Lower risk of decompression sickness after recommendation of conservative decompression practices in divers with and without vascular right-to-left shunt

Christoph Klingmann, Nils Rathmann, Daniel Hausmann, Thomas Bruckner and Rolf Kern

Abstract

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Introduction: A vascular right-to-left shunt (r/l shunt) is a well-known risk factor for the development of decompression sickness (DCS). No studies to date have examined whether divers with a history of DCS with or without a r/l shunt have a reduced risk of suffering recurrent DCS when diving more conservative dive profiles (CDP).

Methods: Twenty-seven divers with a history of DCS recommended previously to dive more conservatively were included in this study and retrospectively interviewed by phone to determine the incidence of DCS recurrence.

Results: Twenty-seven divers performed 17,851 dives before examination in our department and 9,236 after recommendations for conservative diving. Mean follow up was 5.3 years (range 0–11 years). Thirty-eight events of DCS occurred in total, 34 before and four after recommendation of CDP. Four divers had a closure of their patent foramen ovale (PFO). A highly significant reduction of DCS risk was observed after recommendation of CDP for the whole group as well as for the sub-groups with or without a r/l shunt. A significant reduction of DCS risk in respect to r/l shunt size was also observed.

Discussion: This study indicates that recommendations to reduce nitrogen load after DCS appear to reduce the risk of developing subsequent DCS. This finding is independent of whether the divers have a r/l shunt or of shunt size. The risk of suffering recurrent DCS after recommendation for CDP is less than or equal to an unselected cohort of divers.

Conclusion: Recommendation for CDP seems to significantly reduce the risk of recurrent DCS.

Key words

Decompression sickness, decompression illness, patent foramen ovale (PFO), risk, risk management

Introduction

A right-to-left shunt (r/l shunt), caused predominantly by a patent foramen ovale (PFO), is a well-known risk factor for the development of decompression sickness (DCS). First described more than two decades ago, many studies have been published subsequently confirming an increased risk of DCS for divers who have a r/l shunt.[1–9] A 1998 meta-analysis calculated that the risk of developing severe DCS in the presence of a PFO increased by a factor of 2.52 and for any DCS by a factor of 1.93.[10] The risk of a major episode of DCS is directly related to the size of the septal defect.[9]

The presence of a PFO has been accepted as a risk factor for the occurrence of stroke and transient ischaemic attacks (TIA) in young patients, particularly if associated with an atrial septal aneurysm.[11] PFO closure is increasingly performed for the prevention of recurrent stroke or TIA as well as for the prevention of recurrent DCS in divers' on an individual basis.[12–18] However, a recent randomised controlled trial failed to show superiority of PFO closure over best medical treatment for preventing recurrent stroke or TIA.[19] On the other hand, a Swiss working group has recently published good evidence that PFO closure significantly reduces the risk of developing DCS, even though one diver with PFO closure still suffered neurologic DCS.[20] However, there are no consensus guidelines to support this indication in divers.[3]

To our knowledge, no studies have evaluated the influence of reduced inert gas load during diving in divers with or without a r/l shunt and with a history of DCS. For this reason we performed follow up on divers examined in our department for the presence of a r/l shunt with a history of DCS to assess their risk of recurrent DCS after we had provided advice and education on how to reduce nitrogen load when diving.

Methods

The Ethics Committee at Ruprecht-Karls University in Heidelberg, Germany approved this study (Project Number S-030/2008) and all participants gave their written consent. Forty-nine divers with a history of physician-confirmed DCS from previous studies and from our diving medical clinic were contacted.[7,21–23] Having received written consent, a structured telephone interview was conducted using a purpose-designed questionnaire which included health and general diving-related questions and specific questions about history of DCS, recurrent DCS, and whether PFO closure was performed.* DCS was classified as being either 'minor' or 'major'. Minor DCS symptoms included 'bends', cutaneous lymphoedema and cutaneous erythema with or without extreme fatigue, headache and nonspecific

* The questionnaire may be obtained from the authors: <info@tauchersprechstunde.de>

dizziness. Major DCS events were defined by one or more of the following symptoms: severe vertigo; limb weakness; cutaneous sensory level; impaired bowel or bladder control; paresis or paraplegia; blurred vision; dysarthria; amnesia for the event, hemiplegia or loss of consciousness after a dive. To reduce the risk of false-positive diagnosis of DCS, symptoms must have persisted for at least 30 minutes and have occurred within 24 hours of the dive. Number of logged dives, symptoms of DCS, number of DCS events and PFO status (i.e., closure procedure) were recorded.

