TIGHT METABOLIC MONITORING DURING RECREATIONAL SCUBA DIVING IN TYPE 1 DIABETIC PATIENTS

M.Bonomo[1], R.Cairoli[2,7], G.Verde[3], L.Morelli[4], A.Moreo[5], P.Loddo[5], M.Delle Grottaglie[6], L.Ruggeri[8], G.Grieco[1], P.Aghemo[9]

Departments of [1]Diabetology, [2]Ematology, [3]Endocrinology, [4]Hyperbaric Medicine, [5]Cardiology, [6]Ophtalmology – Niguarda Ca' Granda Hospital, Milan, Italy; [9]Sports Physiology Center, Milan, Italy

E-Mail Address: matteo.bonomo@ospedaleniguarda.it

Abstract: To demonstrate that, with a specific training, well-controlled diabetic patients can dive without additional risks, in two special OWD Courses we led 14 young diabetic subjects to obtain the first-level diving licence. The following step was to verify the adopted protocol during normal recreational diving: a group of previously trained patients took part in "DEEP MONITORING", a 5-day program of consecutive dives (2/day), where technical and metabolic parameters were strictly monitored.

Six type-1 diabetic patients participated in the study. Blood glucose was checked at –60', -30', –10', and extra insulin or CHO were taken if necessary. A s.c. glucose monitor (CGMS®, modified for the purpose) was worn also during immersions. Main diving parameters were recorded, and precordial Doppler was performed after immersions.

In 37/56 dives (66.1%) supplementary CHO or insulin were necessary. No serious problems occurred during dives. CGMS showed a progressive lowering from the beginning to the end of dive. All 24-h CGMS glycemic indexes resulted higher than in a control monitoring performed 2 weeks before. No significant bubble formation was evidenced.

These preliminary data suggest that in well-controlled diabetics, SCUBA diving can be performed without additional medical risks, when applying a rigorous protocol for preventing acute metabolic complications.

Introduction

Type 1 Diabetes Mellitus (T1DM) is commonly considered a contraindication for scuba diving by both scientific and diving authorities worldwide, mainly due to the risk of hypoglycemia [1-2]. In recent years, however, several reports have been published, suggesting that this total prohibition could be reconsidered [3-5], and Divers Alert Network (DAN) has recently proposed a change in the current policies in the field [6], possibly allowing a specific group of persons with diabetes to partecipate in scuba diving. On the other hand, it is well known that many patients with T1DM usually dive without declaring their condition [7-9], therefore exposing themselves to risks consequent to the lack of specific training.

The "Diabete Sommerso" Project was launched in 2004 by our Center, together with a pool of specialists operating in the "Niguarda Ca'Granda Hospital", in close collaboration with the "Milan Association of Diabetic Patients"; recently it has been approved as a "Special Project" by DAN-Europe. Our aim was to demonstrate that, with thorough practical and theoretical training specifically targeted at the diabetic situation, well-controlled, complication-free diabetic patients can safely dive, without additional medical and metabolic risks.

In two "Open Water Diver" (OWD) Courses, organized in 2004 and 2005 by a team of motivated scuba instructors, integrating the traditional educational program with additional modules, providing the active participation of expert diabetes specialists in all phases of the training, we led 14 young diabetic subjects to obtain the first-level diving certification. No important technical or medical problems were encountered throughout the courses, either in the pool dives or in the final open water sea dives.

The following step was then to verify the efficacy and safety of the adopted protocol outside the protected setting of an introductory course, during normal recreational diving. For this purpose, we organized a residential 5-day stage on the Isle of Ventotene (Italy), where a group of previously trained diabetic divers took part in "DEEP MONITORING", an intensive program of consecutive dives, during which technical, physiological, metabolic and endocrine parameters were strictly monitored with innovative techniques**.**

Material and Methods

Six well-controlled, non-complicated type-1 diabetic patients, having previously obtained certification in the 2004 (5 subjects) and 2005 (1 subject) OWD courses, participated in the study (see tab. 1 for clinical characteristics). All were treated by rapid (ASPART or LISPRO) and long-acting (GLARGINE) insulin analogues.

