A survey of caustic cocktail events in rebreather divers

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Abstract
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Introduction: Closed-circuit rebreathers (CCRs) are designed to be watertight. Ingressing water may react with carbon-dioxide absorbent in the CCR, which may produce alkaline soda with a pH of 12–14, popularly referred to by CCR divers as a 'caustic cocktail'. This study aimed to explore divers' responses to caustic cocktail events and to investigate if CCR diving experience is associated with experiencing a caustic cocktail.
Methods: An online survey instrument was developed and an invitation to participate was extended to certified CCR divers aged ≥ 18 years. Relationships between number of caustic cocktail events and potential risk factors: age; hours of rebreather diving experience; and number of rebreather dives were explored.
Results: Of the 413 respondents, 394 (95%) identified as male, mean age was 46 years and median length of CCR certification was six years. Fifty-seven percent (n = 237) of respondents reported having experienced a caustic cocktail. The probability of self-reporting none, one, or more caustic cocktail events increased with experience. Divers reported a variety of first aid treatments for caustic cocktails, with ~80% citing their CCR instructor as a source of information.
Conclusions: The more hours or dives a CCR diver accrues, the more likely they will self-report having experienced one or more caustic cocktail events. The majority of CCR divers responded to a caustic cocktail by rinsing the oral cavity with water. A proportion of divers, however, responded by ingesting soda, dairy, juice, or a mildly acidic solution such as a mixture of vinegar and water. The recommendation to immediately flush with water needs reinforcing among rebreather divers.

Introduction

Closed-circuit rebreather (CCR) systems are designed to be watertight and airtight. Bubbles are rarely seen escaping a normally functioning rebreather when it is being used at a constant depth. An exception may be a semi-closed-circuit rebreather, where some of the breathing gas is routinely expelled. In fully-closed rebreathers, when bubbles are seen escaping a leak is indicated and water may be entering the breathing circuit. Ingressing water may mix with the substances packed into the rebreather that absorb carbon-dioxide (CO_2) and a by-product of the consequent reaction between water and the CO_2-absorbing agent is the production of extremely concentrated caustic soda, dissolved NaOH, with a pH between 12–14.[1,2] This mixture is popularly referred to by CCR divers as a 'caustic cocktail'.[3] If this enters the mouth and oropharynx, resulting pain and injury severity may vary from coughing, dyspnoea and dysphagia,[4] through to severe internal corrosive injury.[5]

The Divers Alert Network (DAN) diving incident reporting system (DIRS) collects incident reports from recreational divers, including CCR divers. If the divers supply contact details, then additional information is often sought by DAN in order to compile a more detailed version of events. The incidents are summarised each year in the DAN Annual Diving Report, and the first 500 incidents were recently reviewed.[6] Twenty-six of these (5%) involved rebreathers.[6] In speaking with some of these rebreather divers, it became apparent that there exists a range of home remedies for first-aid treatment after oral contact with caustic soda. These include rinsing with or drinking a mild acid[3] such as a carbonated drink or fruit juice, or to swallow milk or other dairy products.[5]

The accepted first-aid treatment for a oral exposure to caustic soda is to immediately flush repeatedly with water,[7] preferably freshwater but seawater is still effective if this happens to a diver in the sea. Harm will be minimised if the diver immediately removes the rebreather mouthpiece from the mouth and repeatedly flushes the oral cavity with water. However, one diver described waiting till he had exited the water to gargle with soda, reportedly because that is what he was taught during his rebreather diving class. He

also reported suffering burns to the inside of his mouth. In severe cases with the potential for internal corrosive injury, or if symptoms are not mild or improving, it is highly recommended the diver seek medical attention.[8]

It is not known who suffers caustic cocktail events, how soon they occur after rebreather certification, how long into the dive they occur, how frequently they occur, or how divers respond to these incidents. This study aimed to explore divers' responses to caustic cocktail events and to investigate if CCR diving experience is associated with experiencing a caustic cocktail.

Methods

Ethics approval was granted by the Institutional Review Board of Divers Alert Network, approval 023-18 dated 6 April 2018.

A survey instrument was developed and assessed for face and content validity, then hardcopies were pilot-trialled at Boston Sea Rovers, a large recreational diving trade show in the USA. Following this trial, an online version was developed, a second pilot trial undertaken, and minor revisions made. The invitation to participate was extended to certified CCR divers aged 18 years or older. A link to the survey instrument was published on the DAN website as an ongoing research project. The link was shared through DAN's social media outlets (Facebook, Instagram and Twitter) and launch of the study was advertised during four different webinars in the fall of 2020, targeting the recreational and technical diving community. The survey was online from 9 September 2020 to 1 March 2021. Participants were presented with a participant information page and required to anonymously indicate consent before proceeding to the survey. The survey instrument collected data on the divers' age and sex, CCR diving experience, the source of their knowledge of how to respond to a caustic cocktail event and each diver's experiences with caustic cocktail, whether personally experienced or witnessed. The structure of the survey is shown in Figure 1.

