Circulating bubbles and breath-hold underwater fishing divers: a two-dimensional echocardiography and continuous wave Doppler study

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Boussuges A, Abdellaoui S, Gardette B, Sainty JM. Circulating bubbles and breath-hold underwater fishing divers: a 2D echocardiography and continuous wave Doppler study. Undersea Hyper Med 1997; 24(4):309-314. — Since the 1960s, decompression illness after breath-hold diving has been widely debated. The aim of this study was to detect circulating bubbles after breath-hold diving in underwater fishing divers. We used continuous Doppler (DUG, COMEX Pro) and transthoracic two-dimensional (2D) echocardiography (Kontron Sigma 1). This study was conducted during a training course organized by the French Federation of Subaquatic Sports at Minorca (Balearic Islands). Ten breath-hold divers performed repeated breath-hold dives for periods ranging from 2 to 6 h (mean maximum depth 35 meters of seawater (msw)). A dive computer (Maestro Pro Beuchat, analyst PC interface) was used to record diving patterns. No circulating bubbles were detected in the right heart cavities (2D echocardiography) or in the pulmonary artery (continuous Doppler). However, this study had some limits: only 10 subjects were studied and the earliest detection was 3 min after immersion, further studies will thus be required.

breath-hold diving, decompression, bubbles, two-dimensional echocardiography, continuous wave Doppler

Nitrogen desaturation in scuba divers leads to the production of circulating air bubbles during the decompression period and the following minutes. Since the 1970s, these bubbles have been detectable using Doppler ultrasound (1-3). A system of classification to measure the circulating gas bubbles was developed by Spencer (4) and Kisman and Masurel (5). The bubble scores are based on the relative number of bubbles as compared to the heart rate. Several authors have studied a possible correlation between the degree of bubbles present and the probability of decompression illness (DCI) (6-11). Although the significance of this correlation is debated, all authors observed that when no bubbles are detected with the Doppler, the risk of DCI is very low. An interesting application for the detection of circulating bubbles is assessing whether a diving pattern is likely to be aggressive. Although continuous wave Doppler is recognized as a reference technique, it does have its limits in terms of the sensitivity of bubble detection and a non-negligible rate of inter-observer variability which can distort a statistical study when the population studied is very small (12). Echocardiography [two dimensional (2D) and M-mode] yields a visual image of gas emboli in the right heart chambers (13,14).

Since the 1960s, when Cross (15) and Bagnis (16) published articles on Taravai in Polynesian pearl divers, the occurrence of DCI after breath-hold diving has been widely debated. In a breath-hold diver who does not breathe pressurized gas, the only inert gas that dissolves is the nitrogen that remains in the diver's lungs from the last breath before immersion. This gas is exhaled during the recovery stage at the surface between two periods of apnea. Two different mechanisms can lead to the formation of circulating air bubbles in breath-hold divers.

A single dive to a substantial depth seems to cause the production of circulating air bubbles when the diver surfaces and during the first few seconds thereafter, through saturation of the short period tissues. Schaefer (17) demonstrated the presence of microbubbles in arterial and venous blood samples taken during the seconds that followed immersion after a 30 meters of seawater (msw) breath-hold dive.

Repeated dives to depths shallower than 20 msw for several hours with short recovery periods can lead to an accumulation of dissolved nitrogen in tissues equal to the amounts found for scuba divers; the saturation process involves the long and short period tissues (18,19). Accidents reported in pearl divers at the beginning of the 1960s were attributed to this progressive nitrogen supersaturation (15,16). Lanphier (20) set out a safety curve similar to those used for scuba divers, which defines the limits according to the ratio between the apnea time/recovery time.
and the depth of the dive. Frequent breath-hold dives to significant depths could cause neurologic DCI (18). This hypothesis is debatable because this type of accident occurs rarely and is unknown in some populations of professional divers performing underwater fishing for long periods (21). In addition, other etiologies may give rise to neurologic disorders that may be wrongly attributed to DCI; for example, hypoxia, hypercapnia, possibly hypoglycemia, cardiac arrhythmia, dehydration, or any other intervening incident (22–25).