Table 1: Clinical characteristics of patients participating in "DEEP MONITORING"

Patient	Sex	Age (y)	BMI (kg/m^2)	Duration of illness (y)	OWD (y)	Therapy	Insulin (U/24 h)	Glargine (U/24 h)	HbA1c (%)
A.L.	M	38	21.5	10	2005	MDI	49 (13)	13	6.5
C.M.	F	29	20.8	11	2004	MDI	16 (5)	5	6.8
C.G.	F	41	23.8	14	2004	MDI	26 (9)	9	7.7
Q.S.	M	21	22.0	10	2004	MDI	47 (24)	24	8.6
R.N.	M	33	19.5	5	2004	MDI	19 (10)	10	6.3
V.V.	F	32	23.3	14	2004	MDI	41	20	7.4
Mean	-	32.3±7	21.8±1.6	10.7±3.3	-	-	33.0±14.5	13.5±7.2	7.2±0.9

OWD: Open Water Diver - MDI: Multiple Daily Injections

Blood glucose (BG) levels were controlled by intensified SMBG (at least 8/day). Before each dive, BG was checked at –60', -30', and –10', and corrective measures (extra insulin injection or carbohydrate snack) were adopted if necessary, according to an algorithm based on BG absolute levels and dynamic. Another BG control was performed immediately after emersion. When BG >300 mg/dl, blood ketones were tested with a meter. The adopted scheme, derived, with minimal changes, from the CAMP DAVI protocol (10), is shown in Fig. 1.

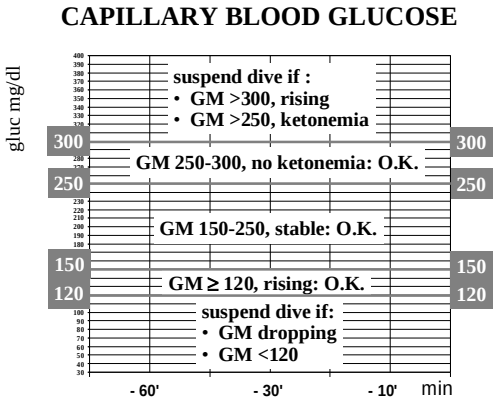

Fig. 1: Algorithm based on self-monitored capillary blood glucose before diving. Decisions on insulin or carbohydrate supplements are taken considering both absolute levels of blood glucose, and their pattern of variation. Also blood ketones are considered, in case of high BG.

During days 3,4 and 5 an external device for continuous s.c. glucose monitoring (CGMS®, MEDTRONIC, with a needle-sensor performing measurements of glucose in the interstitial fluid every 10 seconds, storing an average value into memory at 5' intervals) was applied and worn also during immersions. This type of monitor doesn't show glucose readings in "real-time": stored data become available only after downloading to a PC, with a COM–station using a dedicated software [11,12]. The CGMS® systems used during "DEEP MONITORING" were expressly modified for the purpose with the collaboration of the CNR Institute of Clinical Physiology, water-proofing the sensor at the s.c insertion site, extending the cable, and housing the monitor body in a pressurized aluminium container.

"Basal" continuous glucose monitoring with CGMS® was obtained in all patients in the 2 weeks preceding the residential stage; on this occasion HbA1c was also determined.

HbA1c determination was then repeated four weeks after the end of the stage.

Samples for urinary and salivary Cortisol and Catecholamines were taken before and immediately after diving on days 3 and 4.

Main diving parameters were recorded during all immersions with "Black Box" modified ALADIN® Air X dive computers, supplied by DAN-Europe.

In all diabetic divers, and in 5 non diabetic staff divers, circulating bubbles were evaluated with Doppler ultrasonic method (Oxford Sonicaid 121). Sixty-seconds precordial recordings on vena cava window were obtained between 20' and 40' after dive. Data were analyzed using a two-levels classification, adapted from the Spencer Protocol [13] considering Low Bubble Grade (LBG: sporadic signals, Spencer grades lower than 2) or High Bubble Grade (HBG: frequent to continuous signals, Spencer grades higher than 2), by a specialist in Hyperbaric Medicine (L.M.), not aware of the corresponding dive profiles.

Glycated haemoglobin HbA1c was measured by HPLC with a VARIANT II instrument (Bio-Rad Laboratories GmbH, München, Germany; normal range 4.1-6.1%)

Urinary epinephrine and norepinephrine were measured by HPLC after extraction and purification (BIO-RAD, München, Germany; normal values: epinephrine 1.5-22 µg /24 h, norepinephrine 15-85 µg /24 h).

Serum and urinary (after dichloromethane extraction) cortisol were measured by chemiluminescent method (Medical System, Genova, Italy; normal values 8-25 µg/dl serum, 10-80 µg/24 h urine).

Salivary cortisol was measured by ELISA (Chematil, Napoli, Italy; normal values 0.4-1 µg/dl).

Specimens for salivary dosage were obtained using Salivette® devices (Sarsted, Germany).

Self monitoring of blood glucose (SMBG) was performed with memory-based meters (Ascensia Confirm, Bayer Diagnostics).

Data are expressed as mean ± SD or as percentages. Variations of glucose values during immersions are expressed also as Sample/Basal (S/B) Ratio, calculated by dividing values obtained at various dive times by the baseline value (time 0').

