Short communication

Efficacy and safety of potential irrigation diluents following 'caustic cocktail' ingestion

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Abstract

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Closed circuit rebreather (CCR) diving sets use soda lime, a sodium hydroxide-based 'scrubber' substance to remove CO_2 from exhaled breathing gas thus prolonging dive time and efficiency. Inadvertent water ingress into the set may result in reaction with the scrubber and a highly alkaline solution known as a 'caustic cocktail' may be formed. Ingestion or aspiration of this solution can cause severe chemical burns. Irrigation with freshwater is the mainstay of initial treatment of 'caustic cocktail' injuries in CCR divers. Published advice advises divers never to use acidic diluents to irrigate and neutralise a caustic cocktail solution due to concerns over the potentially exothermic nature of the neutralisation reaction. However, there is limited available evidence to support this advice, and it was felt that further research into the best treatment options available for caustic cocktails is required. This study used an *in vitro* model of an ingested caustic cocktail to investigate pH and temperature changes after adding different diluents (including acidic diluents orange juice or coca cola) to a solution of sodium hydroxide. Acidic diluents reduce pH significantly more than neutral diluents with a respective mean drop in pH of 5.99 compared to 0.78 (P = 0.015). There is no statistically significant difference in temperature change noted between the two types of diluent (P = 0.32) with no exothermia generated. We propose that orange juice or coca cola are more effective irrigation solutions than fresh or seawater, and that advice to divers who use CCRs could change.

Introduction

Closed circuit rebreather (CCR) systems are popular amongst commercial, military and recreational divers, offering extended dive times, more efficient and quieter dives with an absence of bubbles. They remove CO_2 from exhaled gases via a soda lime scrubber. Scrubbers can contain a range of substances, but most feature a significant quantity of sodium hydroxide. Any water that ingresses into the scrubber may react with the soda lime, forming a highly alkaline liquid 'cocktail' comprised primarily of sodium hydroxide solution (Figure 1), within the breathing loop of the CCR. The diver breathing from this system may then aspirate or ingest this caustic cocktail. This can cause acute, necrotic caustic burns of the airway and oesophagus[1] with the mechanism of this injury due to saponification of fats.[2]

The current Diver's Alert Network (DAN) recommendation for immediate first aid[3] is to repeatedly flush the diver's oesophagus with freshwater, to reduce the contact time between caustic cocktail and oesophageal tissues, and to dilute the caustic liquid. UK military divers are similarly instructed as per defence doctrine to use freshwater as the preferred diluent. There is widespread informal resistance to the use of acidic diluents in the diving medicine community based on fears of generating an exothermic reaction during neutralisation and there is specific published advice available stating that affected divers should never use acidic diluents as part of the treatment process.[4] Dilution of the caustic liquid by any less alkaline diluent (such as freshwater) is known to reduce the pH of the ingested mixture, but it was predicted that a mildly acidic diluent (rather than approximately neutral) would do so more rapidly thus minimising 'burn time'. It was unknown if using a mildly acidic diluent to help neutralise an alkaline caustic solution generated a clinically significant exothermic reaction, which could in turn cause further tissue damage. An effective diluent would be one that reduces the pH of the caustic cocktail without making it overly acidic, whilst not generating any significant level of exothermia. We identified a need to investigate pH reduction, over the dilutional effect alone, and the associated potentially exothermic nature of this reaction.

Figure 1
A caustic cocktail solution drained from a CCR set following a UK military diving exercise

Various diluents have been suggested but there is a limited evidence base regarding their ability to alter the pH of the caustic liquid or whether this neutralisation itself may cause exothermic damage to tissues.[5] Diluents such as cola drinks and fruit juice have been proposed given their acidity and potential to more effectively neutralise the caustic solution. There is evidence suggesting that acidic neutralisers prolong a potential exothermic reaction compared to diluents such as water or milk.[6] Alternative evidence suggests that orange juice reduces pH without increasing temperature and that thermal generation is dependent on volume of fluid but independent of type of fluid, whilst pH is independent of volume but dependent on type of fluid.[7] A 1997 canine study found that the addition of 75 ml orange juice to a 50% sodium hydroxide solution within the gastric lumen of 18 subjects caused a temperature reduction in both the lumen and mucosa of 2.1°C and 1.1°C respectively. Where freshwater was used as a diluent, temperature reductions of 2.4°C and 2.1°C were observed.[8] This supports the suggestion that using a mildly acidic diluent does not increase the risk of exothermic injury.

