Dive Computer Use in Recreational Diving: Insights from the DAN-DSL Database

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Data from the DAN Europe Diving Safety Laboratory (DSL) suggest that approximately 95% of recreational diving is carried out today using a dive computer. The most widely dived computers/algorithms, irrespective of brand, use the Bühlmann ZHL-16 or the Wienke RGBM algorithm, with roughly a 50/50 distribution across the DSL population. The vast majority of the 167 recorded decompression sickness (DCS) cases occurred without any significant violation of the respective algorithm's limits, i.e., most occurred while using gradient factors that were well below the maximum allowed by the algorithm. The DSL database and field research also show that many other physiological variables may be involved in the pathogenesis of DCS, even within computed "safe" limits, causing a variable individual response despite similar inert gas supersaturation levels. We conclude that the current computer validation modalities, although important and useful as a basic benchmark, still allow a probability of DCS beyond ideal levels in a recreational setting. In order to limit unexpected DCS a more aggressive "biological" approach is recommended that is able to identify and then control the most significant physiological variables involved in the pathogenesis of DCS, in addition to the inert gas supersaturation levels.

INTRODUCTION

Recreational diving is mostly done with the use of dive computers (DCs) that divers tend to trust with absolute "faith." Not many individuals realize that the validation protocols underlying the marketing of such computers and the algorithms that they use are far from perfect. It is apparent that the validation of DCs is both an expensive and lengthy process, and one that most manufacturers cannot afford to carry out to the necessary level. In most cases manufacturers do not have sufficient data to make the claim that their product functions to a certain level of risk or degree of risk reduction, which is an important issue for the end user, the diver. Even the most reliable DCs still accept a probability of DCS ranging from 2 to 5%, with a probability of neurological DCS in the range of 0.2 - 0.5%. (Divers Alert Network, 2000; 2001; Egi and Gurmen, 2000; Andric et al., 2003; Wienke, 2010).

It seems that divers are generally unaware of these facts, believing that their dive computer is infallible and that accidents will not happen if they follow the information given by their computer. However, those who work in the diving medical field know that this is not the case and that accidents do happen, albeit rarely.

Data gathering is essential to draw useful safety limit conclusions, especially now that technology allows us to readily do so. Scuba diving data collection in the field has also been carried out to some extent by the commercial, scientific, and military diving communities. The DAN DSL database contains records of 39,944 dives from 15,908 dive events, with data from DAN Europe and America in the process of being merged. Most of these dives were made using DCs implementing the Bühlmann ZHL-16 (compartmental model; 44%) or the Wienke RGBM (bubble model; 47%) algorithms. The remaining 9% of divers used their computer in 'gauge' mode, or referred to other decompression software or tables. A total of 181 cases of DCS were reported within this database (0.45% rate of incidence).

ALGORITHM CONSERVATISM AND ASSESSMENT OF SAFETY

When assessing the causes of these 181 cases of DCS, it is important to investigate how the individual divers used their computers, i.e., how far was the algorithm pushed towards the limits of safety?

Gradient factors can be used by divers to choose how fast and close to let the tissue compartments approach the 'M' value (e.g., the Bühlmann ZHL-16 algorithm). The M-value is a 'maximum pressure value' applicable for the respective depth and tissue compartment which, if exceeded, Bühlmann (2002) believed would greatly increase the risk of DCS. If focusing on the computed gradient factor for a hypothetical tissue with a half time of 12.5 minutes, it can be observed that of the 14,000 (of the recorded 39,944) dives analyzed, 95% were well below 80% of the maximum allowed supersaturation, with only a minor portion getting close to the 100% maximum value.

However, exposure factors (EF), or critical volumes, as derived by Hennessy and Hempleman (1977), can be used similarly to assess the risk of no-decompression dives using dissolved gas and safe ascent pressure as measures. If the value for PRT (Pressure Root Time is an indicator of the severity of the dive exposure where P = pressure in bar, T = dive time in minutes) exceeds 25, then the risk of DCS incidence is believed to sharply increase. Dives should therefore be planned to remain below this level, a strategy that has been implemented by the U.K. Health and Safety Executive. When analyzing the calculated EF of dives in the DAN database, it was observed that 60% of the dives were within an EF of 20, another 18% reached an EF of 25, and surprisingly, 32% of dives produced an EF greater than 25.