Student's t test was used to assess differences in means among groups. Categorical data were evaluated by χ^2 test with Yates correction.

The SAS statistical package was used for all analyses.

Results

Data was gathered from 56 dives (maximal depth 23.0±3,1, dive time 44'± 18", minimal water temperature 20.2±1.7); 4 of the programmed 60 dives were missed for reasons not related to medical or technical problems.

Safety and glucose control: Mean self-monitored BG before diving was: –60': 211.3±69.9, –30': 206.5±68.6, –10': 211.8±66.1 mg/dl. In 37/56 (66.1%) some correction was necessary, according to the adopted safety protocol: in 25 cases supplementary carbohydrates (CHO); in 9 cases extra insulin doses; in 3 cases both CHO and insulin. No problems occurred during dives, except for minimal hypoglycemic symptoms (cephalea) on 3 occasions in the same patient. Post-dive glycemic values were 175.9±88.3 (7 >300, 4 <70) mg/dl.

Blood ketones, measured when BG >300 mg/dl, never exceeded 0.5 mmol/l.

Values of HBa1C measured 4 weeks after last dive were similar to those obtained in the pre-stage control (7.2±09 % pre-stage, 7.1±0.9 % post-stage).

Continuous Glucose monitoring: Due to technical problems (1 flood, 1 cable accidental damage, 2 signal "overflow", probably consequence of defective sensor and/or cable waterproofing), CGMS® recordings were available for only 21/36 dives: data showed a progressive lowering of glucose concentrations from the beginning to the end of the dive (200.7±57.5 to 173.1±71.2 mg/dl; mean difference - 13.9%). When considering only immersions not having required corrective measures (extra insulin or CHO) before diving, this declining trend was even more evident (from 194.4±52.1 to 157.6±66.3 mg/dl; -18.8%) Relative changes of BG during non-corrected immersions are shown in fig. 2. No correlation was found between the entity of BG decrease and dive time, maximal depth, water temperature, insulin dosage, pre-dive glycemia.

Examining the 24 h CGMS® profiles, a clear trend toward worse glycemic indexes was found on the diving days than on the pre-stage control monitoring (mean BG: 213.0±55.7 vs 158.6±47.7 mg/dl, time spent within 65-180 mg/dl reference limits: 21.6±26.1 vs 52.2±27.7 %). The comparison was performed on the second of the 3 days of glucose monitoring.

Hormones: Dosages of "stress hormones" showed high concentrations of cortisol and catecholamines before diving, without correlation with glycemic indexes.

Bubbles: No significant bubble formation was found by Doppler examination: all records were classified as LBG, with no difference between diabetic and non-diabetic divers.

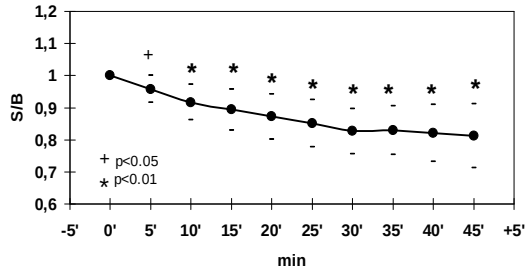

Fig. 2: Relative changes (expressed as Sample/Basal ratio) in s.c. interstitial glucose, evaluated by continuous monitoring, during dives performed without corrective insulin or CHO supplements.

Conclusions

In our experience, the possibility of obtaining continuous glycemic measurements also during immersions, by means of modifications made to the CGMS® system, proved extremely useful in documenting the metabolic effects of scuba diving. This type of exercise is a medium-intensity aerobic activity, but exposed to the effects of rapid changes in environmental pressure and temperature, in situations of mental stress due to the "alien" external ambient: all variables that could interfere with glucose homeostasis**.** The small number of patients examined limits the statistical value of obtained data; however these preliminary data confirm that in experienced, well-controlled, complication-free young diabetic subjects, SCUBA diving within the safety curve can be performed without additional medical risks. This positive result necessitates the application of a rigorous protocol for preventing acute metabolic complications, based on serial pre-dive glycemic determinations followed by insulin or CHO corrections, when necessary. One should take into account that such a result could be obtained at the expense of a temporary rise in glycemic parameters; these changes, however, can be accepted, as transient and not determining a general worsening of metabolic control in the medium term.

The feasibility of glucose monitoring during immersions, demonstrated by the "DEEP MONITORING" project, allows us to hypothesize, in the not too distant future, the underwater use of new-generation monitors, supplying the diabetic diver with a real-time reading of glycemic values and also providing hypo- and hyperglycemic alarms.

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