Rebreather Forum Four consensus statements

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Abstract

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Closed circuit rebreathers have been widely adopted by technical divers as tools for reducing gas consumption and extending depth and duration capabilities. Rebreathers are technologically complex with many failure points, and their use appears associated with a higher accident rate than open circuit scuba. Rebreather Forum Four (RF4) was held in Malta in April 2023 attracting approximately 300 attendees and representatives of multiple manufacturers and training agencies. Over two and a half days a series of lectures was given by influential divers, engineers, researchers and educators on topics of contemporary relevance to rebreather diving safety. Each lecture was followed by a discussion session with audience participation. Potential consensus statements were drafted by the authors (SJM and NWP) during the course of the meeting. These were worded to be confluent with some important messages emerging from the presentations and subsequent discussions. The statements were presented one by one in a half-day plenary session of participants, and discussion was invited on each. After discussion and any necessary revision, the participants voted on whether to adopt the statement as a position of the forum. A clear majority was required for acceptance. Twenty-eight statements embracing thematic areas designated 'safety', 'research', 'operational issues', 'education and training', and 'engineering' were adopted. Those statements are presented along with contextualising narrative where necessary. The statements may help shape research and teaching initiatives, and research and development strategies over subsequent years.

Introduction

The use of rebreather devices to facilitate deeper and longer dives has become common among so-called 'technical divers'.[1] Rebreathers offer several important advantages, including minimisation of gas consumption and optimisation of inspired pressure of oxygen throughout a dive. These are important advantages when attempting to reduce the use of expensive gases like helium, and to optimise the efficiency of decompression. Rebreathers are complex devices with more failure points than typical open circuit scuba, and it is not surprising that their use seems associated with a significantly higher accident rate.[2]

Such is the importance of rebreather technology to the technical diving community that over several decades this single item of equipment has been the subject of four focused conferences designated Rebreather Forums One through Four. Presentations and discussions at these forums have focussed primarily on technological developments, relevant research, and training and safety issues. Rebreather Forum Three (RF3) held in Orlando, Florida, in 2012 was arguably the first of the four meetings held in an era of widespread adoption of rebreathers. Rebreather Forum Four (RF4) was held in Malta in April 2023 attracting approximately 300 attendees and representatives of multiple manufacturers and training agencies. Over two and a half days a series of lectures was given by influential divers, engineers, researchers and educators on topics of contemporary relevance. Each lecture was followed by a discussion session with audience participation.

Following a precedent set at RF3[3] the final half day of RF4 was dedicated to discussion of a series of consensus statements intended to reflect current evidence and strongly supported opinion of the presenters and participants on important contemporary issues.

Methods

Potential consensus statements were drafted by the authors (SJM and NWP) during the course of the meeting. These

were worded to be confluent with important messages emerging from the presentations and subsequent discussions. The statements were not intended to capture all important messages to emerge from the forum; the authors focused on matters that seemed important, widely supported and relatively non-controversial, and that would therefore lend themselves to meaningful consensus.

The statements were presented one by one to a half day plenary session of participants and discussion was invited on each. The amount of discussion was variable with some statements attracting little, and others requiring more debate and wordsmithing which was performed live. As is the case with sessions of this nature some degree of directive chairmanship was required in order to work through the list of statements within the allocated time. For this reason, discussion of some statements had to be truncated but there was substantial discussion of all statements that emerged as controversial for any reason. For transparency, a transcript of the discussion will be presented in the forum proceedings. After discussing each statement a show of hands was taken to gauge agreement and disagreement with the statement. It was announced prospectively that a clear majority of participants would need to agree for a statement to make the published list. Ultimately, after discussion and rewording where necessary, all draft statements were accepted; most unanimously and never with more than 5–10% in disagreement.

The 28 statements are presented in thematic areas designated 'safety,' 'research,' 'operational issues,' 'education and training,' and 'engineering.' The authors acknowledge that some of these statements seem relevant to multiple themes. Most are self-explanatory, but some are accompanied by contextualising narrative from the authors where necessary.