Some studies have confirmed the existence of gas emboli after breath-hold dives. In 1965, during self-observation, Paulev (18) reported paresthesia-type disorders and motor deficit in his left arm after performing approximately 60 breath-hold dives at depths of between 15 and 20 msw. These disorders disappeared quickly after recompression in a hyperbaric chamber. The author attributed these disorders to arterial gas emboli. However, it is important to note that the breath-hold dives were preceded by 8 min in a hyperbaric chamber at a pressure of 3 atm abs (304 kPa), which contributed to increasing the tissue nitrogen supersaturation. Thus, this observation is not representative of a series of dives performed only with apnea. In 1972, Spencer and Okino (26) used continuous wave Doppler and described the signals that suggested circulating air bubbles in Korean divers after 30 breath-hold dives lasting 50 s at depths of about 15 msw. These noises were detected during the hour that followed the last period of apnea. This study seems to suggest sufficient nitrogen supersaturation of the tissues with bubble formation.

The accidents most recently published in the literature, including neurologic disorders in underwater fishing divers, have been attributed to DCI (27,28). Currently, no study gives any insight into the extent of nitrogen saturation in breath-hold divers after underwater fishing competitions. We studied circulating air bubbles in top level breath hold divers during training periods, using two-dimensional (2D) echocardiography and continuous wave Doppler ultrasound recordings.

**MATERIAL AND METHODS**

The subjects were 10 breath-hold divers belonging to the French harpoon fishing team. Their mean age was 29 ± 7 yr, mean height 181 ± 8 cm, and mean weight 74 kg ± 10 kg.

The study was done during the deep harpoon fishing event that was held at Minorca (Spain) from 5–15 October 1995.

The divers were divided into three groups at three separate sites. In each group, a diver’s dive profile was recorded on a Maestro Pro Bechat computer.

![FIG. 1.—Apical four-chamber view. RA = right atrium, RV = right ventricle, TV = tricuspid valve; LA = left atrium, LV = left ventricle; MV = mitral valve.](image)

Circulating bubble detection tests were performed soon after the last period of apnea on 11 and 12 October 1995. A second exam was performed 30 min after the first detection.

**Two methods were used to screen for air bubbles.**

**Continuous wave Doppler:** The equipment (Comex Company) used continuous wave ultrasound with a frequency of 5 MHZ. The Doppler probe was placed along the left edge of the sternum to assess the bloodflow in the pulmonary artery. Recordings were made on magnetic tape to be analyzed later by two independent investigators.

We used the Spencer scale (4), as modified by Kismar and Masrul (5), to classify the bubble production rate. This method is based on the analysis of three parameters:
- the maximum number of bubbles per systole,
- the percentage of systoles containing bubbles, and
- the amplitude of the bubble signal compared to the background noise.

The divers were screened in the standing position at rest and during flexion of the lower limbs.

**Two-dimensional echocardiography:** The screening tests were performed using a Kontron Sigma I apparatus equipped with a 3.5 MHZ probe. Images were obtained from the parasternal view (long axis and short axis) and from an apical four-chamber view (Fig. 1). The subject was placed in a left lateral decubitus position for the parasternal views and in a supine position for the apical four-chamber view. To increase the sensitivity of the method, the diver was asked to perform an isometric contraction of the quadriceps muscles. A qualitative evaluation of circulating bubbles was performed according to an echocardiographic grade described by Powell et al. (29). To screen for bubbles as soon as possible after the last breath hold, the 2D echocardiography was placed on board a boat equipped with a generator. Each exam was
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recorded on video tape and analyzed by two independent investigators.

RESULTS

Ten bubble detection tests were performed on 11 October 1995. On 12 October 1995, due to bad weather conditions, only five bubble-detection tests were possible, then 15 bubble-detection tests were performed on the 10 breath-hold divers (Table 1).

These underwater fishing divers held their breath at a mean maximum depth of 35 msw (between 24 and 40 msw) for a mean duration of fishing of 4 h 3 min (2–6 h). Three of the divers' patterns were recorded on a computer. The technical features of the hardware enabled us to draw the depth curves according to the time parameters, using an interface and a PC program.

