Decompression Induced Venous Gas Emboli in Sport Diving: Detection with 2D Echocardiography and Pulsed Doppler

A. Boussuges [1], D. Carturan [2], P. Ambrosi [3], G. Habib [3], J. M. Sainty [1], R. Luccioni [3]

[1] Service de Réanimation Médicale et d'Hyperbarie, Hôpital Salvator, Marseille, France
[2] UFR STAPS Fac Luminy, Marseille, France
[3] Service de Cardiologie B, Hôpital Timone, Marseille, France

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The aim of this study was to determine the utility of pulsed Doppler and 2D echocardiography for the detection and the quantification of circulating bubbles after decompression. Twenty-three sport divers performed 60 SCUBA dives (mean 32 msw). An evaluation of circulating bubbles was performed using 2D images one hour after diving. Circulating bubbles were also detected with pulsed Doppler. The sample volume was placed in the outflow area of the right ventricle 1–2 cm below the pulmonary valve. 2D echocardiography showed circulating bubbles in right cavities of the heart in 32 cases. Short axis parasternal view and right cavities long axis view were the best incidences. Pulsed Doppler confirmed the results in these 32 cases and detected circulating bubbles in seven other cases. Isometric contraction of muscle limb must be performed to increase the sensitivity of detection. The count of the bubbles may be evaluated when using a combination of Spencer's and Powell's grading. We conclude that 2D echocardiography is less accurate than pulsed Doppler in the detection of circulating bubbles after decompression. Further studies are needed to compare pulsed Doppler guided by 2D echocardiography to continuous Doppler for the detection of circulating bubbles.

Key words: Diving, decompression, gas emboli, echocardiography, Doppler

Introduction

Formation of venous gas emboli as a result of decompression from hyperbaric pressures is well recognized. Such bubbles may be "silent" or may induce symptoms of decompression sickness. Since 1970, circulating bubbles can be detected by ultrasonic methods (9,10,23). The sites monitored with continuous wave Doppler can be the precordial region, the subclavian vein, and the inferior vena cava. Detection of bubbles higher than 50 microns is possible while smaller bubbles are undetectable (11). Considerable researches were conducted by Spencer in United States and Guillerm-Masurel in France to quantify circulating bubbles (14,24). The bubbles are classified on a scale based on the number of bubble signals per cardiac cycle and the number of cardiac cycles containing bubbles. Numerous studies have been performed to correlate the bubble signals with symptoms of decompression sickness (1,5,17,18, 19,20,24). This correlation is discussed but when no circulating bubble was detected the risk of decompression sickness is very low. Furthermore, individual factors can influence the bubble formation, and, after the same dive, the divers with high degrees of circulating bubbles have a higher risk of decompression accident than others (8,19).

Detection of circulating bubbles can be used as an indicator of the safety of a dive and its decompression procedure (6,15,16). Continuous wave Doppler is the most widely used method but the analysis of the signals obtained involves a degree of subjectivity. The inter-observer variability on the grading of intravascular bubble signals can be important and statistics of studies with only a few records can be impaired (22).

Other ultrasonic methods for detecting bubbles have been evaluated. Echocardiography (two dimensional [2D] image or M-mode) can visualize circulating bubbles in right cavities (12,13,21). Echo imaging ultrasound including transesophageal echocardiography have gained wider acceptance for use with venous gas emboli detection. Transesophageal echocardiography is semi invasive and has been used during experimental animal studies (4,7,25). In divers who have suffered decompression illness, transesophageal echocardiography is useful to detect patent foramen ovale (2).

In the present work, we compared 2D echocardiography and pulsed Doppler for the detection and the quantification of circulating bubbles.

Methods

Subjects

From October 1995 to October 1996, 23 sport divers (22 men, 1 woman) age 35 ± 12 years (19–54); height 177 ± 7 cm; weight 78 ± 13 kg performed 60 Self Contained Underwater Breathing Apparatus (SCUBA) dives (mean depth 32 ± 3 msw. mean duration 30 ± 4 min). The mean number of dives for each subject was 3 (ranging from 1–8). No repetitive dive was studied. No order concerning the duration and the profile of the dive was given by the cardiologist. All gave informed consent.

