Control of blood glucose in a group of diabetic scuba divers

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Edge CJ, Grieve AP, Gibbons N, O'Sullivan F, Bryson P. Control of blood glucose in a group of diabetic scuba divers. Undersea Hyper Med 1997; 24(3):201–207.—A preliminary study to examine the hypothesis that the ability of well-controlled (defined as no hypoglycemic episodes within the last 12 mo., $HbA_{1c} < 9.0\%$, and none of the long-term complications of diabetes type I) diabetic scuba divers to control their serum glucose and dive without becoming hypoglycemic during a simulated dive to 27 meters of seawater in a controlled environment is impaired. An open, controlled, crossover study compared blood glucose levels, hematocrits, and hematologic cell counts in a group of eight type I diabetic scuba divers to those from eight age- and sex-matched, normoglycemic control scuba divers. Each diver did one simulated dive and one control exercise on the surface on 2 consecutive days. The simulated dive was done to depth of 375 kPa in a hyperbaric chamber; the control exercise was done at ambient pressure. The order of the dive and the control exercise was randomized. No statistically significant differences were observed between serum glucose levels in the diabetic divers measured during the simulated dive to 375 kPa vs. the serum glucose levels in the diabetic divers measured during the control exercise at the same time points. All divers with type I diabetes remained free of symptoms and signs of hypoglycemia throughout the course of the trial, and no diabetic subject had a serum glucose less than 4 mmol/liter before the end of the trial. As the sample size was small, larger studies including subject with type II diabetes will be necessary to extend these results to the diabetic diving population at large. The authors conclude that, contrary to advice issued by most diving agencies to scuba divers, it may be safe to allow well-controlled subjects with type I diabetes with no long-term complications to undertake scuba diving, and that high partial pressures of oxygen do not seem to lower serum glucose levels significantly in the diabetic diver during the dive.

insulin-dependent diabetes, diving, glucose control

For many years, certification of divers with diabetes by a recognized scuba diver training agency was only possible if the diabetic diver was diet-controlled (1). This policy was based on the theory that if a diver were to become hypoglycemic underwater, with the possibility of a seizure or unconsciousness, then death of the diver would be the likely outcome. Furthermore, such a situation would put the diving buddy at considerable risk. In 1991, the British Sub-Aqua Club (BSAC) decided that such a policy was too restrictive (2), because at the time several scuba divers with type I diabetes were diving without experiencing episodes of hypoglycemia underwater. Both type I and type II diabetic divers have therefore been permitted to dive by the BSAC, the Sub-Aqua Association (SAA), and the Scottish Sub-Aqua (SSAC) provided that they fulfill certain strict criteria [reviewed in (3) and (4)]. Other training agencies, particularly in the United States and Australia, have been debating whether to allow divers with diabetes to scuba dive (5–7).

A database has been established of diabetic divers who are diving with the BSAC, SAA, and SSAC, and some preliminary statistics from this database have been published (8). A recent telephone survey of these diabetic divers has shown that only four episodes of hypoglycemia have been recorded by the divers' more than 1,000 dives, all of which have been corrected using an oral glucose paste, carried underwater by the divers (data to be published). To date, no deaths or accidents underwater as a result of hypoglycemia have been recorded.

Despite the lack of events due to hypoglycemia recorded in the telephone survey, it is possible that nitrogen narcosis, increased partial pressure of oxygen, physical exertion, the psychologic stress of being underwater and hypoglycemia unawareness from previous episode(s) of hypoglycemia or depletion of adrenaline during the dive are causing diabetic divers to fail to register these events. Therefore, to assess further the ability of type I diabetic divers to control their blood glucose during diving, it is necessary to measure blood glucose levels frequently in diabetic divers before, during, and after a dive. An open, parallel study of the effect of pressure on glycemic control in type I diabetic scuba divers was undertaken. The controls were a group of age- and sex-matched non-diabetic scuba divers. As the divers were exercised vigorously during both the dive under pressure and the control "dive" at atmospheric pressure, the trial was done in a hyperbaric chamber. Although this in an artificial diving environment, it enabled rapid assistance to be rendered to the divers should any adverse events occur during the trial. The conditions under which the simulated dive was undertaken, namely to a pressure of 375 kPa, with hard exercise, and with a restricted period post-dive (during which the diver was not allowed food or fluid) giving a total simulated diving trip time of 5 h. were set to try to recreate an energetic and difficult dive with a long period on the surface due to boat engine problems, or lost diver, etc. This scenario is often used as an example of a diving situation that scuba divers with diabetes would not be able to cope with.

