Impact of a sports project centered on scuba diving for adolescents with type 1 diabetes mellitus: New guidelines for adolescent recreational diving, a modification of the French regulations

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Short title: New guidelines for recreational scuba diving for adolescents with type 1 diabetes

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Abstract

Background: Recreational scuba diving has been authorized for type 1 diabetics over 18 years old – the age of majority in France – since 2004, but it remained forbidden for younger diabetics by the French underwater federation (FFESSM). Here, we present a study to evaluate 1) the conditions under which diving could be authorized for 14- to 18-year-olds) with type 1 diabetes and 2) the value of continuous glucose monitoring (CGM) while diving. A secondary objective was to monitor the impact of diving on the teenagers' quality of life.

Subject and methods: Sixteen adolescents (14–17.5 years old) were included. Diabetes was known for 6 years (range, 1–14) and Hb1Ac was 9.0% (range, 7.7–11.9). The study was conducted in Mayotte with both capillary glycemia (CG) and CGM measurements taken during five dives.

Results: the average CG prior to diving was 283 mg/dL and decreased by 75±76 mg/dL during the dive. No hypoglycemia occurred during the dives and four episodes occurred after. Glycemia variations during dives and for the overall duration of the study were greater than for adults, most likely due to the general adolescent behavior, notably regarding diet and diabetes management. CGM was greatly appreciated by the adolescents. They had an overall satisfactory quality of life. No significant variations were observed during the entire course of the study.

Conclusions: Although in need of further studies, these preliminary results show that CGM can be used while diving. CGM records show a continuous decrease of glycemia during dives. Based on these results, the French underwater federation has now authorized diving for adolescent type 1 diabetics following a specific diving protocol that includes HbA1c < 8.5%, autonomous management of diabetes by the adolescent, reduction of insulin doses, and target glycemia prior to the dive > 250 mg/dL.

Keywords: teenager; continuous glucose monitoring (CGM); scuba diving protocol; physical activity; diabetes; French regulations; sports project

1. Introduction

Over the past 60 years, diabetics have adjusted their lifestyle to their disease. Sports were either forbidden or not recommended. In 1998, the French Society for Diabetes (Société Francophone du Diabète, SFD) recommended physical activity and sports for diabetics [1]. At the time, recreational scuba diving, however, remained an emblematic sport forbidden for patients with type 1 diabetes (T1D), notably in France. The main reason for the interdiction was the potential risk of hypoglycemia during the dive and the subsequent risk of drowning. However, this risk remained a hypothesis that has neither been proven nor even assessed. At the end of the 1990s and beginning of the 2000s, several studies, notably conducted in partnership with the Diver Alert Network (DAN) and divers from the UK scuba diving associations (British Sub-Aqua Club (BSAC), the Sub-Aqua Association (SAA), and the Scottish Sub-Aqua Club (SSAC)), demonstrated that T1D divers did not have more diving accidents than other divers [2-5]. In other words, there is no increased risk for T1D divers. In France, the situation started to evolve in 2004 following a French scientific study [6]. The French underwater federation (FFESSM) allowed recreational diving for type 1 diabetics in its affiliated diving clubs. Several specific restrictions, however, were applied such as a maximum dive time of 30 min, a maximum depth of 20 m with a guide, etc. [6]. The results of these various studies [2-6] led to the establishment of an international frame of reference, in 2005, for 1) the criteria that need to be met for T1D patients who want to dive and 2) an insulin and blood glucose management protocol on the day of diving (hereafter referred to as the diving protocol) [7-11]. Further studies have confirmed that the diving protocol can also be used for warm-water diving [12], showed the safety of recreational nitrox use for T1D divers [12], and demonstrated the value of continuous glucose monitoring (CGM) during recreational diving [13, 14]. Between 2005 and 2015, there were no T1D divers involved in the 270–300 yearly accidents registered by the FFESSM. In light of these new results, the restrictions imposed on D1T divers by the FFESSM were re-evaluated in February 2015. T1D divers over 18 years of age – the age of majority in France – now have access to autonomy between 0 and 20 m and the diving protocol has been modified for experienced T1D divers (FFESSM level 2 = CMAS** (Confédération mondiale des activités subaquatiques) divers) with increased diving time, the possibility of ingesting sugar underwater, etc. [15]. However, recreational diving remained forbidden for T1D adolescents, i.e., 14- to 18-year-olds. This restriction is notably due to the lack of knowledge on the potential effects of scuba diving on T1D adolescents. To our knowledge, there has only been one study conducted on seven adolescent (16–17 years old) novice divers [16]. During this study, capillary glycemia (CG) was measured prior to (60, 30, and 10 min) and after diving for a total of 42 dives. It was noted that hypoglycemia was relatively rare over the course of the study, although male adolescents showed a marked pre- to post-dive CG decline. Conversely, a high occurrence of hyperglycemia was recorded during the study. The study concluded that the utility and impact of a deliberate increase of glycemia prior to the dive remained to be established. The strong need to extend the database for young T1D divers was also underlined [16].

