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COMMENTARY

Continuous Glucose Monitoring During Recreational Diving in Type 1 Diabetes: Navigating Clinical and Technical Uncertainties

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Abstract: Recreational diving with self-contained underwater breathing devices is gaining popularity worldwide as a sport and leisure activity. People living with type 1 diabetes mellitus (PLT1D) are no exception, although historically diabetes mellitus, especially insulin-treated, has been described as an absolute contra-indication for diving. However, based on observational data collected by the Divers Alert Network, the presence of background diabetes mellitus became only a relative contraindication for those without significant co-morbidities or long-term complications. Regarding diving activities among PLT1D, the primary concern is the risk of hypoglycaemia, especially in those with impaired awareness. Furthermore, symptoms consistent with hypoglycaemia could be confused with those originating from other factors related to diving. Although avoidance of hypoglycaemia is imperative among PLT1D practicing diving, the risk of severe hyperglycaemia should also be minimised. Continuous glucose monitoring (CGM) nowadays represents the standard of care for PLT1D, but its accuracy during diving activities is still a matter of debate. This commentary aims to summarize the existing data on accuracy, durability, and underwater performance of different CGM devices among PLT1D who engage in diving, and to call for additional research in the field. Based on available results, the application of real-time CGM still requires extreme caution since none of the existing systems has so far met the standards for accurate use in underwater conditions. Further improvements of contemporary CGM devices, validated through large-scale trials, are necessary before their widespread implementation among PLT1D practicing diving. Such advances should further enhance safety during this popular activity.

Keywords: continuous glucose monitoring, diving, type 1 diabetes mellitus

Recreational diving with self-contained underwater breathing devices is gaining popularity worldwide as a sport and leisure activity.[1] People living with type 1 diabetes mellitus (PLT1D) are no exception, although the exact prevalence of scuba diving in this population is difficult to determine. However, available estimations suggest that about 1% of people engaged in recreational diving are using insulin treatment.[2]

Historically, diabetes mellitus, especially insulin-treated, has been described as an absolute contraindication for diving.[3] Excluding individuals with diabetes mellitus from common activities such as diving may contribute to heightened anxiety and diabetes-related distress, underscoring the clinical and social relevance of this issue. However, based on observational data collected in the United States by the Divers Alert Network, the presence of background diabetes mellitus constituted only a relative contraindication for those without significant co-morbidities or long-term complications.[3] Despite minor differences between existing recommendations, several scientific bodies, including the South Pacific Underwater Medicine Society, the United Kingdom Diving Medical Committee, and the Australian Diabetes Society, have also endorsed scuba diving for individuals with diabetes mellitus who meet specific suitability

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criteria.[1] Furthermore, a specific protocol based on serial capillary blood glucose (BG) measurements before and after each dive has been developed, and criteria focused on glycaemic control, the presence of complications, and hypoglycaemia awareness were established for defining eligibility of PLT1D for diving.[1]

Diving is associated with a wide spectrum of health risks, ranging from mild or moderate conditions, such as ear barotrauma and seasickness to potentially life-threatening events, including arterial gas embolism, decompression illness, and pulmonary barotrauma. These arise from changes in ambient pressure, gas composition, and environmental factors, such as low temperatures, which challenge various adaptive mechanisms of human physiology.[1] For individuals with diabetes mellitus, additional risks include impaired nitrogen elimination, increased susceptibility to decompression illness, and fluctuations in BG levels due to pressure, cold, dehydration, and stress.[1,4] Human studies indicate that exposure to a hyperbaric environment can influence glucose homeostasis.[1] In individuals with type 2 diabetes mellitus, simulated hyperbaric conditions have been shown to improve BG concentrations and peripheral insulin sensitivity, while one study reported that hyperbaric oxygenation enhanced residual insulin secretion in PLT1D.[1] Real-world data further suggest that BG levels tend to decline during diving, likely due to altered insulin requirements and sensitivity, increased physical activity, and the physiological effects of the hyperbaric environment on glucose tolerance.[1]

Regarding diving activities among PLT1D, the primary concern is the risk of hypoglycaemia, especially in those with impaired awareness. Furthermore, symptoms consistent with hypoglycaemia could be confused with those originating from other factors related to diving. Indeed, fatigue could result from the expended effort during a dive, while reduced cognitive focus or lethargy could arise from cold stress.[5] Similarly, confusion or mental absence could be the consequence of nitrogen narcosis, while malaise or other physical compromise might result from decompression illness.[5]

Although avoidance of hypoglycaemia is imperative among PLT1D practicing diving, the risk of severe hyperglycaemia should also be minimised. Recommendations suggest frequent pre-dive BG measurements, but this strategy is apparently insufficient to eliminate the risk of hypoglycaemia during diving. On the other hand, although continuous glucose monitoring (CGM) nowadays represents the diagnostic standard of care for PLT1D, its accuracy during diving activities is still a matter of debate.

