCI (see **Table III**) was found, with a relative risk of 8.17 (95% CI: 3.13–21.33) between divers of group 1 compared to diving instructors ($P < 0.0001$, Poisson regression model), a relative risk of 2.18 (95% CI: 0.95–5.05) between divers of group 2 compared to diving instructors (not significant), and a relative risk of 1.97 (95% CI: 1.04–3.74) between divers of group 3 and diving instructors ($P = 0.04$, Poisson regression model). The higher the diving certification was, the rarer the episodes of DCI.

Again, we examined the influence of certification level on the lifetime incidence of severe DCI. Once more we found a strong influence of certification levels on the incidence of severe DCI. We computed a relative risk of 13.6 (95% CI: 2.75–67.36) between group 1 compared to diving instructors ($P = 0.0014$, Poisson regression model), a relative risk of 5.21 (95% CI 1.48–18.54) between divers of group 2 compared to diving instructors ($P = 0.0105$, Poisson regression model), and a relative risk of 1.09 (95% CI 0.22–5.42) between divers of group 3 and diving instructors ($P = 0.9116$, Poisson regression model). Again, the higher the diving certification was, the rarer the episodes of severe DCI.

Lifetime incidence of DCI in technical divers: Technical divers showed a lifetime incidence of 1:8591 ($N = 36$, 42,955 logged dives, 5 episodes of DCI) compared to the rest of the study group, who had a lifetime incidence of 1:5077 ($N = 387$, 238,632 logged dives, 47 episodes of DCI). The difference was not statistically significant.

DISCUSSION

Study Design and Restrictions of Retrospective Data Analysis

Retrospective data collection and analysis offer a variety of limitations. Recall bias may cause an underestimation of the true lifetime incidence in the study group or may lead to an overestimation when mainly divers with medical problems in their history respond to the query. Divers with a history of severe DCI leading to unfitness to dive, divers leaving the sport because of medical problems, and fatalities are not included in this report. Nor is our study population representative for the general population of sport divers as nearly 50% of our study population were diving instructors. This over-representation of well-trained divers is an effect of the recruitment of our population because we offered our questionnaire during diving medical symposia, which are mandatory for many instructors in Germany to attend.

The effect of dedicated divers taking part in medical studies is always a problem when the participation is voluntary. Even a randomized study concept either in a retrospective questionnaire analysis or a prospective follow-up trial leaves the problem that enthusiastic divers rather than beginners participate. The only way to avoid this selection bias would be to force every diving

TABLE I. EFFECT OF LOGGED DIVES ON LIFETIME INCIDENCE OF DCI.

Diving Experience	*N*	Number of Dives	Mild and Severe Diving Accidents: Diving Accidents	Mild and Severe Diving Accidents: Accident per Dives	Severe Diving Accidents: Diving Accidents	Severe Diving Accidents: Accident per Dives
Basic diving experience up to 200 dives	110	11034	7	1:1576	2	1:5517
Intermediate diving experience: 201 to 400 dives	95	27951	5	1:5590	1	1:27951
Advanced diving experience: More then 400 dives	219	245082	40	1:6127	11	1:22280

TABLE II. DISTRIBUTION OF SYMPTOMS IN DIVERS WITH DCS.

Symptom or Symptom Combination	Number of Reported Symptoms
Mild DCS	
Isolated skin symptoms	21
Isolated muscle pain	1
Isolated joint pain	3
Skin symptoms, joint pain	1
Skin symptoms, muscle pain	1
Muscle pain, joint pain	2
Skin symptoms, muscle pain, joint pain	1
Skin symptoms, headache, nausea	4
Skin symptoms, fatigue, joint pain	2
Muscle pain, joint pain, fatigue	2
Severe DCS	
Vertigo	2
Vertigo, hearing loss	2
Vertigo, Tinnitus, hearing loss, loss of orientation	2
Skin symptoms, paralysis of the legs	2
Lung emboli	1
Muscle weakness	3
Speech and visual disturbance, unconsciousness	2

beginner to participate in a prospective follow-up study. This is neither possible nor desired. On the other hand, examining a study population of experienced divers increases the quality of the given answers. Divers study medical facts from the beginning of their career. The answers should be more reliable with a higher certification level of the diver.