METHODS

Experimental methods: Eight normal subjects between the ages 18 and 40 (six male and two female, mean age 26.8 yr) and eight sex- and age-matched type I diabetic subjects (mean age 27.9 yr), selected from the diabetic database, took part in the trial. The average insulin requirement was $0.69 \pm 0.13\ U \cdot kg^{-1} \cdot day^{-1}$ and all subjects had had type I diabetes for a minimum of 5 yr. The ratio of male-to-female divers reflects the sex distribution of male-to-female divers in the diabetic database. The subjects were randomly assigned either to an exercise regimen in a hyperbaric chamber at 375 kPa on the 1st day of the trial, followed by the same exercise regimen in a room at 101 kPa on the following day, or vice versa. The hyperbaric chamber and the room were controlled for temperature (28°–32°C) and humidity (50–70%) throughout the exercise.

The subject fasted from midnight on each day of the study. At 0730 h, 2 ml of blood was drawn from a forearm vein via a cannula for measurement of the serum glucose in duplicate, and a full blood count. The subject was then allowed a usual breakfast, together with the standard dose of insulin that the subject would normally take before a dive. At 0830 h, a further 2 ml of blood was taken. On the day of the dive under pressure, the subject entered the chamber, which was then sealed. Once comfortable, the subject started exercising and was pressurized over 2 min to 375 kPa. The subject performed for 16 min on an exercise bicycle, according to the regimen shown in Table 1. Blood was drawn from the forearm vein at 5, 10, and 15 min after the start of pressurization and, after a small amount had been used to measure blood glucose levels in the chamber using Bayer 4 blood glucose glucometer, was placed in the medical lock and taken to atmospheric pressure. These samples were then used for measurement of hematologic parameters and the duplicate measurement of serum glucose levels (using standard laboratory procedures). After the exercise had been completed, the subject was brought to atmospheric pressure over a period of 5 min. On the day of the dive at atmospheric pressure, the above procedure was followed, except that the subject was placed in a small room, which was sealed for 21 min. After this period, subjects were allowed out of the chamber or the room and could take light exercise around the building. Samples of blood were taken at regular intervals for 5 h after the start of exercise in either the chamber or the room. According to the protocol, no food, fluid, or insulin for the diabetic subjects was allowed during this time unless medically indicated, and no subject required these items on either day during this 5-h trial. This simulated a hard-working dive at depth followed by a problem on the surface, during which time the diabetic diver would not be able to consume food or fluid.

Table 1: Heart Rate vs. Time for the 16-min Exercise Interval

Time Interval (min) From Start of Exercise	Heart Rate, beats/min
0–3	150–160
4–8	130–140
9–12	110–120
13–16	150–160

Throughout the study, subjects were accompanied by an experienced attendant while in the chamber or the room. The dive under pressure was conducted according to decompression diving tables of the Defence and Civil Institute of Environmental Medicine, Department of National Defense, Canada (DCIEM), which are the most conservative tables for general diving purposes. A physician familiar with the study was in attendance on the outside of the chamber or room at all times. The study was conducted in accordance with the Helsinki Declaration (1975), as revised in 1983, and had approval from the local ethics committee. All the subjects taking part in the study gave their signed, informed consent.

STATISTICAL METHODS

The data for white cell counts (WCC), red cell counts (RCC), platelet counts (PC), and hematocrits (Hct) from control and diabetic subjects on the surface day and the chamber day were averaged and the results plotted vs. time. An analysis of variance (ANOVA) was then done on the data for each group of measurements obtained during the chamber day to give the mean difference at each time point between the control divers and the diabetic divers together with their associated 95% confidence intervals.

