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Circulating Venous Bubbles in Children After Diving

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Doppler ultrasonic detection of circulating venous bubbles after a scuba dive is a useful index of decompression safety in adults, since a relationship between bubbles and the risk of decompression sickness has been documented. No study, however, has investigated circulating venous bubbles in young recreational divers after their usual dives. The aim of this study was to determine whether these bubbles would be detected in children who performed a single dive without any modification in their diving habits. Ten young recreational divers (13.1 ± 2.3 years) performed their usual air dive. They were Doppler-monitored 20 min before the dive (12 ± 3 m for 26 ± 7 min) and for 60 min after surfacing, at 20-min intervals. No circulating venous bubbles were detected after the children surfaced. The results showed that during a usual shallow diving session, venous bubbles were not detected in children.

Considerable information has been amassed on the formation of venous gas emboli in adults, both men and women, as a result of decompression from a scuba dive (1,2). Studies have shown that the risk of decompression sickness (DCS) rises with the number of bubbles in the blood (4,9,24). Neurologic DCS (i.e., spinal cord DCS) is presumed to be because of venous bubbles in the epidural plexus surrounding the spinal cord, causing venous stasis and spinal cord ischemia. The role of arterial gas emboli via a right-to-left shunt (i.e., patent foramen ovale: PFO) is suspected in certain forms of DCS (i.e., cerebral and inner ear DCS). Another observation is that age and the fat mass percentage seem to accentuate bubble formation (4). The incidence of PFO is about one in four in the general adult population (17), and it also increases the risk for decompression sickness events by allowing venous bubbles to pass into the arterial circulation (11). Although the frequency of PFO in children is about 30–40%, the fact that it resolves with age suggests that it is more prevalent in children than in adults. Although details on dive profiles are often incomplete for persons presenting with DCS, PFO increases the risk for decompression sickness four- to fivefold (2,23), even in adult divers adhering to decompression tables. In France, more than 300 adult diving injuries related to PFO and requiring hyperbaric recompression have been documented (9). Furthermore, recent cases of decompression accidents in

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young divers (<16 years) have been reported in France (12) and the United States of America (USA) and Canada (Divers Alert Network: DAN, 1). In 2005, the youngest injured diver in France requiring hyperbaric oxygen recompression therapy was 13 years old and the youngest in the USA was an 11-year-old. Moreover, Tsung et al. (26) reported the case of a highly trained adolescent diver who, despite advanced diving certifications, had two separate episodes of diving-related injuries requiring hyperbaric recompression therapy. Thus, even though the French norms for children limit the diving times and depths, it may be necessary to monitor young divers for circulating venous bubbles after usual dives. The aim of our preliminary study was thus to evaluate whether circulating venous bubbles would be present in young divers (<16 years) after they performed a single dive without any modification in their usual diving habits.

Materials and Methods

Participants

Postdive Doppler monitoring was performed in ten young recreational divers (boys) after a single open sea dive (good visibility, quiet sea, no current, and with a water temperature of 21 °C). All were divers from the French Diving Federation (FFESSM) and had responded to an invitation to take part in a national gathering of diving youth. They were selected on the basis of the regularity of their diving practice, age (>8 years and <16 years) and diving experience (>6 months). All children regularly practiced diving in a swimming pool twice a week and used an open-circuit scuba once a week. At least twice a year for 5 days, the children practiced open sea dives. The time since their last air (O_2-N_2) dive was at least 1 week. None of the children had any experience with smoking (25) and all had been found to be fit to dive during a medical diving examination, in accordance with the regulations of the FFESSM, within the 2 weeks before the experiment. Because body fat has been found to be a factor for bubble formation after diving (4), the percentage of body fat was also calculated according to Janz et al. (14). To establish possible correlations with the diving training of young divers, cumulative diving exposure over the entire diving career was assessed by logbook documentation: years of diving practice (YD), maximal depth (MD) and total number of dives (TND). The study was approved by the local institutional review board and informed written consent was obtained from the parents of the children.

Bubble Detection

Bubble detection was performed with a continuous-wave Doppler apparatus (AQUALAB system) equipped with a 5-Mz probe (Figure 1). To improve the accuracy of the cardiac signal, the children were placed in left lateral decubitus, and they lay at rest for 1 min before the beginning of detection. Because the children were in real diving conditions (they had equipped themselves, swum and then climbed out of the pool), they were affected by cold and immersion (diuresis, hemoconcentration, dehydration). Thus their level of bubble release was assumed to correspond to the actual occurrence in all divers respecting the safety rule: little exercise before, during, and after diving. For this reason, we did not follow the

Figure 1 — Doppler detection in a young scuba diver.