Here, we present a new study on T1D adolescent divers with a larger number of adolescents (16) and dives (74). For the first time, we used a commercially available CGM system (FreeStyle Libre®, Abbott; see section 2.3) to follow how the interstitial glycemia evolved during the dive and over the overall duration of the study. Along with CGM, CG was measured prior to and after diving. We tested the effects of diving on various parameters (glycemia, both capillary and interstitial; insulin doses; carbohydrate intake, long-term HbA1c; etc.) for the 16 T1D adolescent divers. The main objectives of this study were to study glycemia variations for T1D adolescents during dives, to determine whether CGM could be used when diving, to define criteria for adolescent novice T1D divers, and to propose a diving protocol notably for insulin management and recommended glycemia prior to diving. As a secondary objective, we tried to evaluate the impact of this sports project, centered on scuba diving, on the well-being of the adolescents. Based on these results and our previous experience [6, 9, 10, 12, 15], we transferred the criteria and diving protocol of the FFESSM for T1D adults to adolescents. We thus proposed 1) a reference framework for the criteria to authorize diving for T1D adolescents and 2) a diving protocol specifically adapted to these divers. Both have been endorsed by the French underwater federation [17]. We also confirm the value of CGM for T1D divers.

2. Material and methods

2.1. Patients and inclusion criteria

Based on their desire to participate in the study, the T1D adolescents were referred by their endocrinologist to the MDs in charge of the study. The inclusion criteria were to:

- be > 14 years and < 18 years old in October 2016, the date of the study;
- have a medical certificate for diving signed by an MD accredited by the FFESSM;
- accept the diving protocol proposed for the study (see section 2.2);
- be able to autonomously monitor the blood glucose level, and follow the capillary glycemia and the continuous interstitial glucose monitoring protocols during the study (see section 2.2);
- complete the survey on their quality of life (see section 2.2);
- be a certified French level 1 (CMAS*) diver before the start of the study in Mayotte;

- sign written informed consent and have parental permission.

We chose to have no a priori exclusion criteria based on HbA1c given that 60% of the patients in the age range considered showed a glycemic imbalance. The goal was to check the implications of this imbalance on diving and to establish whether limits should be implemented in the diving protocol.

Patients having other medical contraindications for diving such as asthma, epilepsy, cardiopathy, ENT pathology, mental disorder, etc., were excluded from the study.

2.2. Study design

Prior to the study in Mayotte, between January and September 2016, each participant had to enroll in a FFESSM diving club to obtain the French diving level 1 (equivalent to a CMAS* diver) and be insured for diving. During the level 1 courses, adolescents used the adult FFESSM T1D diving protocol. Since the adolescents came from various areas of France, the courses were conducted either in swimming pools or at sea. The degree was finally validated for all metropolitan French adolescent divers by two dives in the Mediterranean Sea in Marseille in July 2016. Adolescent divers from Mayotte were certified at sea.

The study was conducted in Mayotte in October 2016. The medical staff included three diabetologists and two nurses. The nonmedical staff was composed of three members of the French nonprofit association “Diabète et Plongée” (Diabetes and Diving) – all of them T1D and experienced divers – and four activity organizers. There was no dive on the first day of the study (D0). Then the T1D adolescents made one daily dive to between 12 and 20 m, over 5 days (D1–D5). They were supervised by dive instructors and accompanied by diabetologists (some of them also diving instructors). The adolescents dived from two boats with both diabetologists and nurses onboard. The nurses stayed onboard during the dives to ensure safety.

The medical protocol included CGM over the course of the entire study. This was completed by CG before every meal (morning, noon, and evening) and 60, 30 and 5 min before diving and just after diving (hereafter referred to as T−60, T−30, T−5, and T+DT, with DT = dive time). The glycemia variation during the dive was defined as the difference between the CG measured just after the dive (T+DT) minus that measured at T−5. CG and CGM results were systematically compared. An individual meeting with each adolescent was conducted every morning and evening. Meals were elaborated by a dietitian from a local nonprofit association (Rediabylang) and took into account the specific diets of some of the adolescents: five halal, one vegetarian, and one low-gluten.

To evaluate the impact of the sports project on diabetes balance, HbA1c was monitored at the time of inclusion, i.e., between 10 and 4 months before the study in Mayotte, when the French first diving degree was validated, a few days prior to the start of the study in Mayotte, then 3 and 6 months after the study.