Decompression procedures were conducted according to the decompression table of the French Navy 90 or the decompression table of the French Ministry of Labour 92.

2D Echocardiography and pulsed doppler

Bubble detection was performed one hour after diving. The ultrasonic apparatus was a Vingmed CFM 750/A (Diasonics) using a 3.25 MHz probe. Ultrasonic examinations were done in supine position both at rest and during periodic isometric contractions of the quadriceps. Images were obtained from the parasternal view (long axis and short axis) and from the apical four chamber view. Gas bubbles appear as high intensity "blobs" in the images. A quantitative evaluation of circulating bubbles was performed using 2D images. The 2D study was recorded on video tape over a period of 5 min.

Circulating bubbles were also detected with pulsed Doppler. The sample volume was placed in the outflow area of the right ventricle 1–2 cm below the pulmonary valve. Apical four-chamber view and aortic blood flow Doppler study were systematically obtained to detect circulating bubbles in the left cavities. The pulsed Doppler study was recorded on video tape.

The 2D echocardiography and pulsed Doppler studies were analysed by two independent investigators. All cardiologists had at least five years of previous clinical experience. Interobserver variability was < 5%. In case of discrepancy a consensus was obtained.

To quantify circulating bubbles in the venous circulation, bubble scores were calculated using the Spencer Doppler code (24) and a 2D echocardiographic grade built by Powell (21). Then a new grade combining 2D echocardiographic and Doppler analysis was proposed.

Results

Circulating bubbles were detected in 39 of the 60 SCUBA dives. Twenty of the 23 divers demonstrated circulating bubbles. Bubbles were observed only in the right cavities of the heart.

2D Echocardiography

The 2D images were of good quality in 16 subjects, moderate quality in four subjects and of poor quality in three subjects.

Circulating bubbles were observed in right cavities of the heart in 32 cases (16 divers). Table **1** gives the bubble grade according to Powell's score. Circulating bubbles were detected from short axis parasternal view (Fig. **1**) and right cavities long axis view in respectively 31 cases and 30 cases. Circulating bubbles were detected from the four chamber view in divers with a high bubble grade and good echogenicity (16 cases). No circulating bubbles were observed in the left cavities of the heart.

Table 1 Detection of circulating bubbles with 2D echocardiography

	Positive detection	Grade 1	Grade 2	Grade 3
Apical four chamber view	16	0	14	2
Right cavities longitudinal view	30	6	22	2
Parasternal short axis view	31	6	23	2
Combination of all incidences	32	7	23	2

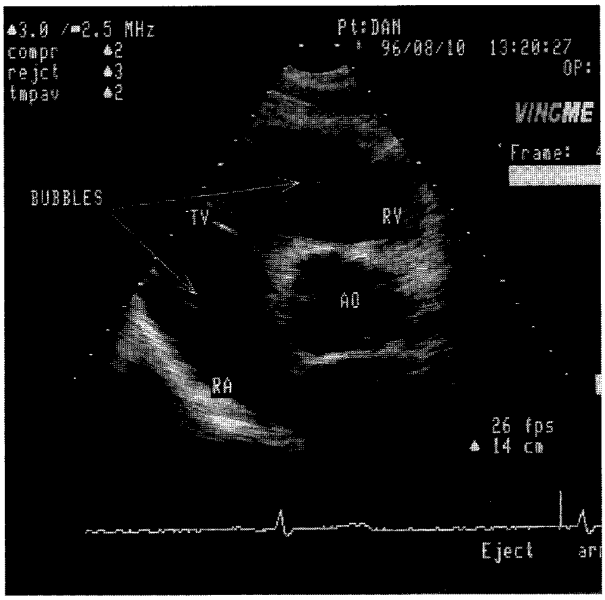

Fig. 1 2D echocardiography: circulating bubbles in the right cavities of the heart (short axis parasternal view).
RA: Right atrium, RV Right ventricle, OA Aorta, TV Tricuspid valve