Figure 1
Online survey structure flowchart

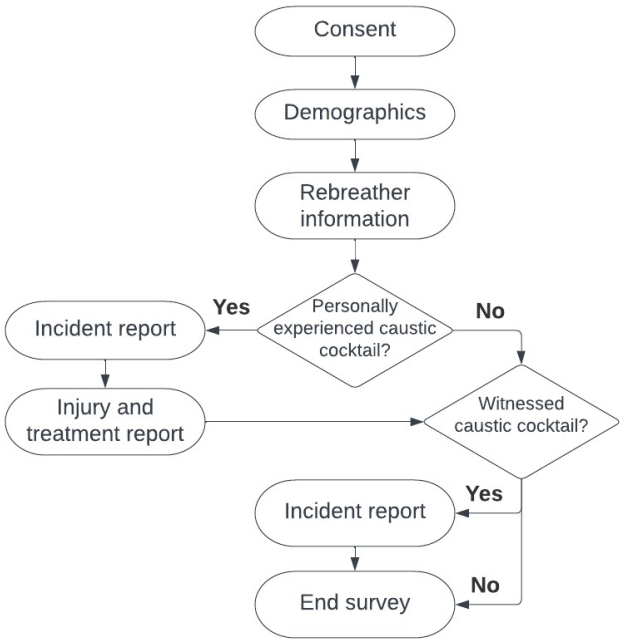
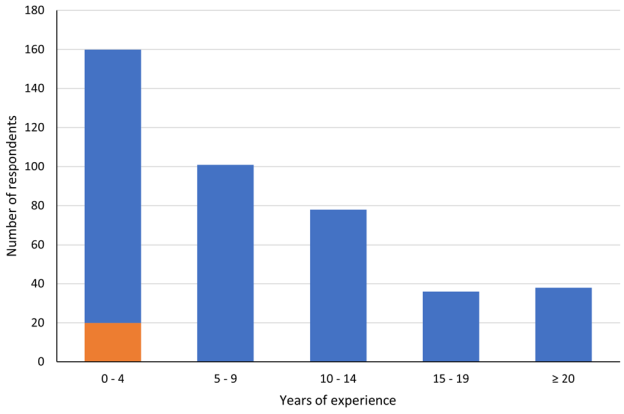


Figure 2
Number of years of experience diving with rebreathers among the 413 respondents; orange subsection represents divers with less than one year of experience



ANALYSIS

Data were stored in Microsoft Excel and analysed using SAS version 9.4 (SAS, Cary NC, USA). Frequencies are reported by counts and percentages. Normally distributed variables are described by means and standard deviations (SD), whereas variables with non-parametric distributions are described with medians and inter-quartile ranges (IQR). The relationships between number of caustic cocktails personally experienced and type of rebreather configuration preferred was explored using a chi-square test, with odds ratio (OR) and 95% confidence intervals (CI) estimated.

Self-reported pain scores were tested for normality using a Shiparo-Wilks test and, being non-normally distributed, the association between pain and seeking medical treatment was assessed using a logistic regression, which does not rely on a Gaussian distribution of residuals.

Potential risk factors (age, hours of rebreather diving experience, and number of rebreather dives) were explored for association with a caustic cocktail event using an ordinal logistic regression model, with four outcome levels, (0, 1, 2, ≥ 3 experiences). The model was parsimoniously optimised using backwards elimination, with the goodness of fit assessed using the log likelihood ratio test (LLRT). At each stage a chi-square score test tested the proportional odds assumption. Regression parameters were iteratively estimated using Fisher's scoring method. Significance was accepted at $P < 0.05$.