This commentary aims to summarize the existing data on accuracy, durability, and underwater performance of different CGM devices among PLT1D engaged in diving and to call for additional research in the field.

A summary of studies evaluating the use of various CGM devices during scuba diving among PLT1D is presented in Table 1. While these studies provide valuable insights into device accuracy, durability, and underwater performance, several limitations affect their reproducibility and comparability. First, the relatively small sample sizes reduce the reliability of data interpretation. Second, heterogeneity in research methodologies, environmental conditions, and accuracy assessment parameters, along with missing data on device survival in some studies, limits precise cross-study comparisons. Moreover, none of the studies evaluated the reliability or latency of CGM alarms during dives, a factor potentially critical for the timely detection and management of hypoglycaemia. Finally, in certain cases, studies were supported by CGM manufacturers, which may have introduced reporting bias.

Since none of the currently available CGM devices have met the criteria for nonadjunctive use during diving, further technological improvements are necessary. Future research should involve robust, head-to-head trials with larger and more diverse participant populations, conducted under varying environmental conditions. Such studies would enable the collection of more reliable data on device accuracy and durability, and help explain the previously reported discrepancies in underwater performance.[10] Additionally, meticulous evaluation of CGM alarm performance during dives is urgently needed, as this feature is critical for the timely detection of life-threatening events, such as severe hypoglycaemia and diabetic ketoacidosis. Future CGM development should also address factors that may degrade device function, including repeated changes in pressure and humidity, a wider glycaemic range, and greater glycaemic variability.[10] However, given that the underwater environment presents significant logistical and safety challenges for clinical research, investigations in this setting should be limited to small-scale studies primarily aimed at advancing our understanding of physiological mechanisms.

Although existing CGM devices do not yet meet the standards for reliable and safe standalone use underwater, they may still serve as a valuable adjunct for planning and monitoring dives in PLT1D, provided they are used alongside standard safety protocols requiring serial capillary BG measurements before and after each dive. While CGM use can

Table 1 Summary of the Results of Studies Assessing the Use of Continuous Glucose Monitoring Devices During Scuba Diving Among People Living with Type 1 Diabetes Mellitus

Study	Device	Reference Standard	Participants	Dives	Water Temperature	Accuracy (MAD/MARD/MeARD)	Device Survival
Adolfsson et al[2]	Medtronic® CGM system	CPG	12 adult PLT1D and 12 healthy adults	117 recreational dives; 58 dives of PLT1D (depth of 18–22 meters, duration of 42–52 minutes)	8–11°C	MAD (within the group of PLT1D): 14.4 ± 6%	85% over 48 hours
Bonomo et al[6]	Medtronic® CGM system	CPG	9 adult PLT1D	27 dives (mean maximal depth of 21.5 meters, mean duration of 46 minutes)	Mean minimal of 20.8°C	MeARD: 13.1%	56%
Lormeau et al[7]	FreeStyle Libre®	CPG	16 adolescents with T1D	74 dives (depth 12–20 meters, mean duration 47.8 minutes)	28°C	NA	NA
Gamarra et al[8]	Dexcom G6®	CPG	11 adult PLT1D	88 dives (64 dives at depth <18 meters and 24 dives at depth 18–30 meters)	NA	MARD: 13.4%	NA
Herold et al[9]	Dexcom G6® and FreeStyle Libre 3® (simultaneously)	CPG	1 adult with T1D	4 dives (maximal depth of about 20 meters)	Mean water temperature 25°C (minimum of 2°C for 10 minutes)	MARD (under pressure): 8.9% (Dexcom G6®); 8.2% (FreeStyle Libre 3®); MARD (post-dive): 6.4% (Dexcom G6®); 9.7% (Free Style Libre 3®)	NA
Gamarra et al[10]	Dexcom G7® and FreeStyle Libre 3® (simultaneously)	CPG	13 PLT1D	202 dives (average depth of 27.1 meters; average duration of ~45–60 minutes each)	Constant water temperature of 28–29°C (without thermocline)	MARD: 31% (Dexcom G7®); 14.2% (FreeStyle Libre 3®); MeARD: 19.7% (Dexcom G7®); 11.6% (FreeStyle Libre 3®)	NA

Abbreviations: CGM, Continuous glucose monitoring; CPG, Capillary plasma glucose; PLT1D, People living with type 1 diabetes mellitus; T1D, Type 1 diabetes mellitus; MAD, Mean absolute difference; MeARD, Median absolute relative difference; NA, Not available; MARD, Mean absolute relative difference.

enhance safety during diving activities, users must be clearly informed about its limitations, and diving without adherence to established safety protocols should be strongly discouraged.

In conclusion, technological advances have significantly improved the quality of life for people living with diabetes mellitus, and CGM has the potential to further enhance safety for PLT1D engaging in diving. Nonetheless, unresolved challenges, particularly in underwater data transmission and accuracy, mean that its application still requires caution.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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