usual protocol of studies conducted in hyperbaric chambers, which begin monitoring once the participants are at rest after performing three deep knee bends. The probe was placed in the precordial site, with the ultrasonic wave being directed into the pulmonary infundibulum. The signals were recorded for 2 min and graded in a blind manner by two experienced investigators, according to the Spencer Doppler code (24). Bubble signals were classified on a scale from 0 to 4 (0 representing no detectable bubbles), on the basis of the number of bubble signals per cardiac cycle, and the number of cardiac cycles containing bubbles. If any discrepancy in the interpretation of the signals occurred, the recordings were studied again until consensus was reached. Before the dive, a recording of each child's cardiac signals was made to establish a reference. Moreover, because aerobic exercise before diving can modify venous gas bubble formation in humans (8), the children were instructed not to perform any exercise for at least one week before the dive, as well as during and after diving. The ten young recreational divers were Doppler-monitored 20 min before the dive (12 ± 3 m; 26 ± 7 min) and for 60 min after surfacing, at 20-min intervals. To avoid modifying the children's diving habits, no particular instructions were given to the instructor, who was responsible for monitoring the children's diving profile (depth and time).

Statistical Analysis

Graded bubbles were compared between before and after diving up to 60 min using a Wilcoxon matched-paired signed-rank test. A *p*-value of less than .05 was considered to be significant. Analyses were performed using Statview software (Abacus Concepts, Inc., Berkeley, CA, 1992).

Results

Table 1 presents the baseline anthropometric characteristics and cumulative diving exposure over the entire diving career. The reporting of recreational activity was considered adequate and properly recorded in logbooks by the instructors and/or parents of the divers. The children had had no diving accidents or signs or episodes of decompression sickness. They performed one dive to a depth of 12 ± 3 m, for a short time (26 ± 7 min). However, for all these young divers, several successive descents to this relatively shallow depth, each lasting 7–10 min, were observed and were interspersed by 2–5-min periods at or near the surface (Figure 2; yo-yo dives). During each ascent to the surface or close to it, the ascent rate was 17 $m.min^{-1}$. No circulating venous bubbles (grade 0 for all dives) were found in any of the divers in the 60 min following their dives.

Discussion and Conclusion

To our knowledge, this is the first study to search for circulating venous bubbles in diving children. The main finding was that bubbles were not detected after a shallow single dive.

This study was preliminary and we did not want to impose a diving profile. We were nevertheless surprised by the diving depths and the dive profiles. The children made only one dive to a shallow depth (12 ± 3 m), for a short time (26 ± 7 min), with yo-yo profiles. Repetitive dives are widely practiced in recreational diving, and yo-yo dives are more typical in children, who generally practice diving in shallow water. Yo-yo dives are a series of several short dives separated by very brief intervals. An example would be several successive descents to a relatively shallow depth for 15–20 min, interspersed by 5-min periods at or near the surface. This diving pattern in children adds not only to the risk of DCS but also to the risk of pulmonary barotraumas with cerebral arterial gas embolism (AGE). Cerebral AGE occurs when alveolar gas ruptures into the pulmonary veins and is then carried via the heart into the cerebral circulation. Bubbles may also reach the brain via abnormal arteriovenous channels within the lungs or through a PFO (18,23,29). Indeed, although the children's dives required the simplest form of decompression control, i.e., without stops during the ascent to the surface, even a simple decompression profile must be correctly executed to avoid accidents. A shallow dive with a slow ascent certainly places the diver at lower risk of DCS but divers and instructors need to remember that no dive is without some risk. Although no bubbles were detected in the children, this does not mean that no bubbles formed. Since venous gas microemboli (VGM) with an undetectable diameter of less than 30 μm may be present without overt clinical symptoms, the risk of decompression sickness (DCS) is never nil (20). It is thus important to remember that DCS is a probabilistic event and has a chance of occurring in nearly any dive, even though the probability may be very small (28). A grade 0 indicates that the decompression pattern is safe for divers in a given population, but for an individual of that

Table 1 Characteristics of Young Recreational Divers (Boys) and Cumulative Diving Parameters

Age (years)	Height (cm)	Body mass (kg)	% Body fat	YD	TND	MD
13.1 ± 2.3	161.9 ± 10.0	49.2 ± 9.8	19.7 ± 5.3	2.5 ± 1.9	17 ± 14	13 ± 9

Note. YD = years of diving practice; TND = total number of dives in sea water; MD = maximal number of dives. Values are means ± *SD*.