To evaluate the impact of diving and, more generally, of taking part in a long-term sports-based project, on the well-being of the teenagers, we used the standard French survey on the perceived quality of life “VSP-A vécu et santé perçue de l’adolescent.” The teenagers completed this survey three times: at inclusion in the study, just after their stay in Mayotte, and 6 months later.

The diving protocol was initially the one used for adults but was modified by the diabetologists during the study (see sections 3 and 4). For example, after the first dive, the target glycemia level prior to the dive (T−5) was increased from > 200 to > 250 mg/dL. For this study, ketonemia was systematically measured when blood glucose was higher than 300 mg/dL at T−60.

All participants and their parents gave their written informed consent.

2.3. Material

Interstitial glucose levels and tendencies (indicated by five types of arrows: steep ascending, ascending, stable (horizontal), descending, steep descending) were measured using the FreeStyle Libre® (Abbott) continuous glucose monitoring system. CG and ketonemia were measured using Optium Medisens® and Optium FreeStyle® strips (Abbott), respectively.

During dives sensors were protected either by a pad and a Tegaderm™ film (3M) or by kinesiotherapy tape (K-tape®). The latter solution proved the most efficient and the most appreciated by the adolescent divers.

Dives were made using 12-L air-filled steel tanks and 3-mm wetsuits without a hood.

When needed, carbohydrate intake consisted of soft drinks, fruit juices, chocolate or cereal bars, or dried fruit.

3. Results

Sixteen adolescents (five girls and 11 boys) were included in the study: 15 from metropolitan France and one from Mayotte. The average age was 15.6 ± 1.0 (2σ) years (range, 14–17.5). The subjects' weight was 63.2 ± 7.5 kg (range, 57–76) and 64.6 ± 13.8 kg (range, 51–100), height 163.0 ± 7.6 cm (range, 155–175) and 169.1 ± 9.0 cm (range, 156–183), and body mass index (BMI) 23.8 ± 5.3 kg/m^2 (range, 20.6–27.9) and 22.5 ± 7.1 kg/m^2 (range, 17.6–30.9) for girls and boys, respectively. T1D was known for an average of 6.3 ± 3.9 years (range, 1–14). Seven adolescents were treated with multiple injections and nine with an insulin pump. The insulin pump needs to be disconnected just prior to diving and reconnected shortly after. Reconnection was forgotten a few times by the adolescents during the study. At the date of inclusion, the average insulin dose was 64.9 ± 18.6 IU (range, 38–95), i.e., 0.93 ± 0.85 IU/kg/day (range, 0.4–1.90) with no noticeable male/female difference, and the average HbA1c was 9.0 ± 1.1% (range, 7.7–11.9).

In Mayotte, one daily dive had been planned over 5 days, for a total of 80 dives. Seventy-four dives were actually performed, between 12 and 20 m deep, in water at 28°C. The average dive duration was 47.8 min (range, 40–58). There was no barotraumatic incident. Six dives had to be cancelled: three because one of the adolescent had behavior difficulties, one because of positive ketonemia, one because of low blood sugar prior to diving, and one because of muscle cramps.

The average CG before immersion (T−5) was 283 mg/dL. There was an average decrease of 75 ± 76 mg/dL (1σ, range, −117 to +239) during the dive (Fig. 1). The decrease was observed for both males (−50 ± 78 mg/dL, n = 43 dives) and females (−118 ± 68 mg/dL, n = 24 dives). There were 16 occurrences of CG above 300 mg/dL at T−60. Thirteen ketonemia readings were between 0.2 and 0.5 mmol/L (n=13) and three values were higher: 0.6, 1.4, and 2.1 mmol/L. The dive was cancelled for the adolescent with ketonemia at 2.1 mmol/L. The ketonemia value of 1.4 decreased to 0 after 45 min, and the adolescent was allowed to dive.

Eight post-dive CG readings were below 100 mg/dL: five between 60 and 100 mg/dL and three between 40 and 60 mg/dL. Four occurred on dive #4, which was characterized by underwater current, hence likely requiring more intense physical effort due to increased finning. There were carbohydrate intakes prior to three of these eight dives. The CG and CGM prior to (T−5) were above 200 mg/dL for six of these eight dives. One dive had a T−5 CG of 107 mg/dL and a concordant CGM of 122 mg/dL with a steep ascending tendency arrow. This led the medical staff to allow the dive. Finally, for one dive, there was a strong discrepancy between the CG (130 mg/dL) and the CGM (276 mg/dL). The medical staff chose to use the CGM value, which was less prone to a dilution effect (see below and section 4.3). For these eight dives, the tendency arrows were: stable (n=4), no indication (n=1), steep ascending (n=1), and steep descending (n=2). For the latter, there was a 20-g carbohydrate intake for one dive but not for the other as the T−5 CG was 248 mg/dL.