The data for serum glucose were analyzed by a standard 2 × 2 crossover analysis, ignoring the possibility of a carryover effect (9). The results are presented graphically as the estimated treatment difference between measurements made on the day of the simulated dive (diving measurements) and measurements made on the day at the surface (surface measurements), together with an associated 95% confidence interval. Each time point was analyzed separately with no adjustment for multiple testing, and control divers and diabetic divers were analyzed separately. The former is justifiable because our primary interest was to show that no difference exists between measurements made under conditions on the surface and measurements under conditions of diving; the latter is necessary because of the large difference between control divers and diabetic divers with respect to variability. Additionally, analyses were performed of glucose levels adjusted for baseline values, maximum change from baseline, and average change from baseline. These analyses were deemed necessary because of evidence that differences existed between the surface and diving measurements at baseline.

RESULTS

Figure 1 shows the average data for the WCC, RCC, PC, and Hct of the normal and diabetic divers on the pressurized dive day and the atmospheric pressure day. Statistical comparisons of the data for the diabetic divers with that from the control divers showed no significant differences between the two populations for the WCC, RCC, PC, or Hct at any time point (Fig. 2).

In Fig. 3, *A* and *B* show the individual serum glucose data from the diabetic divers on the surface day and the chamber day, and *C* shows the averaged data for the serum blood glucose from both diabetic divers and control divers on the surface day and the chamber day. Comparison of the data for the diabetic divers on the chamber day showed no statistically significant difference with the data from the diabetic divers on the surface day (*D*).

DISCUSSION

Diving conditions in the coastal and offshore waters surrounding the United Kingdom are some of the most challenging in the world for scuba divers. The waters are frequently cold and dark, and may be strongly tidal, necessitating periods of hard physical activity by the diver. Furthermore, the diver may occasionally be in the water after the dive for a considerable time, either waiting to be picked up by the dive boat or swimming to the shore. In view of such conditions, all diabetic divers are required to carry glucose paste or tablets with them at all times to avoid hypoglycemia. Diabetic divers are able to use the glucose paste underwater by inserting the nozzle of the tube between the mouthpiece of the second stage of the regulator and the corner of the mouth and squeezing the tube. In addition to providing the diabetic diver with a source of glucose, this procedure does not require him or her to remove the regulator from the mouth. The method has been used in a practice situation underwater by diabetic divers and has been found to work well. Further precautions taken by the diver include measurement of the blood glucose using a calibrated glucometer both before and after the dive (with correction of the blood glucose taking place if necessary), training of the dive buddy to recognize the signs of hypoglycemia in the diabetic diver, and education of the other dive members in the club about the problems of diabetes in the diving situation.

This preliminary study examined how well the well-controlled diabetic diver could regulate his or her insulin to avoid a hypoglycemic attack (without the use of glucose paste) for one dive (diabetic divers would not normally undertake dive trips longer than about 2 h without access to food and fluids). In additions, we looked at whether the effect of pressure and hard exercise would cause the blood glucose levels in the diabetic diver to fall faster than in a diabetic diver performing the same level of exercise at atmospheric pressure.

The results illustrated in Fig. 3 show that even though the diabetic divers were exercised hard for 16 min under pressure, it was over 4 h before the first of the diabetic divers' serum glucose measurements were less than 5 mmol/liter, at which point the diabetic diver would in practice require a further intake of carbohydrate. Furthermore, in this group of diabetic subjects, the 20-min period under a pressure of 375 kPa of air decreases the blood glucose concentration slower than when the diabetic subject is breathing air at 101 kPa. This result contrasts with the data from Springer (10) who reported that whole blood glucose concentration (WBGC) decreased by an average of 51 mg/dl (2.8 mmol/liter) in 25 "insulin-dependent diabetics" after hyperbaric oxygen (HBO_2) therapy; such data have often been quoted as a justification for not allowing diabetic subjects to dive. There are three reasons why there should be such a discrepancy:

- The diabetic divers in our study undertook only a single period of exercise under pressure. The subjects in the report by Springer (10) had been given several treatments with HBO_2. Multiple treatments with HBO_2 may