All divers had received either a transcranial or carotid Doppler sonography to screen for a vascular right-to-left shunt (r/l shunt), either as a participant of one of our previous studies or as a patient in our clinic. A r/l shunt was diagnosed as small when five or more air microbubble signals occurred in the Doppler spectra of either middle cerebral artery or carotid artery after the Valsalva manoeuvre. The r/l shunt was classified as large if more than 20 signals were detected, in accordance with our previously published classification system.[7,24] After confirmation of DCS and confirmation of PFO status, all divers were educated to perform any future diving using 'conservative' dive profiles (CDP). At the time of examination of the divers who took part in our earlier studies, there had not been a formal recommendation for divers to practice CDP, as exists today.[25,26]

Recommendations for CDP included: use of nitrox, but with decompression times calculated on air tables; no dives deeper than 25 metres' sea water (msw); no repetitive dives; minimising Valsalva manoeuvres, no decompression dives and a 5-minute safety stop at 3 msw. These recommendations were not obligatory and divers were free to choose their individual nitrogen-reducing methods. Even though we recommended all divers with a history of DCS at the time of presentation to dive conservatively in the future, we cannot be sure whether the divers adopted this advice or not.

STATISTICS

The 'risk of DCS' was calculated by division of DCS events by the number of logged dives multiplied by a factor of 10,000 for easier presentation of the otherwise very small values. Statistical analysis was performed with SAS Version 9.1® (Cary, USA). A Wilcoxon signed-rank test was performed for the comparison of the median of two related samples (risk of DCS before and after recommendation for CDP). The significance level was defined as $P \leq 0.05$ and highly significant when P was ≤ 0.01. The absolute risk for DCS before and after recommendation for CDP was compared using confidence intervals. Risk of DCS per diver before and after recommendation for CDP was compared using a McNemar test. Box-and-whiskers plots were generated for graphical presentation of the results of both groups according to the definition of Tukey: the box represents the upper and lower quartile, the centre line represents the median and the vertical lines represent the whiskers.[27]

Results

Of 49 divers who were examined after DCS for presence of a r/l shunt and whom we tried to contact, 32 divers (65%) gave their written consent to take part in this study. Telephone interview revealed that five divers had stopped diving after their examination in our institution, leaving 27 divers in this survey. Twenty male divers and seven female divers with an average age of 47 years (range 31–65 years) performed in total 27,087 dives, 17,851 before examination in our department (median 400, range 60–2,600), and 9,236 after recommendation for CDP (median 200, range 60–2,400) respectively. Time between examination in Heidelberg and the telephone interview varied between 0 and 11 years (mean 5.3 years). Thirty-eight incidents of DCS occurred in total, 34 before recommendation for CDP and four in three divers after recommendation for CDP. Twenty major and seven minor DCS events occurred in the first group and three major DCS events in the second group. After receiving a recommendation to dive using CDP, 17 divers used enriched air nitrox as a breathing gas, three divers used trimix and seven divers used air as their breathing gas.

R/L SHUNT

On examination, nine of the 27 divers had no demonstrable shunt, nine had a small and nine a large r/l shunt.

After examination in our department and before telephone interview, four divers, two with a small and two with a large shunt, had undergone closure of their PFO. Three divers had PFO closure immediately after examination in our institute and one diver had PFO closure after she had two episodes of neurological DCS. After PFO closure, no further DCS events occurred in any of the four divers. Owing to the small sample size no statistical analyses were performed on this group. Further, all four divers who had PFO closure were excluded from statistical evaluation of DCS risk before and after recommendation for CDP as, after PFO closure, they no longer met the inclusion criteria for a r/l shunt.

DCS RISK BEFORE AND AFTER RECOMMENDATION FOR CDP

The absolute risk of suffering DCS before examination in our department for the remaining 23 divers was 0.002 or 20/10,000 (events of DCS / dive). After examination in our department and recommendation for CDP the absolute risk of suffering DCS was 0.0003 or 3/10,000 (events of DCS/ dive). The absolute risk difference for DCS before and after examination was 0.0017 or 17/10,000 (95% confidence intervals, 0.0009 to 0.0025). As the confidence interval does not include zero the risk reduction is significant with a relative risk reduction of 85%.