On the 1st day of the study (D0, no dive), the average total daily insulin dose was 58.9 ± 17.3 IU. An average decrease of total, base, and bolus insulin of 16.3, 11.3, and 16.3%, respectively, occurred between D0 and D5. However, four adolescents increased their insulin doses during the study.

CGM values were logged before each meal as well as four times prior to and after diving (T−60, T−30, T−5, and T+DT). A total of 650 CGM measurements (interstitial glycemia) were recorded together with the glucose tendencies, indicated by arrows in the FreeStyle Libre® system.

Prior (T−5) and immediately after the dive (T+DT), the CGM values were often higher than the CG values: on average 33 ± 13 (1σ) mg/dL (range, 7–49) and the average offset increased slightly to 46 ± 3 (1σ) mg/dL after the dive but stayed within error (Supplementary Table S1). Of the 296 tendency arrows recorded (74 dives with arrows recorded at T−60, T−30, T−5, and D+DT), 29.4% showed stability, 13.2% a moderate increase, 15.5% a strong increase, 11.5% a moderate decrease, 8.1% a strong decrease, and 5.4% a "HI" indication, i.e., interstitial glycemia > 500 mg/dL. Tendency arrows were used to permit dives in seven specific cases: once with a CG at 107 mg/dL and six times with CG between 120 and 150 mg/dL. There was one case of a strong discrepancy between the CG (130 mg/dL) and the CGM (276 mg/dL). The medical staff concluded in an altered reading of the CG due to hemodilution (wet finger due to the environment + seawater; see section 4) and took the CGM value into account. CG after the dive was 94 mg/dL.

CGM values logged every 15 min for eight divers during the dive showed continuous and gradual variations of the interstitial glucose level during the dive (Supplementary Table S2). The sensor appears to be insensitive to a prolonged stay under seawater. The adolescents gave a satisfaction score of 9.3 out of 10 for the FreeStyle Libre CGM device.

During the stay in Mayotte, five insulin-pump catheters and four CGM sensors were torn off and two CGM sensors temporarily stopped functioning. Twenty-seven benign hypoglycemia (< 60 mg/dL) and 64 hyperglycemia (> 300 mg/dL) episodes were recorded out of 240 measurements, as well as three cases of ketosis (ketonemia > 0.6 mmol/L).

There were no significant variations of HbA1c from prior to the stay in Mayotte and 3 and 6 months after the study.

The adolescents gave a satisfaction score of 8.5 out of 10 for the stay in Mayotte during the study. To the question "do you think you will continue diving," ten answered yes, three did not know, one will stop, and two did not answer. The results of the VSP-A quality-of-life survey completed by the adolescents at inclusion in the study, at the end of the stay in Mayotte, and 6 months after are summarized in Supplementary Table S3. Overall, the adolescents experienced good psychological well-being. No significant variations were observed during the entire course of the study (from inclusion to 6 months after Mayotte). Four adolescents exhibited more fragile psychological behavior during the stay in Mayotte. Their overall glycemia variability during the stay and glycemia decrease while diving was higher than that of the rest of the group.

Finally, it is worth noting that during the study in Mayotte, insulin management by adolescents included forgotten boluses, prolonged insulin-pump disconnection, and overcorrection of hyperglycemia, which made the interpretation of the results more complex than for adults but also reflects the reality of managing diving for T1D adolescents.

4. Discussion

Based on several medical studies [2-12], the ban on diving for adults with T1D has been lifted in many countries over recent years and the associated restrictions have been progressively loosened. However, for T1D adolescents (14–18 years old) scuba diving remained strictly prohibited. There is a considerable lack of knowledge on the subject with only one medical study available [16]. There are also specific issues associated with adolescents such as a greater variability of glycemia levels due to hormonal changes, potential distraction in insulin and diet management, etc. The risk of underwater hypoglycemia is a major concern for T1D divers. In the present study, we closely monitored glycemia changes prior to and after the dive as well as during the dive using both CGM and CG. We also explored the general effect of diving on the teenagers' short- and long-term well-being.

Both the average CG variations and the standard deviation during the dive for adolescents (−75 ± 76 mg/dL) seemed to be higher than for adults (−50 ± 64 mg/dL) [6, 9-12] (Table 1). Greater glycemia variability while diving has, however, already been observed for adults diving in warm waters, most likely due to longer dive times (Table 1). For adolescents there were more episodes of hypoglycemia, hyperglycemia, and ketosis outside of the dives than for adults. Despite a higher target glycemia prior to diving for adolescents (250 mg/d vs. 200 mg/dL for adults) the number of dives that required carbohydrate intake before diving (20%) was lower than for adults (47%) while the average intake was similar (34 and 28 g for adolescents and adults, respectively). This can probably be partly explained by a more erratic diet for the adolescents. The differences between adults and adolescents are summarized in Table 1.