Our study aimed to investigate whether diluents other than freshwater have the potential to reduce pH more quickly and to document the extent, if any, of the exothermic nature of this neutralisation.

Methods

This was a single centre, demonstration-of-concept, observational study.

Diluents tested were freshwater, seawater, cola soft drink (Coca-Cola brand) and orange juice. These diluents were selected as they are the standard suggestions for first aid and are portable for remote dive teams. Milk was excluded as this is not practical for dive teams to carry.

All investigations took place in a temperature and humidity-controlled chamber, with parameters set to 35.0–37.0°C and 60–70% humidity. This temperature allows for a measurement of the neutralisation and exothermic reactions in the context of the temperature of the normothermic human body. The controlled humidity prevented variation in evaporation of solutions and is approximate to the humidity range used in diving equipment to maintain comfortable breathing and prevent dehydration.[9]

The pH of the sodium hydroxide solution and the diluents was tested and recorded prior to use.

The samples were not randomised as an observer would be able to distinguish diluents by their appearance and smell.

A single trial was conducted for each diluent. We combined the datasets for the orange and coca cola trials and for the salt water and freshwater trials to assess for a difference between acidic and neutral diluents.

pH and temperature measurements were carried out in 1 L conical flasks. The conical flask is a model for the contained environment of the oesophagus *in vivo*. Five test sets were assembled:

a. 50 ml sodium hydroxide
b. 50 ml sodium hydroxide + 300 ml freshwater added at 60 seconds
c. 50 ml sodium hydroxide + 300 ml cola drink added at 60 seconds
d. 50 ml sodium hydroxide + 300 ml orange juice added at 60 seconds
e. 50 ml sodium hydroxide + 300 ml salt water added at 60 seconds

Baseline pH and temperature were measured at commencement using digital thermometers and pH meters. The pH meters were calibrated with known pH solutions prior to the experiment beginning. Thermometers were similarly calibrated. The pH and temperature probes were immersed in the solution being tested. Diluents were added at 60 seconds. Thereafter pH and temperature were measured every 10 seconds for first two minutes, every 30 seconds from two minutes to four and a half minutes with final observations at 30 minutes and 60 minutes.

Results

No clinically significant exothermia was detected in any of the tests carried out. The mean change in temperature of the acidic diluents was -5.85°C (standard deviation [SD] 0.05) and the mean change in temperature of the neutral diluents