DCI Incidence

We found an overall lifetime incidence of DCI of 1 case in 5463 dives (1:5463). This is also comparable to previous retrospective studies by St. Leger Dowse et al. (1:5000) (14) and Taylor et al. (1:5082)(15). The only available data from a prospective study, PDE by DAN, shows an incidence rate of DCI of 1:3003 (2), which is slightly higher but similar to our data. Even though a prospective study like PDE offers a better data source to analyze the risks of diving and the contributing factors for the development of DCI, DAN has not offered such an analysis to date. Therefore, our data seems to be consistent with most other studies.

The only study reporting a higher DCI incidence, from Sweden, was published in 2003. Hagberg and Oernhagen found an almost sevenfold higher lifetime incidence of DCI with 1:657 in male divers and 1:787 in female divers (6). They examined dive masters and instructors and claimed that this could lead to a higher incidence rate in their study group. In contrast, in our study group, diving experience seemed to be protective rather than a reason for a higher lifetime incidence of DCI. As the work of Hagberg and Oernhagen is the only work that found this very high lifetime incidence of DCI, we think that either Swedish divers are at higher risk of DCI or there might be other unknown reasons for the difference in the lifetime incidence of DCI.

Diving depth: With increasing diving depth, the risk of DCI increases (5). For this reason, we examined whether divers with a lifetime maximum diving depth to 40 m or less are at lower risk of DCI. Interestingly, only 20% of all non-technical divers dived within this limit even though diving associations recommend avoiding a depth of more than 40 m. On the other hand, we found an increased risk in the group that dived within these limits. This might be due to the lower diving experience of these divers, as we found diving experience to be associated with a lower risk of DCI.

Diving experience: Diving experience and the level of diving certification had a strong impact on the lifetime incidence of DCI in our study group. We found a decreased risk for overall DCI with increasing number of logged dives (see Table I). Divers who had performed 200 or less dives had a lifetime incidence of DCI of 1:1576, whereas divers with 201 to 400 dives, and divers with more than 400 dives, had a lifetime incidence of DCI of 1:5590 and 1:6127, respectively. Our study population showed a difference between the low and high experience groups, whereas the average and high experience group showed no difference. The investigated divers with 200 or less dives were at a higher risk of DCI than those with more than 200 dives. This could be a selection effect, because divers with DCI in their history tend to leave the sport and, therefore, do not perform more dives to increase their log number. On the other hand, this affects all experience groups equally. Inexperienced divers with DCI in their history who left the sport should not appear in this study. A selection factor favoring divers who are not prone to suffer from DCI could be the reason for the reduced DCI risk in the more experienced groups. These divers have the chance to accumulate more dives and, therefore, appear in the average and high experience group.

We cannot distinguish whether a selection factor or diving experience itself reduces the risk for DCI. But St. Leger Dowse et al. (14; expressed in years of diving) as well as Hagberg and Oernhagen (6) also showed reduced risks for DCI in the more experienced groups, so we assume this is not an artifact of our study. To investigate whether the reduced risk of DCI lifetime incidence

TABLE III. LIFETIME INCIDENCE OF DCI CATEGORIZED BY CERTIFICATION LEVEL.

Diving Certificate	N	Number of Dives	Mild and Severe Diving Accidents		Severe Diving Accidents	
			Diving Accidents	Accident per Dives	Diving Accidents	Accident per Dives
No certificate and one star	56	4740	5	1:948	2	1:2370
Two stars	80	24,820	7	1:3546	4	1:6205
Three stars and four stars	108	59,118	15	1:3941	2	1:29,559
Instructor/Trainer/Supervisor	184	194,189	25	1:7768	6	1:32,365

is only an effect of diving experience or also an effect of certification level, we compared the risks for DCI between the different certification level groups (see Table III). Again, we found a very strong trend of reduced lifetime incidence of DCI with increased level of certification with an Odd's Ratio of 8.17 (95% CI: 3.13–21.33) between diving beginners and instructors. Increasing certification levels accompany increasing numbers of logged dives and it was impossible to distinguish between these two cofactors; there were insufficient diving instructors with few logged dives. But Hagberg and Oernhagen (6) also found a reduced risk for DCI when comparing instructors and dive masters. Therefore, a trend of increased certification levels associated with a reduced risk for DCI could be the reason.