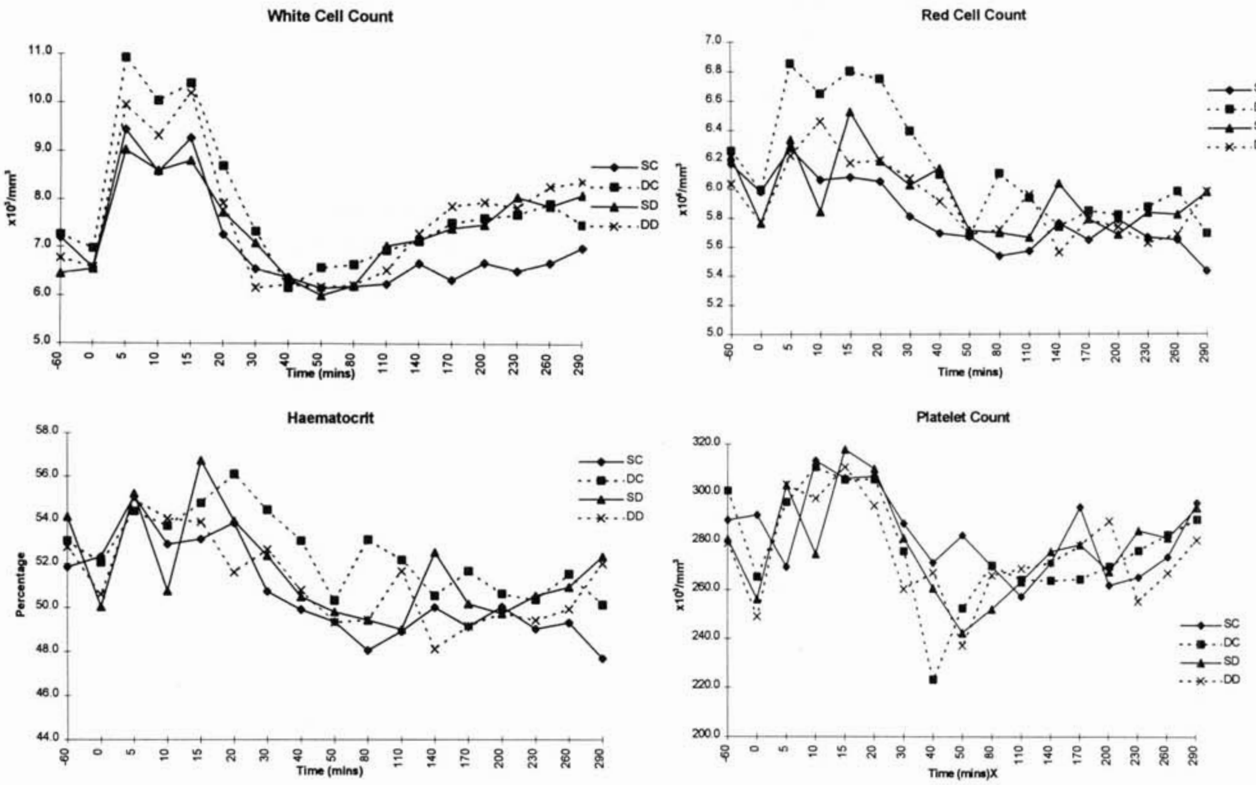

FIG. 1—Composite figure showing the mean data from control and diabetic divers for the WCC, RCC, PC, and Hct as a function of time. The time interval shown is for 60 min before the start of exercise and for 290 min after the start of exercise. *SC* = data from control divers during the surface day; *DC* = data from control divers during the chamber day, including 18 min bottom time at 375 kPa; *SD* = data from diabetic divers during the surface day; *DD* = data from diabetic divers during the chamber day, including 18 min bottom time at 375 kPa. *Note* that the time axis is non-linear for greater clarity.

be necessary to cause serum glucose levels to fall. This explanation is supported by Lerch et al. (11), who reported in their multi-dive study on novice diabetic divers that both long- and short-term insulin requirements dropped over a period of 7 days. However, by measuring the serum glucose levels frequently in their diabetic subjects, the potential problem of hypoglycemia being present underwater did not seem to arise.