Table 1
pH and temperature changes throughout duration of testing

Time (s)	Control		Fresh water		Salt water		Cola drink		Orange juice	
	Temp °C	pH	Temp °C	pH	Temp °C	pH	Temp °C	pH	Temp °C	pH
0	33.5	11.93	31.8	11.89	32.4	11.92	34.1	11.89	34.1	11.77
10	35.9	12.04	26.3	11.76	25.8	10.49	28.3	7.03	28.2	4.66
20	35.9	12.02	26.5	11.68	25.8	10.32	28.5	6.29	28.2	4.54
30	36.0	11.98	26.6	11.65	25.8	10.18	28.5	6.2	28.5	4.47
40	36.1	11.97	26.8	11.62	25.1	10.09	28.5	6.16	28.6	4.44
50	36.1	11.92	27.0	11.60	26.0	10.01	28.5	6.14	28.9	4.41
60	36.1	11.95	26.4	11.58	26.1	9.97	28.8	6.14	29.0	4.4
70	36.1	11.95	26.8	11.58	26.1	9.9	28.8	6.14	29.1	4.39
80	36.3	11.94	27.0	11.58	26.2	9.87	28.8	6.13	29.2	4.39
90	36.5	11.94	27.1	11.58	26.4	9.86	28.9	6.12	28.7	4.37
100	36.6	11.94	27.3	11.57	26.3	9.85	28.9	6.12	28.8	4.37
110	36.5	11.94	27.5	11.57	26.4	9.83	28.9	6.12	28.9	4.36
120	36.4	11.94	27.5	11.57	26.4	9.82	29	6.13	29.0	4.36
150	36.5	11.94	27.7	11.57	26.4	9.81	29.1	6.12	28.9	4.34
180	36.4	11.94	27.9	11.56	26.4	9.79	29.5	6.12	29.1	4.35
210	36.5	11.94	28.0	11.56	27.1	9.76	29.5	6.12	29.4	4.35
240	37.1	11.94	28.2	11.56	27.1	9.75	29.4	6.12	29.6	4.34
270	37.5	11.94	28.5	11.56	27.5	9.74	29.4	6.12	29.3	4.34
300			28.5	11.56	27.7	9.73	29.4	6.12	29.6	4.34
1800			31.2	11.48	31.1	9.52	32.1	6.20	32.9	4.29
3600			33.2	11.41	33.1	9.42	33.8	6.24	34.8	4.27

was -6.05°C (SD 0.55). The pH was reduced substantially more by addition of acidic diluents than neutral diluents; the mean change in pH of the acidic diluents was -5.99 (SD 1.125) and for the neutral diluents was -0.78 (SD 0.65). Changes in temperature and pH over time are shown for the various combinations of caustic solution and diluents in Table 1 and Figures 2 and 3.

Discussion

These results may provide an initial evidence-base to guide recommendations for first aid actions to be taken in caustic cocktail incidents.

We demonstrated that there is no exothermia generated by any of the diluents used, and hence mildly acidic diluents should not be discounted based on concerns over further injury being caused by heat generation. Instead, we observed that all diluents reduced the overall temperature of the mixture as they were held at normal room temperature outside the controlled chamber. Furthermore, the acidic diluents used reduced pH of the cocktail solution significantly more than pH neutral diluents. This supports our suggestion that neutralisation of the alkaline solution may be better achieved with household acidic drinks than with neutral diluents. As the acidic diluents used are both approved for and regularly consumed by humans, we know that there is no risk of their inherent acidity resulting in tissue damage. The lowest pH mixture we measured was 4.27, although Coca Cola alone was measured to have a pH of 2.74. Further study would be required to better understand if subjecting injured tissue to a greater pH absolute change is more harmful than reducing it to a neutral pH.

Only a single trial was conducted for each diluent as a demonstration of concept. However, we did observe a substantial difference between the acidic and neutral diluents.

There are limitations to extrapolating this work to the *in-vivo* setting. The *in-vitro* model of this work allowed us to control for endogenous temperature and pH fluctuations. The absolute nature of the temperature and pH changes in an *in-vivo* setting will depend on many factors including body temperature, diluent temperature, gastric pH, and oesophageal pH. It does not take into account the human body's own physiological buffering systems, although these are likely to have limited effect given the very high pH of a typical caustic cocktail solution.

Further testing would be required on living tissue to assess for any specific gross damage caused by a particular combination of diluent and caustic solution. However, in this study nothing has been identified that would rule out any of the diluents being used as a potential first aid measure.

We acknowledge that the ability of the diluent to wash away the caustic cocktail from the affected tissue is not measured. However, this is likely to be a constant for all diluents tested and has no bearing on pH reduction or exothermia.