Contrary to the study by Pollock et al. [16] where only male adolescents showed a decrease of the glycemia during the dive, in this study a decrease was observed for both male and female adolescent divers.

It is worth noting that practicing a regular physical activity would presumably minimize the glycemia decrease, hence the risk of hypoglycemia after several days of diving. However, the glycemic reaction to diving over the study was similar for all the adolescents. A possible explanation is that none had a regular physical activity prior to the study.

The overall insulin reduction (16.3%) was approximately 40% lower than for adults (25.8%) (Table 1). However, as some adolescents showed a tendency to hypoglycemia at night, likely indicating that insulin doses were too high, we recommend a decrease of the basal insulin dose of at least 20% the day before the first dive and a decrease of the bolus prior to diving of 50%. In addition, hyperglycemia corrections prior to the dive should be limited. These recommendations are similar to those prescribed in the case of a prolonged physical activity of moderate intensity [1, 18].

Carbohydrate intake before diving − following the diving protocol − was limited (15 dives out of 74 (20%) with an average intake of 34 g/dive), although the CG target prior to the dive was raised from > 200 to > 250 mg/dL given the high glycemia variability observed during the first day of diving (see below). This can be explained by the fact that the overall carbohydrate intake outside of the diving times was high. It is worth noting that eight of the 15 dives that required carbohydrate intake concerned two adolescents. The amount of carbohydrate ingested was appropriate and identical to what is recommended for adults.

During the study, the reconnection of the insulin pump after the dive was forgotten a few times. Therefore, it appears that diving with an insulin pump requires a certain level of maturity and/or skill in the management of the device or external monitoring by an adult.

The adult T1D diving protocol adopted by the French underwater federation was followed as an initial reference. However, we decided to increase the target glycemia prior to diving to > 250 mg/dL given the considerable glycemia variability observed during the first dive (from −226 to +117 mg/dL). The average CG at T−5 was 283 mg/dL (*n*=69). Eight dives ended up with a CG below 100 mg/dL (T+DT). In a few cases, CG values were much lower than CGM values prior to and after diving. It is indeed unusual to have CGM values higher than CG. A possible cause is the humidification and/or the weakening of the finger pads due to prolonged exposure to seawater and a consequent hemodilution. Having a perfectly dry finger onboard a diving boat, i.e., in a wet and sea-salt-covered environment, is indeed very difficult. Another hypothesis is the delayed reaction between the CGM and the CG (ca. 10–15min). However, the CGM devices did not indicate a decreasing tendency for interstitial glycemia. This is further confirmed by the fact that, based on the CGM results, the medical staff authorized three dives that would have been forbidden based on CG and no hypoglycemia occurred during these dives. Therefore, CGM appears to be a very useful additional control device while diving, notably because it allows one to closely follow changes in glycemia prior to the dive. Applying the precautionary principle, we recommend a target glycemia for adolescent divers > 250 mg/dL prior to diving and no dive if the CG is < 200 mg/dL. During the study, however, since CGM was available, the medical staff authorized dives for CG between 160 and 200 mg/dL when there was a tendency arrow showing increasing glycemia. This approach could be considered in the future for trained and experienced adolescent divers with CGM as well as for patients with well-balanced T1D.

Post-dive extraction of the CGM values (every 15 min) from the record during dives were in agreement with what is expected from a continuous and gradual evolution and did not seem to be affected by pressure (approximately 3 bars) (Fig. 2, Supplementary Table S2). In the eight cases where CG was < 100 mg/dL at T+DT, there was a gradual decrease of approximately 20% every 15 min. Contrary to what was observed in previous studies [12], the decrease was not accentuated after 30 min of diving, probably because of the absence of a noticeable effect of the cold in Mayotte (water temperature, 28ºC). If the CGM values could have been read during the dive, values < 150 mg/dL would have led to ending the dive 15 and 30 min earlier for three and two dives, respectively.

CGM therefore appears a very advantageous tool for diving. While the manufacturer does not recommend the use of the FreeStyle Libre® (Abbott) for more than 30 min in water, the results of this study (74 dives) show that this CGM device appears to be robust underwater. The slight increase in the offset between CG and CGM observed just after the dives (section 3) is likely due to the delayed reaction (10–15 min) of the interstitial compared to the capillary glycemia. Overall, there were no long-term discrepancies between the CG and CGM during the overall duration of the study. Indeed, long-term and specific studies are needed to confirm these preliminary results. In addition, the temperature range of sensor functioning (10–40°C) has to be taken into account during the dive as well as prior to and after the dive. For example, during the study, two sensors temporarily stopped functioning after the adolescents remained exposed to the sun on the boat before diving. Hence, we recommend that T1D divers should always have a CG control device on the diving boat to supplement the CGM.