- The pressure of oxygen during our study (74 kPa) was not high enough for this effect to become manifest in our diabetic divers. Springer (10) used a pressure of O_2 of 200 kPa for several periods of 90 min each. Our study subjected the diabetic divers to a single period of only 20 min under pressure.
- The diabetic divers in our study were well controlled with none of the long-term complications of diabetes. In Springer's study (10), the diabetic subjects were receiving HBO_2 therapy for complications brought about by the diabetes such as foot ulceration or osteomyelitis. It is therefore possible that hormonal imbalance or the presence of infection could cause HBO_2 therapy to lower the blood glucose level in those subjects.

Our group of diabetic divers differed from those examined by Lerch et al. (11) in two important aspects. First, the diabetic subjects in our group were all experienced divers. Those examined by Lerch et al. had not undertaken formal scuba training before their trials. Second, our group of diabetic subjects tended to start with higher blood glucose levels (5–19 mmol/liter) than those examined by Lerch et al. (9–12.3 mmol/liter). Despite the lower levels of blood glucose in their group, no episodes of hypoglycemia were recorded and no emergency glucose was used during their trial. However, the main aim of our trial was to examine diabetic divers after they had taken what they considered to be their normal dose of insulin before a dive, but as a result of these differences between the two trials, it may be possible in future to offer more informed advice as to a desired level of blood glucose measured immediately before a dive.

The data obtained for the WCC, RCC, Hct, and PC from the control divers throughout the dives show no statistically or clinically significant difference at any time between the