A further analysis of the 14,000 dives from the DAN DSL database showed that 99.9% were performed without violation of the computer algorithm, and less than 1% had M-values marginally above 100% for only the fastest tissue, yet the proportion of dives with an EF exceeding 25 was unusually high at 32%. However, the incidence of DCS was less than 0.5%, indicating that both the algorithms and the EF calculations are not capable of accurately predicting DCS risk.

DCS INCIDENCE AND TYPE OF DIVE COMPUTER USED

The DSL collection system was initially only compatible with some compartmental model dive computers, only allowing a direct comparison of DCS incidence between compartmental and bubble models with some level of bias. However, a short while after the DAN dive data collection program was implemented, collection from virtually all types of dive computers on the market was made possible and direct comparison between both level of use and DCS incidence with compartmental and bubble models began. From a sample of 10,738 dives, dived with Bühlmann ZHL-16 or Wienke RGBM algorithms, 165 DCS cases were recorded, almost equally distributed between the two (1.35% vs. 1.75%).

This incidence is higher than the overall incidence of DCS from the entire sample of dives we analyzed (0.45%), but this could be due to the relatively small sample size and may equilibrate towards more “normal” percentages with the increase of the number of recorded dives. However, it is interesting to note that only 10% of these DCS cases approached the maximum allowed inert gas supersaturation according to the selected algorithm (between 90% and 99% of the M-value) while another 10% occurred with supersaturation levels between 80% and 90% of the M-value. Unexpectedly, 80% of these DCS cases occurred with supersaturation levels lower than 80% of the maximum allowed by the specific algorithm, with an average supersaturation level of 75% of the M-value (median = 0.8 (80%); SD = 0.25).

This surprising finding suggests that the level of supersaturation upon decompression alone may not be responsible for the occurrence of DCS. Instead, other contributing factors should be considered when evaluating risk and validating optimal decompression procedures. The DAN Europe DSL's goal is to identify the non-mathematical, physiological variables associated with decompression that can allow for better recreational diving decompression safety.

PHYSIOLOGICAL MEASUREMENTS: VENOUS GAS EMBOLI (VGE)

Although VGE may be detected in divers in the absence of DCS, it is established that the higher the venous bubble load in the body, the more likely DCS is to occur (Francis and Mitchell, 2003). Therefore, measurement of VGE can be used in place of DCS as endpoint to aid in validation of decompression safety.

DAN has performed a total of 1,181 Doppler measurement analyses have to date and a further 2,100 await evaluation. The data distribution shows that the mean depth of the dives performed is roughly 28.5 m (min. 5 m; max. 192 m) and as noted previously, 95% of the documented dives are below maximal saturation of medium half-time tissues. Accordingly, the Doppler data show a low occurrence of high bubble grades.

Nevertheless, even if bubble scores are low, this does not totally prevent DCS. We are now focusing on gathering data on other physiological parameters, such as the importance of hydration on bubble production, with the aim of optimizing the reduction of bubble production.

CONCLUSIONS

Dive computers have come a long way since the 'Deco Brain' and the first black and yellow Uwatec model. Many recreational divers now trust and rely on DCs completely to calculate their dive profiles and decompression obligations. The fact that present day decompression models allow the diver to change the level of conservatism is a major step forward towards "personalizing" the dive computer. However, some elemental facts are overlooked and it is often forgotten that the implemented algorithms do not interact directly with the human body. For example, a dive computer does not take into account behavioral and environmental factors that influence the diver, such as how much alcohol has been consumed or what medication has been taken. The algorithm does not calculate the dive differently because the diver is dehydrated or suffering from electrolyte imbalance due to illness.

The limitations of dive computers need to be stressed and acknowledged. Some diving educational organizations tend to skip teaching the use of the diving tables because of reliance on computers, but this is a mistake because computers can fail or break.

DCS events are rare and thus it can be stated that the current use of dive computers is generally safe. However, analysis of the DAN DSL database shows that despite low bubble grades and the low supersaturation levels attained, some DCS incidents are still observed. DCS occurrence can thus be considered partially dependent on other (physiological) factors, which need further investigation.

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