Figure 2
Figure illustrating absence of clinically significant exothermia generated during testing; gradual warming of all solutions reflects background temperature of the heat chamber (~37°C)

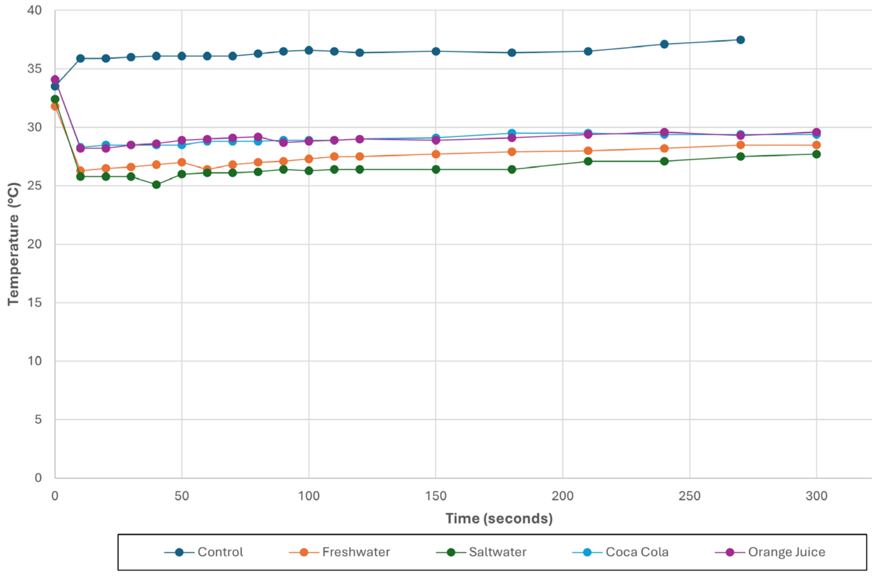
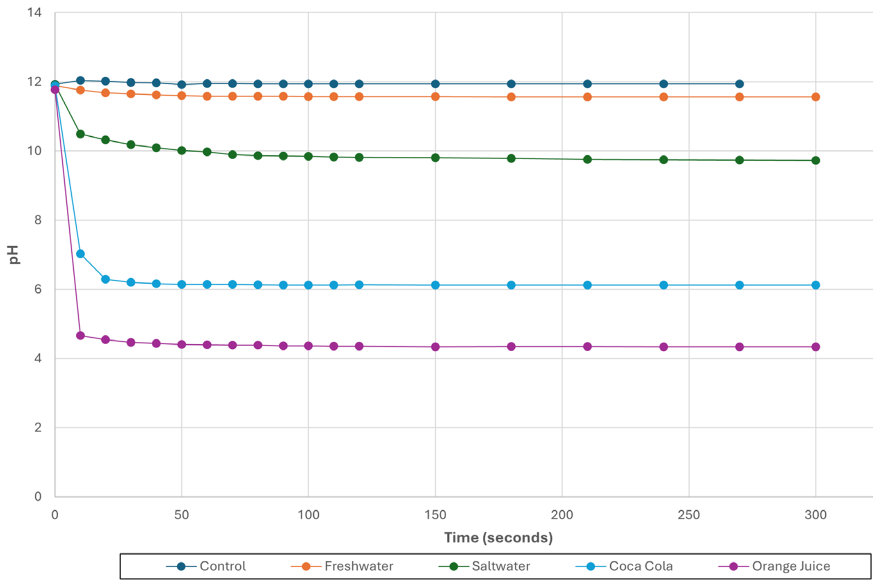


Figure 3
Figure demonstrating improved pH reduction using mildly acidic diluents in comparison to neutral diluents



Conclusions

This observational study indicated that mildly acidic diluents are more effective neutralising agents than their more alkaline counterparts. They reduce pH more quickly and do not generate exothermia to any significant extent. Where freshwater was used there was almost no reduction in pH. This study highlights that traditional guidance for the first aid management of caustic cocktails should be reviewed. We suggest that mildly acidic diluents should be considered as an alternative to water for flushing of the oral cavity, and ingestion for oesophageal flushing, as part of the first aid management of caustic cocktail injury patients. Guidance for CCR divers, supervisors and those at risk of caustic cocktail ingestion may be changed to reflect this. This area would benefit from further study using a wider range of diluents and using live tissue models.

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Conflicts of interest and funding

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