Physical activity is strongly recommended for adolescents. While all the outcomes of physical activity on young T1D remain difficult to fully assess, most studies show an improvement of glycemic control and a decrease of HbA1c [19, 20]. However, young and adolescent T1Ds seem to exercise less than healthy ones. This is notably the case for female adolescents and appears to begin at an early age. The main reasons for this appears to be 1) the perception T1D adolescents have of themselves as having a low capacity for physical exercise, 2) the loss of control of the diabetes, 3) the availability of time for physical activity, and the fear of hypoglycemia [21]. Over the entire course of this study (from the inclusion to 6 months after Mayotte), there were no significant change in the average HbA1c in this group of adolescents.

Finally, given the glycemia variability recorded outside of diving during this study, we recommend limiting the diving activity to one dive per day.

5. Conclusions

Young (14–18 years) T1Ds have high glycemia variability. However, there was no underwater hypoglycemia despite this greater glycemia variability for T1D adolescent diabetics compared to adults. In addition, despite substantial variability, the average decrease in glycemia during the dive (−75 ± 76 mg/dl) argues for a deliberate increase of glycemia prior to diving. We therefore recommend a target glycemia level prior to diving > 250 mg/dL. The reduction of insulin doses for T1D adolescents was 40% lower than for adults. Based on these results, we recommend a decrease of the basal and bolus prior to diving of 20% and 50%, respectively. While adolescents with sometimes high HbA1c were included for the purposes of the study, we recommend HbA1c < 8.5% as a criterion for being authorized to dive, in agreement with the principle of precaution. Overall, diving did not induce any significant change on the long-term HbA1c of the T1D adolescents. Finally, as a preliminary test pending further investigation, this study has shown that CGM can be used for diving and could prove to be an extremely valuable complementary tool for diabetes management for scuba divers.

A proposal for new regulations for adolescent T1D divers has been made and accepted by the French underwater federation [17]. Diving for young (14–18 years old) T1Ds is therefore authorized following the criteria and diving protocol described in the appendix of Lormeau et al. [6] with the following modifications: only the French level 1 (CMAS*), one dive/day, parental authorization for diving, a parent or legal representative present on the dive boat, a medical certificate signed by a diabetologist or a pediatrician, HbA1c < 8.5%, no ketosis or severe hypoglycemia in the 3 months prior to the issuance of the medical certificate, and the ability to self-manage diabetes. Diving protocol: reduction of insulin doses (basal −20% and bolus −50% prior to the dive), a target glycemia prior to the dive (T−5) > 250 mg/dL, and the dive being cancelled if < 200 mg/dL. No correction of hyperglycemia up to 300 mg/dL and a correction bolus reduced by 50% if > 300 mg/dL. Glucose monitoring can be done either by capillary glycemia (CG) or by an interstitial glucose monitoring system (CGM). For patients using CGM, we strongly recommend having a CG monitoring system for redundancy given that CGM sensors can be torn off or malfunction, in particular because of temperature changes.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Table 1. Comparison between the four French studies on type 1 diabetes and diving.

Location	Golfe Juan	St Gilles les Bains	Marseille	Mayotte
References	[6, 9, 11]	[10, 12]	[12]	this study
Age group	Adults	Adults	Adults	Adolescents
Date	Nov. 2003	Jan. 2005	Sept. 2012	Oct. 2016
Water temperature (ºC)	14	27	14	28
Number of patients	15	11	15	16
male	12	8	10	11
female	3	3	5	5
Average age (years) (range)	40 (28–55)	41.5 (22–54)	36.2 (28–50)	15.5 (14–18)
Diabetes duration (years) (range)	9 (1–30)	8.9 (2–22)	11.8 (3–30)	6 (2–14)
Average HbA1c (%)	7.2	6.6	7.06	8.99
Total number of dives	87	111	70	74
Average dive duration (min)	30	36	34	48
Glycemia variation during dive (mg/dL)[a]	−40 ± 68 (204-164)	−67 ± 70 (274-207)	−43 ± 55 (214-171)	−75 ± 76 (283-208)

Decrease of insulin dose on the 1st day (%)	5.3	19.6	25.1	4.4
Average decrease of insulin [b] (%)	19.3	30.4	27.6	12.2
Carbohydrate intake before dive (g/dive) (range)	50 (15–155)	16 (15–90)	18.1 (10–90)	34 (10–60)
Number of dives without carbohydrate intake / total number of dives (in %)	44/87 (51%)	68/111 (61%)	34/70 (49%)	59/74 (80%)
Number of hypoglycemia episodes during dive (after dive)	0 (0)	0 (1)	0 (0)	0 (4)
Number of ketosis episodes during the study	0	2 [c]	0	4

[a] average ±1σ glycemia variation during dive: a negative value indicates a decrease of the glycemia during the dive. Numbers between parentheses are the average glycemia prior to (T−5) and after (T+DT) dive.
[b] Average maximum decrease of insulin doses during the study.
[c] One ketosis episode after a night dive and one due to clogged insulin pump catheter.