It is also appropriate to consider the risk per diver of suffering DCS. Before examination in our department, 23 divers had one or more DCS events. After recommendation for

Figure 1
Box plots of DCS risk before and after advice on reducing nitrogen loading during diving with respect to the presence or absence of a patent foramen ovale; DCS risk – DCS events per 10,000 dives multiplied by 10,000

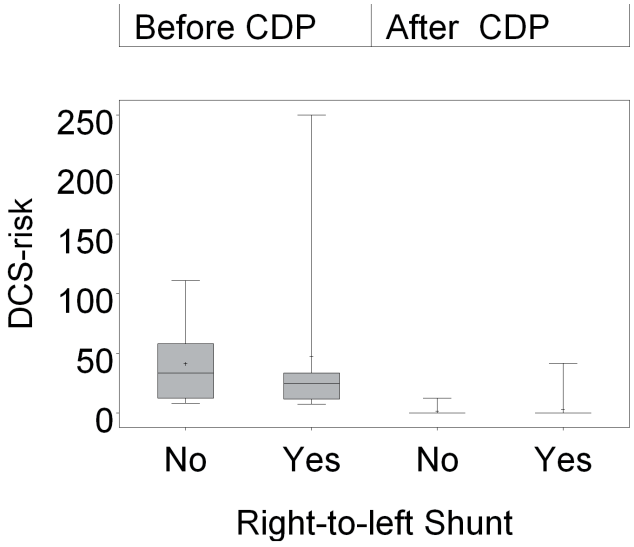
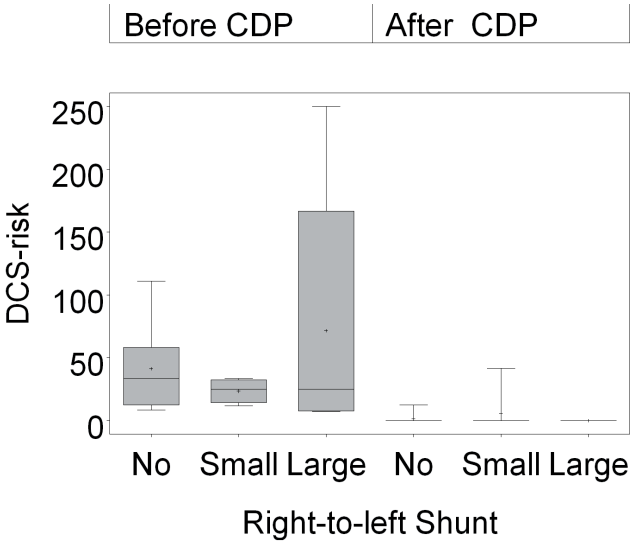


Figure 2
Box plots of DCS risk before and after advice on reducing nitrogen loading during diving with respect to right-to-left shunt size; DCS risk – DCS per 10,000 dives multiplied by 10,000



CDP, only two divers suffered one episode of DCS. Using the McNemar test, this difference is highly statistically significant ($P < 0.001$).

R/L SHUNT

Of the 23 divers who did not have a PFO closure, fourteen divers had a r/l shunt (seven small and seven large r/l shunts) and nine divers had no shunt. The mean DCS risk (multiplied by a factor of 10,000) for divers without a shunt was 41.3 (range 8.0–111) compared to 47.6 (range 7.4–250) for divers with a shunt. After the recommendation of CDP the risk lowered to 1.4 (range 0–12.5) for divers without a shunt and 3.0 (range 0–41.7) for divers with a shunt. This difference was highly significant in both groups ($P = 0.008$ and $P < 0.001$ respectively (Figure 1).

R/L SHUNT SIZE

The mean DCS risk for divers without a shunt was 41.3 (range 8.0 to 111) compared to 23.5 (range 11.8–33.3) for divers with a small shunt and 71.6 (range 7.4–250) for divers with a large shunt. After recommendation of CDP the risk reduced to 1.4 (range 0–12.5) in divers without a shunt, 6.0 (range 0–41.7) in divers with a small shunt and zero in divers with a large shunt. The DCS risk decreased in a highly significant manner after recommendation of CDP in divers with no shunt ($P = 0.008$) and significantly in divers with small or large r/l shunt ($P = 0.031$ and $P = 0.016$ respectively, Figure 2).