Pulsed doppler

Circulating bubbles were accoustically detected in the artery blood flow and were visualised in the flow spectrum as echogene elements (Fig. **2**). Pulsed Doppler confirmed the results of 2D echocardiography in 32 cases and detected circulating bubbles in seven other cases (Table **2**). The seven cases of discrepancies between negative 2D echocardiography and positive pulsed Doppler were observed in six divers: three of them with poor echogenicity, three of them with moderate echogenicity. No discrepancy was noticed in patients with good echogenicity. No circulating bubble was detected in the aortic blood flow.

Table 2 Results of circulating bubble detection

Grade	0	1	2	3	4
Powell (2D Echocardiography)	28	7	23	2	–
Spencer (Pulsed Doppler)	21	12	7	19	1
2D Echocardiography and Pulsed Doppler	21	12	7	18	2

Table 3 2D- Echocardiographic and pulsed Doppler grade

Grade 0	Complete lack of bubble signal (2D Echocardiography and pulsed Doppler)
Grade 1	Occasional bubbles, the great majority of cardiac periods are free of bubbles (2D Echocardiography and pulsed Doppler)
Grade 2	Flow of bubbles (2D Echocardiography), many but less than half of the cardiac periods contain bubble signals singularly or in group (pulsed Doppler)
Grade 3	Flow of bubbles (2D Echocardiography), majority of the cardiac periods contain bubble signals singularly or in group (pulsed Doppler)
Grade 4	Bubbles fill cardiac chambers (2D Echocardiography), all the cardiac periods contain bubble signals in group (pulsed Doppler)

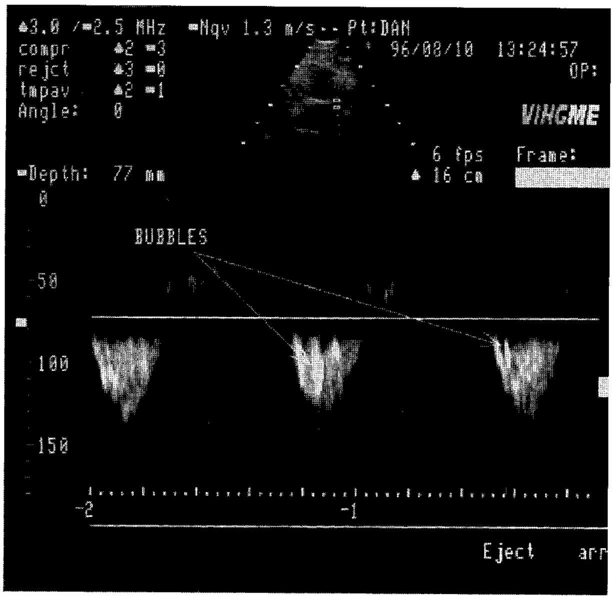

Fig. 2 Pulsed Doppler: bubble detection in pulmonary blood flow

Isometric muscle contraction effect

The level of circulating bubbles was higher during isometric contraction of quadriceps in 12 of 22 cases. Of these 12 bubble detections, three were negative at rest.

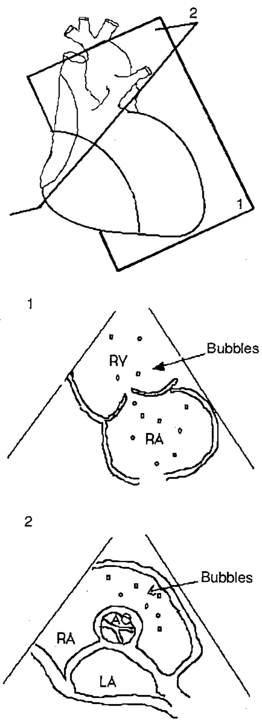

Fig. 3 2D echocardiography: best incidences. **1**: Right cavities longitudinal view. **2**: Parasternal short axis view. RA: Right atrium, RV: Right ventricle, AO: Aorta, LA: Left atrium

2D Echocardiography and pulsed doppler grade

A 2D echocardiography/pulsed Doppler grade was built with a combination of Spencer and Powell grades (Table **3**). Table **2** gives the bubble grade according to the 2D echocardiography and pulsed Doppler grade.