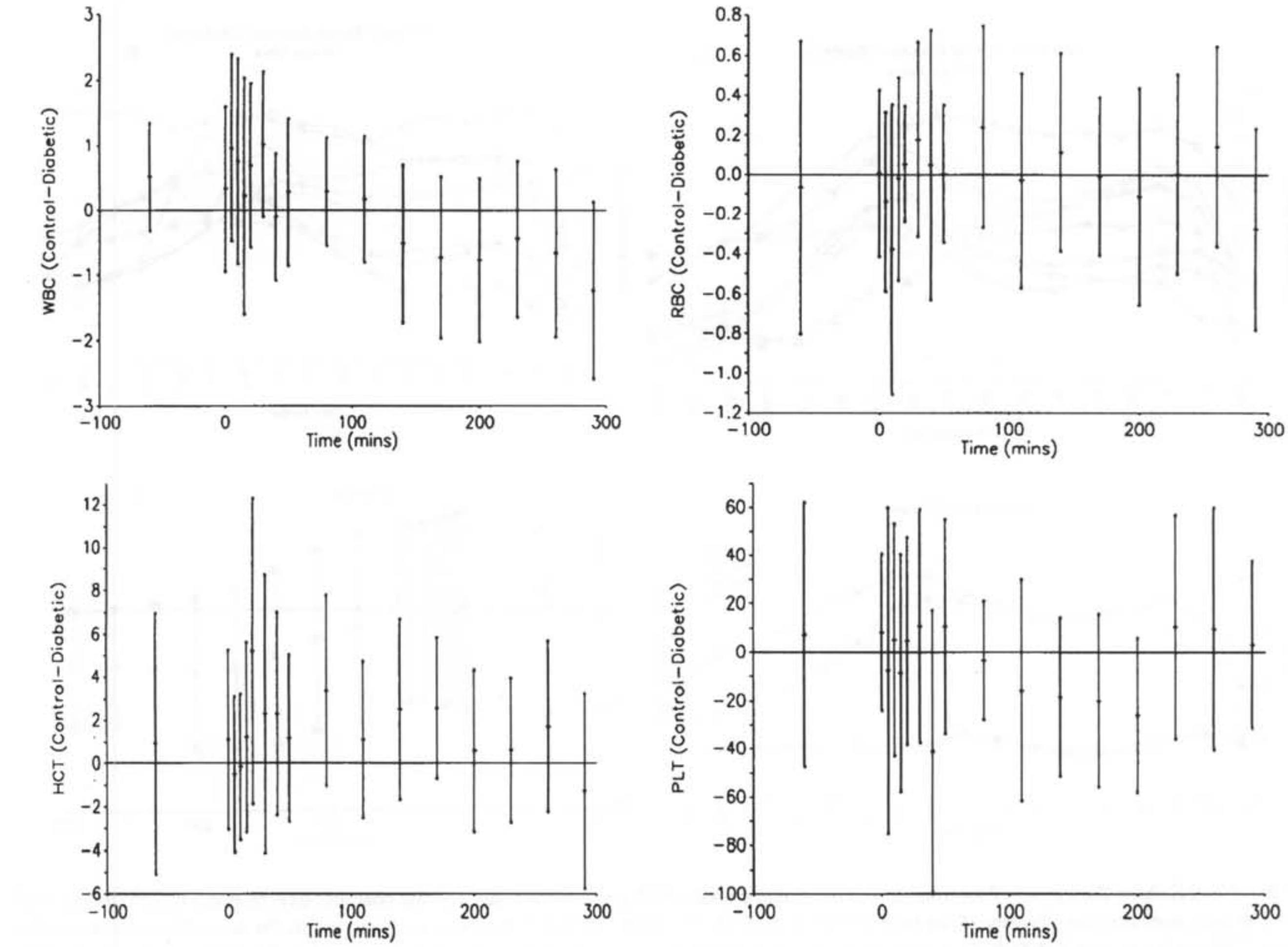

FIG. 2—Composite figure showing the data from control and diabetic divers on the chamber day for the WCC, RCC, PC, and Hct as a function of time. Data are plotted as the difference in means between control and diabetic divers. Error bars represent 95% confidence intervals. Confidence intervals all span the line indicating equality of the mean data for control and diabetic divers; therefore the differences are not significant.

control divers and the diabetic divers, either on the dive day or the surface day. However, this was a pilot study and hence our sample size was small. Therefore, it is important to note that our statistical results, while valid for our population of diabetic and control divers, may not be representative for all divers with type I diabetes. Larger studies, including divers with type II diabetes, will be necessary to ensure that these results are representative for the whole diabetic diving population.

The RCC, Hct, and remained clinically stable throughout the course of the trial, but the WCC was observed to rise sharply at the start of bicycle exercise, and to fall to approximately the pre-exercise value at the end of the bicycle exercise, both on the surface day and on the dive day. This suggests that the WCC rises in response to exercise rather than to the increase in pressure, which is consistent with the data reported by Philp et al. (12,13) who found no increase in total leukocyte count immediately after decompression from a simulated air dive or up to 96 h later. Although our data suggest that the contribution that acute blood cellular changes make to the risk of decompression illness is similar in control and diabetic subjects, longer term blood cellular differences between the control and diabetic subjects may alter the risk profile of divers with type I diabetes.

This study took place in a warm environment with high humidity, which resembles tropical diving conditions rather than those conditions found around the United Kingdom. It was necessary to conduct such a preliminary study in the safety of the chamber environment so that the divers could be monitored and untoward accidents avoided as far as possible. Now that the results from the study are known, and well-controlled diabetic divers have been shown to be able to avoid hypoglycemia for the duration of the trials, it will be possible to study diabetic divers in cold waters.