The three divers yielded the following diving curves:

- Breath-hold diver 1 performed 48 breath holds each averaging 2 min 12 s during a 4-h underwater fishing period. The duration of these periods of apnea totaled 43% of the total time. The ratio for time spent on the surface to underwater was 1:3. The mean depth for the breath-hold dives was 28 msw (17–39 msw).
- Breath-hold diver 2 performed 39 periods of apnea of a mean duration of 2 min 41 s during 3 h 38 min of underwater fishing. The duration of apnea was 48% of the total time. The ratio for time spent on the surface to time spent at depth was 1:1. The mean depth for the breath-hold dives was 31 msw (24–40 msw).
- Breath-hold diver 3 performed 39 breath holds for an average duration of 2 min 47 s during an underwater fishing period of 5 h 9 min. The duration of apnea was 35% of the total time. The ratio for time spent on the surface vs. time spent underwater was 1:8. The mean depth of apnea was 30 msw (17–38 msw).

The record for breath-hold diver 3 for the first 3 h of underwater fishing on 11 October 1995 is shown on Fig. 2. When making dives to 40 msw the descent takes from 35 to 45 s and the ascent from 30 to 40 s.

The 2D echocardiography and Doppler examinations were performed in 73% of the cases within 30 min of the last breath hold for the day (extremes 3–75 min).

We found no evidence of circulating air bubbles (grade 0 Powell, grade 0 Kisman–Masuré) with either of the procedures used (2D echocardiography, continuous wave Doppler).

DISCUSSION

Records compiled for the underwater fishing divers we studied in the Balearic Islands could theoretically induce a high degree of saturation. Therefore, if we refer to the data supplied by the computer, we observe that two divers out of three did not have sufficient time to recover (that is, the ratio between time on the surface and time underwater was insufficient) according to the safe limits prescribed by Lanphier (Fig. 3). Despite these potentially aggressive conditions, we were unable to detect any circulating air bubbles with the two investigation techniques we used.

However, our bubble detection was not sufficient to confirm that the divers tested were not substantially supersaturated in nitrogen. To avoid imposing constraints upon the divers, we did not perform the tests immediately after the last apnea dive (minimum 3 min). Some of the

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bubbles may thus have been released during desaturation of the tissues, as described by Schaefer (17), without being noticed. However, the absence of circulating air bubbles in these divers seems to suggest that the long half-time compartments were not sufficiently supersaturated. Although we used two different detection techniques to increase sensitivity, micro-bubbles, smaller than 30–50 μm may not have been detected. Additionally there is a high degree of variation in individual susceptibility to decompression, and on any given profile there will be those who produce bubbles and those who do not (30). Within the small population there could have been a bias inherent to non-bubble producers.

Out future studies will have a 3-fold purpose:

- To increase the population screened: currently, 15 observations have been made in 10 different divers. Increasing the sample will limit biases resulting from subjects who do not produce bubbles under these conditions.
- To screen for bubbles soon after the last period of apnea, which was not always possible in Minorca.
- To study breath-hold divers after periods of intensive underwater fishing (for example after competitions), apnea under these conditions being more frequent than in training courses and the ratio between time on surface and time underwater being shorter.

The accidents most recently published in the literature, including neurologic disorders that suggest DCI, have been reported in breath-hold divers using underwater scooters (27). With this sort of device the dives are deeper and the divers descend and return to the surface faster than breath-hold divers without scooters, resulting in an increase of time at the bottom. The sharp variations in the surrounding pressure are likely to lead to the production of bubbles of
inert gas. Studies of breath-hold divers using this type of underwater propulsion device would thus seem to be very worthwhile.

During the last few years, an extraordinary increase in the performance of underwater fishing divers has been recorded. Computer-processed diving curves have enabled us to visualize a fast succession of dives between 30 and 40 msw in depth over a period of several hours in underwater fishing divers in the French underwater fishing team. These diving curves should theoretically expose the divers to inert gas supersaturation with a resulting risk of DCI. We were not able to demonstrate circulating air bubbles in breath-hold divers using two high-performance test techniques (continuous wave Doppler ultrasound and 2D ultrasound echocardiography). This study is, however, not sufficient to eliminate the possibilities of bubble formation in short half-time compartments.

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REFERENCES