Figure captions

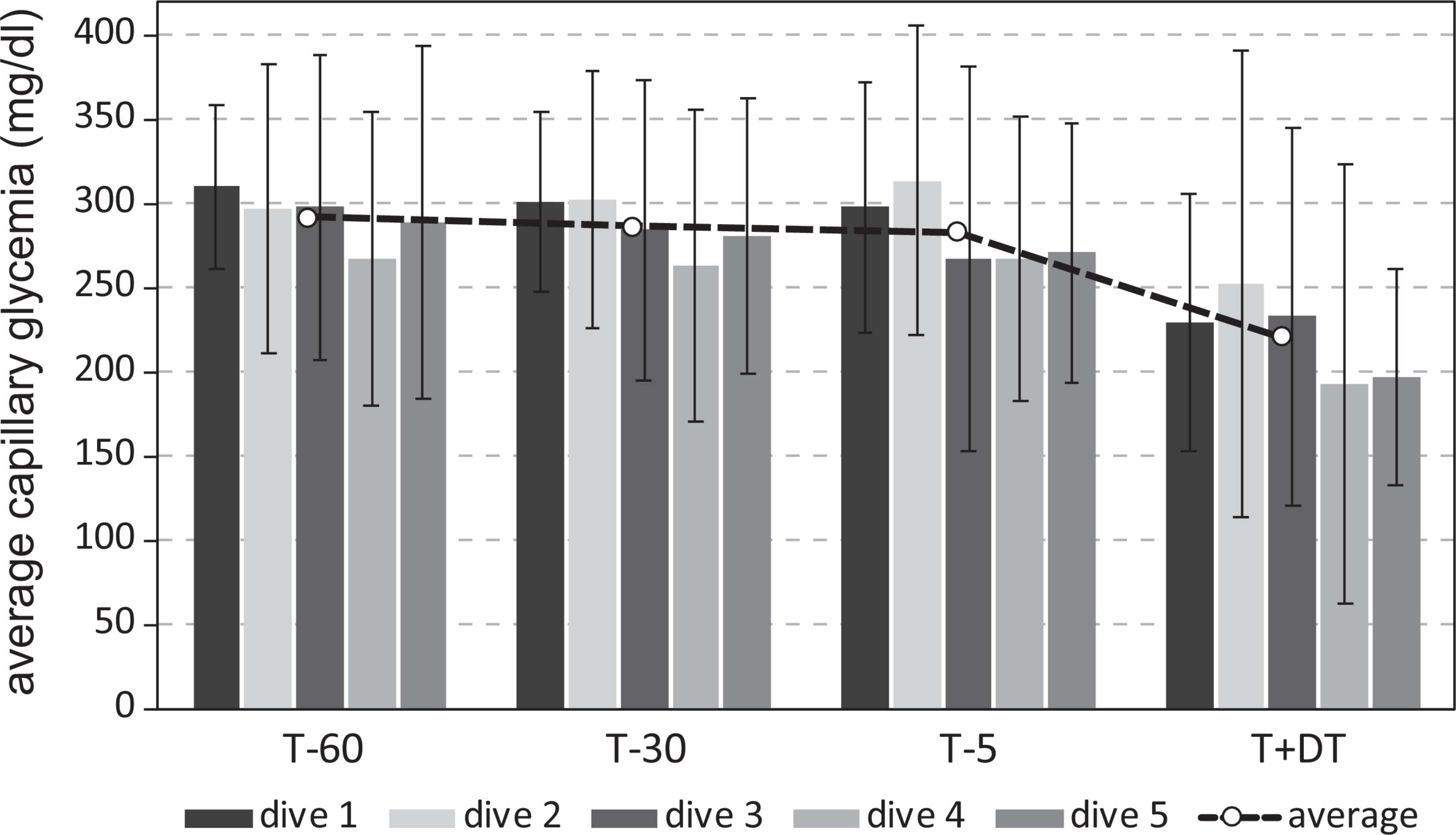
Figure 1. Average (16 adolescents) capillary glycemia (CG) 60, 30 and 5 min prior to dive (T−60, T−30, and T−5, respectively) and just after diving (T+DT) for dives 1–5 (grey rectangles). For each dive, the standard deviation of the CG is also reported (vertical black bars). The overall average capillary glycemia variations from T−60 to T+DT is also shown (thick dashed line).