Statements

THEMATIC AREA 'SAFETY'

Accident data

Analysis of contemporary rebreather accident data indicates a continued need for integrated effort to reduce the rates of injury, morbidity, and mortality associated with rebreather diving.

Cardiac health surveillance

The forum endorses the principle of periodic cardiac health surveillance for all rebreather divers with an emphasis on targeted annual or biennial evaluation for divers older than 45 years even in apparent good health.

Contextualising narrative: the forum resolved that this statement should be accompanied by citation of relevant supportive medical literature. Various studies have identified the importance of cardiac events as the disabling injury in recreational diving fatalities,[4,5] and an expert consensus guideline for cardiac evaluation of divers was recently published.[6]

Accident analysis

The analysis of accident, incident, and injury data from rebreather incidents should consider wider contextual elements and error-producing conditions and not just immediate contributory factors.

Solo diving

The forum recognises that solo diving may increase the likelihood of a fatality in the event of a rebreather diving incident.

Pre-entry checklists

The forum strongly advocates the use of a pre-entry checklist (in a check and response format if practicable) administered just prior to water entry. This should be a brief checklist addressing contextually relevant critical safety items such as "*rebreather switched on*," "*oxygen cylinder on*," "*diluent cylinder on*," "*wing/buoyancy device/dry suit inflation connected and working*."

THEMATIC AREA 'RESEARCH'

Training and sales data

The forum strongly endorses continued collection of anonymised rebreather diver training and rebreather unit sales data by the Divers Alert Network (DAN) Research Department as an adjunct to interpreting diver accident statistics.

Mishap and near-miss reporting

The forum advocates self-reporting of diving mishaps and near-misses, and reporting of fatalities, to the DAN diving incident reporting system.

Contextualising narrative: The DAN diving incident reporting system was nominated in this statement because of its high visibility, global scope, and accessibility for divers anywhere in the world. However, the forum also acknowledged the value of national or regional systems of relevant data collection and analysis (such as that run by the British Sub-Aqua Club [BSAC]) and also advocates for maintenance of diver reporting to such systems. Data sharing between DAN and regional groups was also discussed and was supported.

End-tidal CO_2 monitoring

The forum identifies as a research priority/goal the development of capnography and accurate end-tidal CO_2 monitoring for rebreathers.

Regenerating CO_2 absorption technology

The forum identifies as a research priority the development of regenerating CO_2 absorption technologies.

Full-face masks

In relation to a documented RF3 research priority, the forum recognises the emergence of data pertaining to the efficacy of full-face masks in preventing water aspiration in unconscious subjects.[7] This strengthens the argument for considering their use in scenarios associated with an elevated risk of oxygen toxicity such as in-water recompression.

Real-time physiological monitoring

The forum endorses ongoing research into strategies for real-time diver physiological monitoring.

THEMATIC AREA 'OPERATIONAL ISSUES'

Bailout rebreathers

The forum identifies as a priority or goal the development and documentation of practices and/or monitoring for optimising bailout rebreather use.

Mouthpiece retaining straps

The forum recognises the use of correctly deployed mouthpiece retaining straps as a strategy for avoiding loss of the mouthpiece and minimisation of water aspiration in the event of loss of consciousness underwater.

Bailout valves

The forum recognises the potential advantage of a bailout valve for transitioning from closed- to open-circuit in the event of hypercapnia or other events requiring bailout; this advantage requires a high performance open-circuit breathing system.

Mixed mode diving

The forum recognises mixed mode diving as a legitimate buddy option in dives of appropriate scope but recommends a mixed mode briefing, and pre-establishment of strategies for gas sharing.

Contextualising narrative: 'Mixed mode' in this context refers to divers using different underwater breathing apparatus types working as a buddy pair, for example, an open-circuit diver diving with a rebreather diver.

Mixed platform diving

The forum recognises mixed platform diving as a legitimate buddy option and recommends at least a mixed platform briefing with emphasis on emergency procedures.