The results indicate that a diabetic diver with no episodes

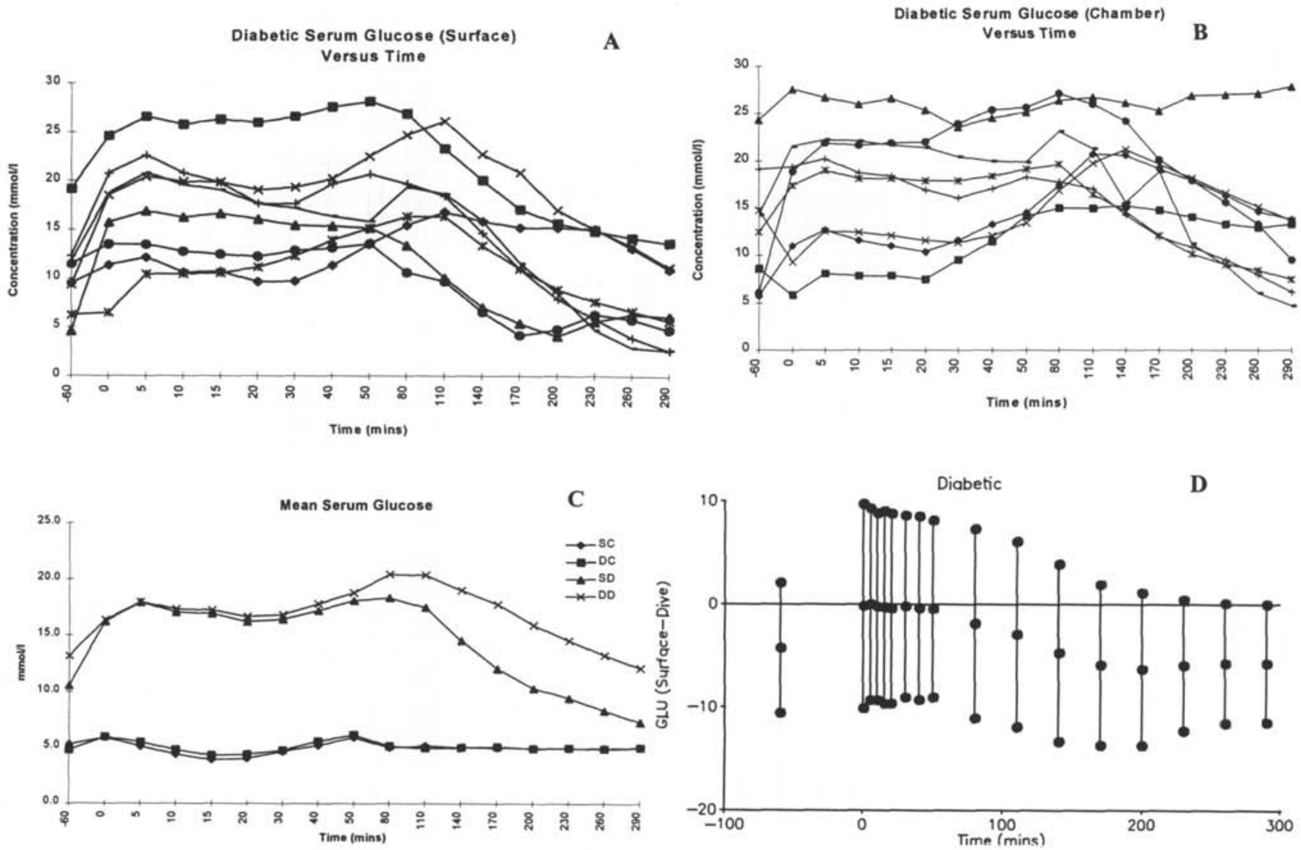

FIG. 3—*A* and *B* show the glucose data from individual diabetic divers during the surface day and the chamber day, respectively, plotted vs. time up to 290 min; *note* the non-linearity of the time axis for greater clarity. Same symbol in the two panels represents the same diabetic diver on the 2 days. *C* shows the averaged data from control divers and diabetic divers on the surface day and the chamber day. *SC* = data from control divers during the surface day; *DC* = data from control divers during the chamber day, including 18 min bottom time at 375 kPa; *SD* = data from diabetic divers during the surface day; *DD* = data from diabetic divers during the chamber day, including 18 min bottom time at 375 kPa. *D* shows the difference in means between diabetic divers on the surface day and the chamber day. Error bars represent the 95% confidence intervals at each time point. Error bars all span the line indicating no difference in serum glucose concentration for the diabetic divers between the surface day and the chamber day; differences are therefore not statistically significant.

of hypoglycemia in the last 12 mo., with an HbA1c < 9.0%, and none of the long-term complications of diabetes may be able to undertake scuba diving at depths of up to 30 m without becoming hypoglycemic, provided that: a) the diabetic diver renders him or herself hyperglycemic before the dive; b) does not stay in the water for longer than about 2 h; c) is able to have access to accurate glucose monitoring equipment, a source of glucose, and adequate hydration after the dive; and d) his or her diving companions are able to use the glucose monitoring equipment and to provide first-aid in the form of administration of glucose or glucagon and O_2 in the event of the diabetic diver having a diving accident in or under the water.

Further work will be necessary to extend the results of this study to the diabetic diver population as a whole, using larger numbers of diabetic divers (type I and type II) and taking blood before, during, and after diving in the sea. The study should also examine the situation where more than one dive per day is undertaken.

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