Figure 2. Interstitial glycemia of one adolescent diver over five dives. Two of the dives are characterized by a final interstitial glycemia < 100 mg/dL. The value of the interstitial glycemia underwater are CGM data recovered after the dive: T1 is the first measurement taken by the sensor after the start of the dive. Tn is Tn−1 + 15 min.

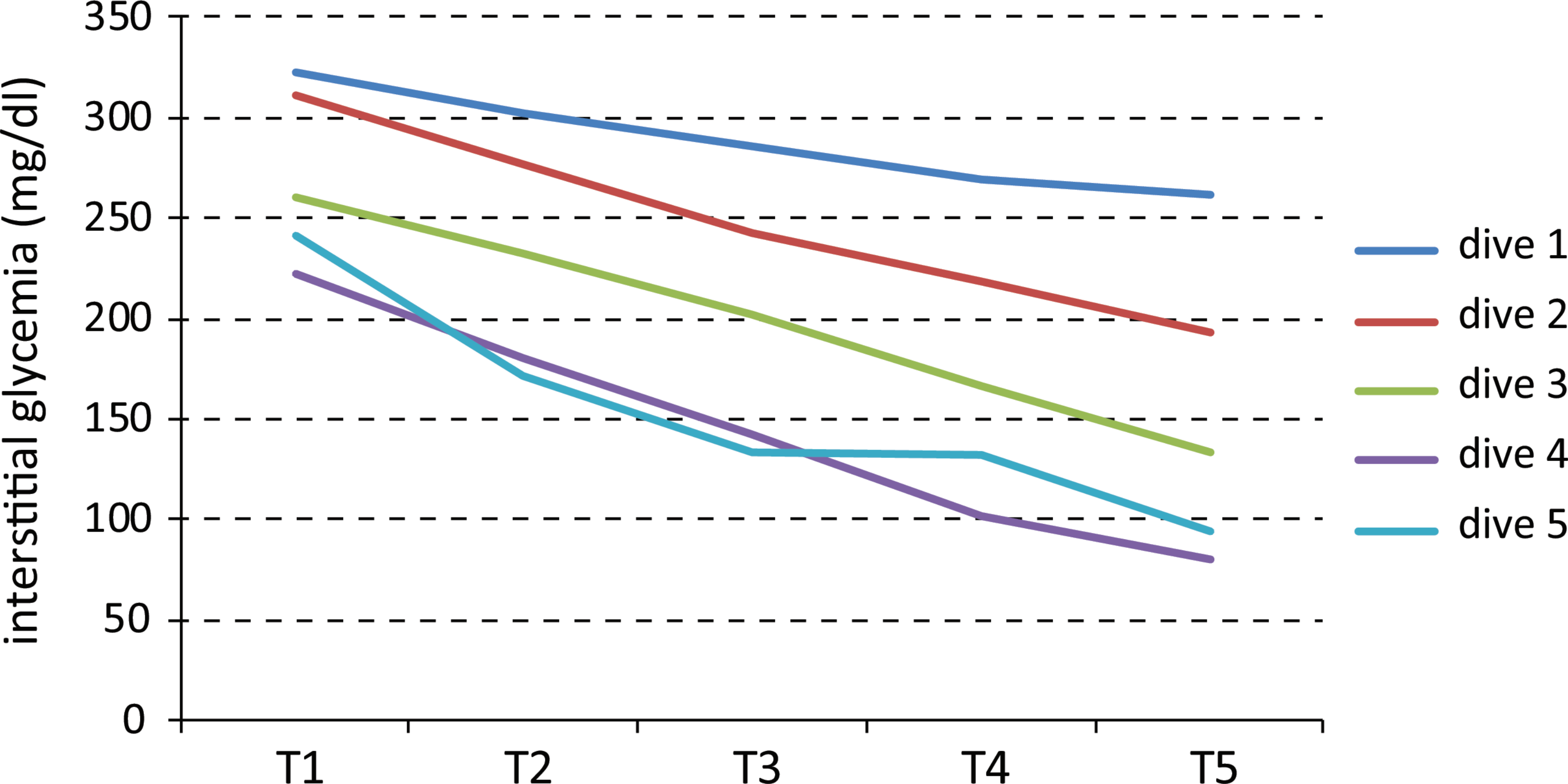
Appendix A. Supplementary data

Supplementary material (Tables S1, S2, and S3) associated with this article can be found as Excel files.

http://www.sciencedirect.com,doi...



average capillary glycemia (mg/dl)
400
350
300
250
200
150
100
50
0
T-60
T-30
T-5
T+DT
dive 1
dive 2
dive 3
dive 4
dive 5
average



interstitial glycemia (mg/dl)
350
300
250
200
150
100
50
0
T1
T2
T3
T4
T5
dive 1
dive 2
dive 3
dive 4
dive 5