Discussion

Although many institutions recommend reduction of nitrogen load or decompression stress to prevent recurrent DCS it is surprising that no studies have been performed to substantiate the success of these recommendations.[25,26] The same applies for recommendations for divers with a r/l shunt. In the 1990s, when a r/l shunt was identified to be a risk factor for DCS, many diving medical specialists promoted a routine examination of divers in order to exclude a shunt. As a result of further studies, it became clear that even though the risk for DCS is increased with a r/l shunt, it remains quite small and the recommendations to screen for a r/l shunt have vanished.[10]

When DCS has occurred, especially after so called 'undeserved' cases of DCS, divers are encouraged to seek screening for a shunt. If a shunt is revealed in a diver who had 'undeserved' neurological DCS, some diving medical societies classify these divers as ineligible to scuba dive.[26] There are also several diving medical specialists who recommend divers with a history of DCS and a positive r/l shunt to undergo closure if it turns out to be a PFO, even though there is no clear evidence to indicate that this intervention reduces the risk of DCS or neurologic events.[16–19]

However, in a 2011 study of 83 scuba divers with a history of DCS and a follow up of 5.3 years, 28 divers had no PFO, 25 had a PFO closure and 30 continued diving with a PFO without closure.[20] At the beginning of the study there were no significant differences between the groups in the number of dives, dive profiles, diving depth or cumulative dives to more than 40 msw. After follow up, whilst there were no differences between the groups in respect to minor DCS events, the risk for major DCS was significantly higher in the divers with PFO and no closure than in divers with PFO

closure or divers without PFO. Although this offers new evidence that PFO closure reduces the risk for major DCS, the authors do not recommend closure in all divers with a history of DCS but rather recommend further studies to confirm these results.

In our study, only four divers underwent PFO closure and these remained free of DCS events thereafter in 1,436 dives. The group size and number of logged dives are insufficient to draw any conclusions about this intervention. In the 14 divers with a PFO but no closure, advice on reducing nitrogen loading simply resulted in an significant absolute risk reduction in DCS incidents. A similar, highly significant reduction in risk was also seen in the nine divers without a shunt. Even when the data were stratified by shunt size, and despite smaller group sizes, the differences remained significant. These data strongly suggest that recommendations for CDP, or possibly simply having had a previous DCS event, results in highly reduced risks of suffering recurrent DCS. Interestingly, the DCS risk after recommendation for CDP in both divers with or without a PFO was less than or equal to the risk of unselected cohorts of divers.[28,29] This outcome requires further study.

Our study has several limitations. Firstly, this is a small retrospective study of divers who were recruited from previous studies conducted at various times. The response rate (32 of 49) from divers whom we attempted to contact was satisfactory, given the extensive time period covered, and only five of these divers had ceased diving. Secondly, although the diagnosis of DCS was confirmed by a diving medical specialist, the divers were not examined by us at the time of their acute presentation with DCS and reporting bias is possible. Thirdly, examination for a r/l shunt was performed by more than one examiner and two techniques were used. Therefore, it is possible that the prevalence of r/l shunt may differ between groups as well as the r/l shunt size. Fourthly, there was no control group that continued to dive without any recommendations to change their diving habits. Finally, it is not possible to be certain that the divers from this study applied CDP.

Whether the risk reduction was as a result of our recommendation or the divers changed their diving habits independently of our recommendations after their first incident of DCS, it remains compelling that there are impressive risk reductions for DCS following the initial incident and counselling. A causal relationship has not been established in this study in the absence of a control group that continued diving without changed diving habits. Despite the limitations of our study, we would encourage hyperbaric units that treat diving accidents on a regular basis to commence a prospective study to address this issue. Given the large risk differences we observed, the study groups could be relatively small and it should be feasible to perform a controlled randomised study, with results from our study being used to inform the relevant power calculation.

Conclusion

We observed a highly significant reduction of DCS risk after providing divers with recommendations for conservative dive profiles (CDP), whether or not they had a r/l shunt. After recommendations for CDP, the risk of suffering recurrence of DCS was smaller than or equal to that of an unselected cohort of divers. Nevertheless, because of the heterogeneity of our small study population we cannot make general recommendations. A prospective, randomised study is needed to confirm our preliminary observations and to provide further information towards the reduction of risk for recurrent DCS.

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