Contextualising narrative: 'Mixed platform' in this context refers to divers using different brands or models of the same underwater breathing apparatus type working as a buddy pair, for example, two divers using different brands of rebreather.

Bailout rebreather symmetry

The forum recognises symmetric (same rebreather unit) or asymmetric (different rebreather unit) multiple rebreather systems as options for an alternative breathing or bailout system.

Contextualising narrative: 'Symmetric' in this context refers to multiple rebreathers of the same make and type, and 'asymmetric' refers to multiple rebreathers of different makes or types.

Head-up Display

The forum recommends the display of safety-critical information such as loop oxygen status on a head-up display.

Expedition standard operating procedures and emergency action plan documentation

The forum endorses the compilation of a contextually tailored and detailed dive plan/standard operating procedures document and emergency action plan prior to rebreather diving expeditions.

Emergency preparedness

The forum endorses the importance of emergency preparedness including a validated emergency action plan, oxygen supplies, access to appropriate medical support with adequate medical supplies, and evacuation plans during rebreather diving expeditions; particularly to remote locations.

In-water recompression

The forum recognises the recent medical endorsement of emergency in-water recompression of selected divers by appropriately equipped teams trained in oxygen decompression.[8,9]

THEMATIC AREA 'EDUCATION AND TRAINING'

Manufacturer-training agency coordination

The forum recognises the challenges for training agencies in maintaining confluence between course content/availability and emergence of new rebreather technologies. The forum endorses close liaison between training agencies and manufacturers (including factory trainers) to share information about emerging technologies and manufacturer expectations on training approaches using their platforms.

Knowledge gap targets

The forum identifies the following as common knowledge gaps that constitute educational opportunities for rebreather instructors and leaders to address:

– Predispositions, symptoms, and frequency of immersion pulmonary oedema
– Increasing risk of deeper dives executed perfectly on the same decompression algorithm (i.e., these are not iso-risk exposures)
– Scope of variability in venous gas emboli counts in individual divers serially performing identical dives and the associated implications for interpretation of individual monitoring of venous gas emboli post-dive
– The difference between CO_2 inhalation and hypoventilation as the two mechanisms of hypercapnia in rebreather diving
– Correct management of ingestion/inhalation of caustic scrubber by-product (i.e., a 'caustic cocktail')
– Functional characteristics of CO_2 scrubbers

Contextualising narrative: It is emphasized that this list is not intended to define all relevant knowledge gaps. Rather, it contains items that emerged as obvious educational opportunities in the various presentations and discussion at Rebreather Forum 4.

Diver retraining/updating

The forum recognises the potential for skill and knowledge degradation over time or during periods of diving inactivity and encourages training agency initiatives to promote continuing education and training, refresher options, and/or recertification as appropriate.

THEMATIC AREA 'ENGINEERING'

Oxygen sensor replacement warning

The forum recommends that manufacturer's consider incorporating oxygen sensor replacement warnings in rebreather operating systems.

Contextualising narrative: The context in which this discussion took place was that these warnings would be based on elapsed time since sensor manufacture.

Gas density warning

The forum recommends that rebreather manufacturers consider incorporating gas density displays and/or alarms in the user interface.

Contextualising narrative: The discussion around this statement included strong advocacy for viewing gas density as a dive planning and operational concern that requires careful consideration. Reference was made to recently published data identifying an inspired density threshold of 6 $g \cdot L^{-1}$ beyond which the risk of CO_2 retention rises significantly, especially during exercise.[10]

Orientation monitoring

The forum identifies optimally positioned accelerometers or inclinometers within rebreathers as an opportunity for capturing diver trim and movement data that could be used for training, performance, and forensic evaluation.

Inspired CO_2 monitoring

The forum recognises the potential safety advantage of inhale side CO_2 or scrubber monitors, but acknowledges that they may fail to detect some causes of hypercapnia.

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Conflicts of interest and funding

Professors Mitchell and Pollock are members of the *Diving and Hyperbaric Medicine* Editorial Board. However, this publication is a straightforward replication of the consensus statements agreed upon by the RF4 delegates and not a report of original work by the authors.

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