DCI with neurological symptoms (classified as severe DCI in our report) is of major importance as symptoms are more serious, like muscle weakness, paraesthesia, vision, speech, hearing, or vestibular dysfunction, or para and hemiplegia. Severe DCI can also lead to permanent disability and failure of function of organs and body parts. Therefore, severe DCI has a strong impact on divers and their health status. We thus examined the incidence of severe DCI. Naturally, this led to decreased numbers of incidents. Once again, we could observe the trend that inexperienced divers with less than 200 dives had a higher risk of severe DCI compared to divers with more than 400 dives, but the difference was not significant. It is also possible that the influence of diving experience, expressed in logged dives, does not have such a strong influence on the incidence of severe DCI than on the incidence of overall DCI. But it could also be possible that the reduced number of incidents led to a statistical weakness.

Interestingly, we found a strong impact of certification level on the incidence of severe DCI despite the smaller numbers in this group. Divers with one-star and two-star certification levels (diving beginners) had a statistically significant higher risk of severe DCI compared to diving instructors. Therefore, the level of certification also had a strong impact on the lifetime incidence of severe DCI. The less certified the divers were, the higher the lifetime incidence of severe DCI. Even though this finding cannot be generalized to the diving community as we examined a special, not representative, subgroup of experienced divers, this finding should be further examined as it offers a possibility of reducing the risk of DCI in general as well as severe DCI.

Technical diving: Even though technical diving is commonly known as an especially hazardous way of diving, there is not much literature examining the risk to technical divers from DCI. Thus, we here examined whether technical divers were at higher risk of developing DCI. Technical divers had a lifetime incidence of DCI of 1:8591 compared to 1:5077 in the rest of our study group. The difference was not statistically significant. Also, Hagberg and Oernhagen compared divers who undertook at least four out of eight types of technical diving to divers who performed less than four out of eight different types of technical diving. They found a statistically significant reduced risk in divers with more than four out of eight types of technical diving (6). Contrary to these findings, Doolette in 2004 published a case series of 200 technical dives to a maximum diving depth of 120 m seawater (msw) (4). There were 2 episodes of DCI treated by hyperbaric oxygen, resulting in an incidence rate of DCI of 2 cases per 200 dives [1% (CI 0.1%–3.4%)]. Applying these findings to our data, one could suggest that the technical divers were at higher risk of developing DCI than recreational divers. Doolette additionally found an increased decompression health score in technical divers who dove to more than 90 msw. An increased decompression health score is representative for increased decompression stress (3).

Possibly, technical divers in our study dived mainly to less than 90 msw and, therefore, no increased lifetime incidence of DCI was found. Another explanation for our finding could be that technical diving is often associated with cave and wreck diving and, therefore, the possibility of fatality is increased. Our study does not include fatalities as Hagberg and Oernhagen's study did. However, like Doolette's and Hagberg and Oernhagen's, our study examined only small numbers of technical divers and, therefore, the data has to be regarded with caution. Nevertheless, in our study population a higher diving experience in the technical divers was associated with a reduced lifetime incidence of DCI, but further studies are necessary to explore the risks of technical diving.

Conclusion

Our data shows a lower lifetime incidence of DCI in divers with more experience. However, our study population does not represent the general diving community and should not be used to draw general conclusions. Rather, our data generates hypotheses and gives additional information in planning prospective studies. We recommend examining the relative risk of DCI in inexperienced divers in further studies. If inexperienced divers are really at higher risk of DCI, diving federations should intensify their efforts to increase the experience levels of their divers and should give clear diving time and depth limitations for diving beginners to reduce the incidence of DCI.

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