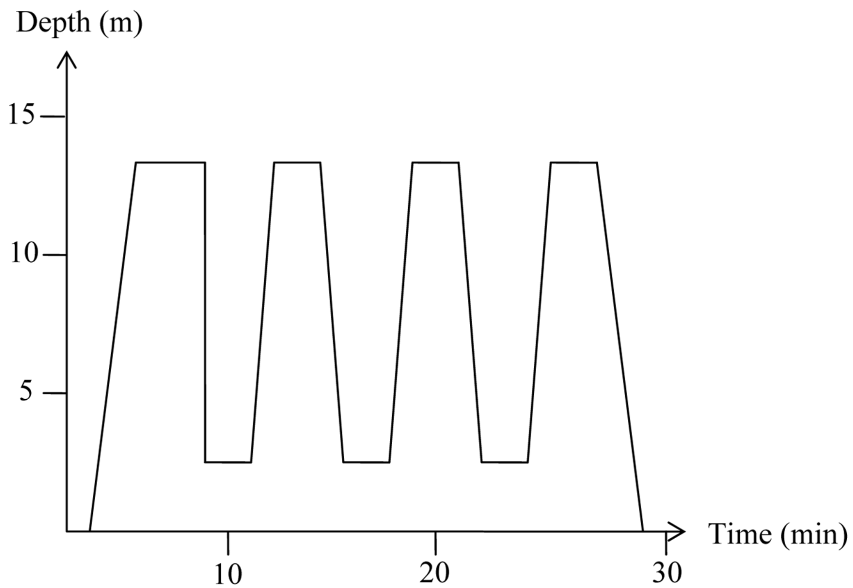

Figure 2 — Example of schematic dive profile of the young recreational divers.

population an accident is always possible, even when no bubbles can be detected. For example, the accident rate is about 1% with a grade 0; 0.5% with a grade 1; 5% with a grade 2; 11% with a grade 3 and 31% with a grade 4 (22). Assessing the risk of developing DCS is not simply a question of the number of circulating venous bubbles that are present. The assessment must also take into account the possibility of bubbles in tissue and complex biologic reactions. Nevertheless, the duration, depth, and ascent protocol of the children's dives allowed us to classify these young divers as being at low risk of DCS. In general, the greater the depth and duration of diving and the more rapid the ascent, the greater the risk of DCS will be.

Many other factors have been suggested to either increase bubble formation or predispose tissues to bubble injury. Obesity, aging, excessive physical exertion during the dive, predive physical condition, dehydration, cold and poor general condition are factors that may predispose an individual diver to DCS (4–6). Older divers have been shown to generate more venous bubbles than their more youthful counterparts after equivalent dives (9,15). In fact, DCS susceptibility is increased by age and indirectly increased by the greater fat mass that develops with aging. Since nitrogen solubility in fat tissue is high, an elevated percentage of body fat increases the total nitrogen content in the body, with a consequently increased DCS risk (4–6). For Broome et al. (3), however, the poor aerobic fitness associated with obesity or overweight contributes to the bubble formation process. Our children, although their percentage of fat mass and body mass index could be classified as "normal" (13), did not practice other sports, which could increase their DCS risk.

Limits

Although the risk of decompression sickness is never nil (20) and smaller asymptomatic bubbles may be present, the shallow diving profile seen in the children of the current study was unlikely to elicit bubbles. There is considerable variation in diving responses: some individuals are bubble prone and individual divers may respond differently to similar dive profiles at different times. It is therefore necessary to use some judgment in interpreting the results. Moreover, our Doppler apparatus was not capable of detecting bubbles with a diameter less than 30 μm (20), and it cannot be used as a real-time decompression monitor because bubbles are detectable only after the surface is reached. Nevertheless, ultrasonic bubble detection is a good tool for postdive evaluation, with the advantage of being compact, robust and inexpensive. Because of the small number of participants, further studies will be necessary to generalize these results.

Recommendations

Children's respiratory, psychological, cardiovascular, thermoregulatory, otolaryngological, and musculoskeletal characteristics influence their capacity to react during diving (7,21,27). Children thus have their own specific needs when diving, and they must not be considered merely as small adults. We recommend that instructors establish slow ascent rates (<10 m · min^{-1}) with a safety stop for 3–5 min at 3–5 m (16). A safety stop presents a good opportunity for children to exercise buoyancy control during the ascent. Last, by lowering the minimum age for recreational diving, diving organizations, instructors and parents increase the probability of having cognitively immature children enrolled in diving programs. These children would clearly be at greater risk for accidents. Scoring high in trait anxiety on a validated psychological measure was found to be reasonably predictive of future panic behavior while diving in college-age beginner divers (19).

In conclusion, this study evaluated the occurrence of venous bubbles in young divers and detected no bubble formation after dives. The absence of bubbles could be explained by the shallow water dives, which are usual for children and which allow no tissue saturation. Further studies will be undertaken to improve our understanding of children's physiology during diving so that they can be helped to develop into adult divers who take minimal risks.

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