Discussion

Many studies have focused on the diagnostic value of ultrasonic methods for the detection of circulating bubbles during decompression (6,15,24). Continuous Doppler is the routinely employed method. However, recently scepticism has been cast on the accuracy of the ultrasonic findings (22). In more recent years, echo imaging ultrasound devices have gained wider acceptance for use with venous gas emboli detection. We simultaneously used continuous Doppler (DUG) and transthoracic 2D imaging during a saturation dive at the COMEX Hyperbaric Center in 1993 (3). Both techniques seem to have the same sensitivity.

In the present study we evaluated 2D echocardiography combined with pulsed Doppler for the diagnosis of circulating bubbles one hour after a sport dive.

In agreement with previous studies (7,21) we found that 2D echocardiography can detect bubbles in right cavities of the heart. Best incidences were parasternal short axis view and right cavities longitudinal view (Fig. **3**); they must be systematically performed. Circulating bubbles were detectable in the four-chamber view in divers with a high bubble grade and good echogenicity.

In our study, 2D echocardiography alone was less sensitive than pulsed Doppler combined with 2D echocardiography. Indeed pulsed Doppler showed bubbles in 32 of 32 cases with echocardiographic evidence of circulating bubbles and in seven cases negative at echocardiographic examination. The lesser sensitivity of echocardiography can be explained by a poor or rather poor quality of 2D images in 1/3 of our population. However, 2D echocardiography was useful for bubble detection with pulsed Doppler because it allowed a precise localization of pulsed Doppler window in right ventricle outlet, immediately proximal to the pulmonary valve. This precision can be interesting because an oscillatory motion of the bubbles is proved in the right ventricle and in the pulmonary artery (4); therefore exploration in these sites can count twice as many bubbles or more and overestimate bubble count. In contrast, oscillatory motion of the bubbles seems less important in ejectional blood flow at the pulmonary level. Continuous wave Doppler does not allow a precise localization of bubble detection. Therefore count precision could also be affected by this technique. This remark must be demonstrated in a complementary study.

Quantification of circulating bubbles can be performed by 2D echocardiography combined with pulsed Doppler. Thus we developed a new grading for bubble count, combining pulsed Doppler and 2D echocardiography.

Moreover, our study confirmed that isometric contraction of the muscles of the lower limbs can increase the sensitivity of bubble detection. This manoeuvre probably increases the release of stationary bubbles in the inferior vena cava and in lower limb vein. It can be of interest when bubbles are rare (12,16).

Combination of 2D echocardiography and pulsed Doppler of the pulmonary artery seems useful to allow a precise quantification of circulating bubbles. However, further comparative studies with continuous Doppler are needed to confirm or to invalidate these observations.

Conclusion

Methodology of detection of circulating bubbles using pulsed Doppler and 2D echocardiography has been defined in our study. Visualization of circulating bubbles with 2D echocardiography was possible. Short axis parasternal view and right cavities long axis view were the best incidences. However, this method was limited by diver echogenicity. Pulsed Doppler guided by 2D imagery was more sensitive for this detection. Combination of 2D echocardiography and pulsed Doppler can be proposed to increase the accuracy of Doppler detection only. Isometric contraction of muscle limb must be performed to increase the sensitivity of detection. The count of the bubbles may be evaluated when using a combination of Spencer's and Powell's grading. Pulsed Doppler guided by 2D echocardiography seems to be a good method to detect circulating bubbles induced by decompression but further studies are needed to compare it with the reference method: continuous Doppler.

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Corresponding Author

Dr. Alain Boussuges, M. D.
Assistant des Hôpitaux et Chef de Clinique à la Faculté
Service de Réanimation Médicale et d'Hyperbarie
Hôpital Salvator
249 Bd de Sainte-Marguerite
PB 51
13 274 Marseille Cedex 9
France