Table 1
Reported preferred rebreather configurations

Configuration	Frequency *n* (%)	Caustic cocktail *n* (%)
Back-mount	312 (76)	167 (53)
Side-mount	34 (8)	30 (88)
Chest-mount	32 (8)	20 (63)
Back-mount and side-mount	19 (5)	12 (63)
Back-mount and chest-mount	9 (2)	4 (44)
All three configurations	1 (0)	1 (100)
Missing	6 (1)	0 (0)

Table 2
Reported sources of advice for responding to a caustic cocktail; EMS – emergency medical services

Advice	*n* (%)
Instructor during training	322 (78)
Manufacturer	117 (28)
Dive team members / divers at dive site	109 (26)
Social media	55 (13)
Medical professional (diving physician / EMS)	51 (12)
Divers Alert Network	30 (7)

Table 3
Frequency of personally experienced caustic cocktails

Number of events	Age Mean (SD)	Number of dives Median (IQR)	Number of hours Median (IQR)	Total
0	45 (10)	200 (81–400)	250 (92–550)	175 (42)
1	48 (10)	200 (100–500)	300 (137–700)	174 (42)
2	46 (10)	442 (200–1,000)	600 (300–2,000)	46 (11)
≥ 3	49 (8)	700 (450–2,700)	1,000 (450–2,700)	17 (4)

Results

Of the 413 respondents, 394 (95%) identified as male and mean age was 46 years (SD 10). Respondents reported a total of 3,492 years of experience since first certified to dive rebreathers (median 6 years, IQR 3–12), 177,330 CCR dives and 278,279 CCR diving hours. The median number of self-reported dives was 200 (IQR 100–500) and the median reported hours of rebreather diving was 300 (IQR 120–750). Forty-four participants (11%) reported ≤ 50 hours experience. The range of years of experience is shown in Figure 2. The rebreather configurations used, and the respective proportion of users reporting a caustic cocktail are presented in Table 1.

After excluding multiple configuration sub-groups ($n = 29$ participants, < 1%) and the six missing configurations, compared with chest-mount, the odds of reporting having experienced a caustic cocktail event were lower in back-mount divers (OR 0.69, 95% CI 0.32, 1.45) and greater in side-mount divers (OR 4.50, 95% CI 1.27, 15.95), as shown in Table 1.

There were 37 manufacturer brands named by the participants. When asked if they self-pack their CO_2 scrubbers, 23 (6%) reported using pre-packed cartridges, and 389 (94%) reported refilling their own scrubbers, (one did not report their preference). It is worth noting that the ability of using pre-packed cartridges is determined by design of the rebreather, some models allow for both options.

CAUSTIC COCKTAIL EXPERIENCE

Regarding the participants' reported sources of advice for what to do in the event of experiencing a caustic cocktail, the various responses are shown in Table 2.

Other reported sources of advice for what to do in the event of a caustic cocktail included books, magazine articles, internet searches, and internet forums. Fifty-seven percent (n = 237) of respondents reported having personally experienced a caustic cocktail. One hundred and seventy-five participants (42%) reported not having experienced a caustic cocktail themselves. The frequency of personally experiencing a caustic cocktail among those 237 participants is presented in Table 3.

Fitting age, dives, and hours to the ordinal logistic regression model with reported number of caustic cocktails experienced as the outcome variable, age was removed first as least-significant (P = 0.09), and the fit of the model was not significantly worse off (LLRT $P > 0.05$). Next for removal

was the variable 'hours of experience on CCR', ($P = 0.07$) but this significantly worsened model fit (LLRT $P < 0.05$) therefore the optimised model shown in Equation 1 retained number of hours experience and number of dives experience. The proportional odds assumption held true at each stage of the model optimisation.

$$Ln\left(\frac{P_j}{1-P_j}\right) = \alpha_i + (0.000488\ Dives + (0.000192)\ Hours$$

Eq. 1

The modelled probability of outcome state j, (of 1, 2 or ≥ 3 caustic cocktails experience, compared with no caustic cocktail history), is P_j, where $\alpha_1 = 0.0108$, $\alpha_2 = -2.1017$ and $\alpha_3 = -3.6171$; *Dives* is the number of CCR dives; and *Hours* is the number of hours rebreather diving experience. In this sample of CCR divers, for every 100 additional dives, the odds of self-reporting an additional caustic cocktail increased by 5%, (OR 1.05, 95% CI 1.009, 1.093), and for every 100 additional hours of experience, the odds of self-reporting an additional caustic cocktail increased by 2% (OR 1.019, 95% CI 0.999, 1.041).

Regarding the most recent dive during which participants had experienced a caustic cocktail, the event occurred after a median of 40 minutes (IQR 10–60) into the dive. After the caustic cocktail occurred, the first thing the participants reported flushing their mouth with, drank, or ate in immediate response are presented in Table 4.

On a scale from 1 to 10, with 1 being minimal and 10 being maximal, the reported pain scores after experiencing the caustic cocktail are shown in Figure 3. Of the 237 divers (57%) who reported having experienced a caustic cocktail, n = 34 (14%) reported having sought medical advice, including 10 who contacted the DAN medical assistance helpline. The median pain score for participants who did not seek medical treatment was 2 (IQR 1–4) and the median score for participants who did was 5 (IQR 3–7), OR 1.4 (95% CI 1.2, 1.6). Twenty-two of the 237 divers (9%) reported taking medications as a result of the caustic cocktail.

Discussion

The proportion of respondents who identified as male is far higher than found during the Behavioural Risk Factor Surveillance System surveys of US divers,[9] 'Discover Scuba' participants worldwide,[10] or in other large surveys of recreational divers. Why such a high proportion of responding rebreather divers should be male is unknown, though this is a survey of divers with an interest in reporting a link to caustic cocktails, not a randomly sampled representative sub-set of CCR divers. The reported median of 200 dives over a median of six years is similar in scale to the estimated average of 30 dives per year per recreational rebreather diver made in a study of CCR fatalities.[11]

Figure 3
Distribution of pain scores after experiencing a caustic cocktail

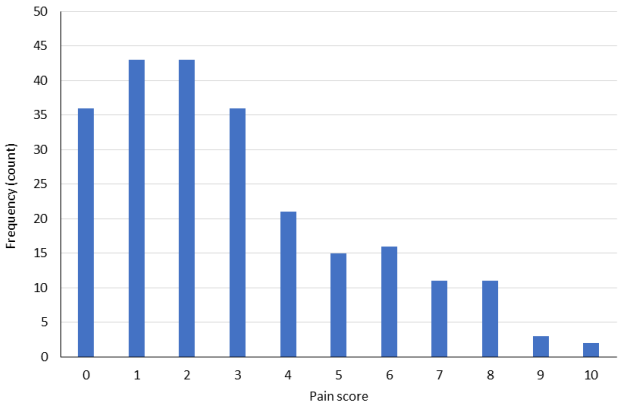


Table 4
First-aid treatment for most recent personally experienced caustic cocktail events

Treatment	*n* (%)
Water	186 (79)
Soda	19 (8)
None	10 (4)
Milk / yoghurt	6 (3)
Fruit juice	5 (2)
Mild acid	5 (2)
Other	4 (2)
Total	235 (100)

We cannot draw inference from Figure 2 regarding when a caustic cocktail may be experienced by CCR divers, other than to conclude they were reported by divers with less than one year of CCR experience through to divers with more than 20 years of experience. There appeared to be no difference in age between divers reporting 1, 2 or ≥ 3 caustic cocktail experiences. The number of experiences with caustic cocktails did appear associated with exposure, both in number of hours rebreather diving and number of rebreather dives. In this study, divers with 1–5 years of experience were the most frequent group to respond to our survey to report experiencing or witnessing caustic events. In short, it appears a caustic cocktail event can happen at any stage of a rebreather diver's CCR diving, but the more hours and more dives experience they accrue, then the more likely they will experience a caustic cocktail event, regardless of whether they have experienced one previously. The odds of reporting having experienced a caustic cocktail event were lower in back-mount divers than in chest-mount divers, and greatest in side-mount divers. Survey study designs cannot investigate causality however, so prospective research is needed to determine if any particular configuration is more prone to water ingress, bearing in mind that different configurations are used in different environments.

Many respondents reported low pain scores associated with caustic cocktail events, and a minority reported extremely high pain scores, but pain scores were missing for nearly half the participants. Perhaps unsurprisingly, among those who did report pain scores, (n = 237, 57%), there appeared to be an association between higher pain scores and the odds of seeking medical treatment.

LIMITATIONS

Future research should explore differences between rebreather divers who have experienced a caustic cocktail and rebreather divers who have not, preferably prospectively. This survey, as with surveys in general, suffers from many limitations such as non-random sampling, and the results may not be representative of rebreather divers in general. Even so, the relationships between self-reported variables may offer some insight into the caustic cocktail experience. To our knowledge, this is the largest online survey of rebreather divers, and the first subjected to peer-review.

Conclusions

Caustic cocktail events can occur at any time on the spectrum of CCR diving experience, but the more hours and/or the more dives a CCR diver accrues, the more likely they will self-report having experienced one or more caustic cocktail events. Where the response to a caustic cocktail event was reported, the majority of CCR divers responded by rinsing the oral cavity with water, having been advised to do so by their instructor during rebreather dive training. A proportion of CCR divers, however, responded by ingesting soda, dairy, juice, or a mildly acidic solution such as a mixture of vinegar and water (a treatment recommended in the 1970s).[3] The recommendation to immediately flush with water[7] needs reinforcing among rebreather divers and emphasis should be placed on educating rebreather instructors who, according to our findings (Table 2), are the primary source of advice for most rebreather divers.

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