Comparison of continuous wave Doppler and pulsed Doppler guided by 2D echocardiography in the detection of venous gas emboli.

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ABSTRACT

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We compared the sensibility for the detection of venous circulating bubbles of pulsed Doppler guided by 2D-echocardiography versus traditionnal continuous Doppler with blind positionning of the transducer, the current reference method.

The study was carried out in two differents situations : during an Helium/Hydrogen saturation dive in 4 professionnal divers, and after recreationnal underwater SCUBA dives in 26 sports divers.

During the saturation dive, the detection sensitivity and specificity were the same with both techniques. Following the recreationnal dives, the pulsed Doppler guided by 2D-echocardiography detected, in 3 cases, circulating bubbles which were not seen by continuous Dopler.

In conclusion, if the two methods are equivalent in terms of sensitivity when the ultrasound exploration is easy to perform and yields a good Doppler signal (i.e. in young athletic divers). image guided pulsed Doppler is more precise and capable of screening circulating bubbles in cases for which the examination is more difficult to perform due to a reduced ultrasound window.

INTRODUCTION

During the decompression stage, after a period in a hyperbaric environment. bubbles may form and circulate in the venous blood flow. These bubbles are made up of the neutral gas in the breathing mixture which is trapped in the blood and the tissues in a supersaturated state when the surrounding pressure drops. Since the 1970s, these circulating bubbles can be screened by Doppler effect (1. 2. 3). Continuous wave Doppler is currently considered to be the gold standard non-invasive method. Several sites can be explored, including the pulmonary artery, the subclavian vein and the lower vena cava. This procedure is capable of detecting bubbles over 50 microns in diameter, however smaller bubbles which may form during decompression are not picked up (4). Spencer and Kisman-Masurel's research using

Doppler effect ultrasonography resulted in classification systems to quantify the circulating bubbles (5. 6). The bubble scores rate the number and frequency of bubbles compared with the heartbeat. Several studies have researched into the correlation between the bubble rating and probability of a decompression accident (5. 7-12). The correlation is debatable, but all the authors have observed that when no circulating bubbles are screened the risk of an accident is very low. Bubble screening can therefore be used as a security indicator for diving profiles. A decompression profile that does not induce the production of bubbles in a diving population is a safe profile. The main quality of a bubble screening procedure is therefore its sensitivity.

Although continuous wave Doppler is currently the most widely used procedure, it does remain limited with respect to bubble detection sensitivity and also its inter-observer variability, which may be quite high and thus distort a statistical study when the population studied is small (13).

Alternative detection procedures have been tested. TM and 2D mode echocardiography provides a visual image of bubbles circulating in the right heart chambers (14-16). Transoesophageal 2D mode ultrasonography has been demonstrated useful in screening bubbles, however, as it is an invasive examination. its use is limited top experimental protocols in animals (17-19). Transthoracic (2D or TM) ultrasonography is less invasive and provides good visual information on bubbles circulating in the right heart cavities. In a recent study, we demonstrated that pulsed Doppler guided by 2D image provide a better method for the detection of venous gas embolism than 2D echocardiography alone (20).

The objective of this study was to compare the detection sensitivity of pulsed Doppler guided by 2D echocardiography versus continuous wave Doppler, the current reference method. This study was carried out during a saturation dive in 4 professional divers and after underwater dives in 26 sports divers.

MATERIAL AND METHODS

Saturation dives

The Helium/Hydrogen saturation dives were carried out at the COMEX Hyperbaric Center in Marseilles. Four professional divers participated. The protocol was approved by the Center's ethics committee. The diving protocol included a 3 day compression phase. followed by a 9 day stay at a pressure of 36 atmospheres, followed by a 12 day decompression period. The breathing mixture was composed of Heliox (He-O2) with a constant O2 partial pressure at 0.4 atm. During the stay at maximum depth, hydrogen was added to the breathing mixture during 6 hour periods for 4 consecutive days. When the hydrogen was added, the pressure increased from 36 to 37.5 atm. Conversely, at the end of the 6 hour sessions, the hydrogen was replaced by helium and the pressure was brought back down to 36 atm. Four hours after the hydrogen was withdrawn, two bubble screening methods were used : continuous wave Doppler (COMEX Pro) using a 5 MHz frequency probe, and pulsed Doppler guided by 2D echocardiography (Diasonics CFM 750).

Divers

Four professional divers were studied. They were aged 28 +/- 2 years (26-30 years). Their height was 177 +/- 6 cms (168-183), their weight was 78 +/- 8 kgs (69-88) and their body mass index was 25 +/- 2 kg/cm^2 (22-28).

Bubble screening

Continuous wave Doppler screening method

The probe was positioned by the divers themselves after a 3 day training period. The screening sessions lasted for one minute. The continuous wave Doppler ultrasound signal was transmitted outside the hyperbaric chamber, to allow a physiologist to guide the examination. The screening sessions were carried out at rest and after movement, 4 hours after hydrogen withdrawal and the decompression from 37.5 to 36 atm. The precordial region was studied to record the ejection blood flow into the pulmonary artery. The circulating bubbles were graded using the Spencer score (5). The quality of the screening was assessed for each recording and rated as satisfactory, average or poor.

The screening sessions were recorded on magnetic tape and then analyzed by two independent investigators. If any discrepancy in the interpretation of the signals occurred, the recording was studied again in order to reach a consensus.

Pulsed Doppler guided by 2D echocardiography screening method

The circulating bubbles were screened 4 hours after the exchange of hydrogen for helium, using a Diasonics Vingmed CFM 750/A type ultrasonography machine. The ultrasonography unit was located outside the hyperbaric chamber and connected up to a 3.25 MHz probe inside the chamber, via a leadthrough in the hull. The examination was carried out by the divers who had gone through a week's prior training with a cardiologist. They could monitor the results of their ultrasonography tests on the ultrasonography unit screen through a porthole and each screening session was guided by a cardiologist, who performed controlled the ultrasonography unit screen (Figure 1, 2).

The explorations were performed in dorsal decubitus at rest and during isometric contraction of the quadriceps muscles. For each diver, images were obtained from the parasternal view (long axis and short axis) and from an apical four chamber view. Pulsed wave Doppler screening was performed by studying the pulmonary artery blood flow. The sample volume was placed in the outflow area of the right ventricle just below (1 to 2 cm) the pulmonary sigmoid valves on the short axis parasternal view (figure 3). The screening sessions lasted for one minute. The explorations were recorded on a video tape and subsequently analyzed by two independent investigators. All of the cardiologists had at least 5 years prior clinical experience. The variability in the analysis of the results was low and in case of any discrepancies. the results were submitted to a further analysis to reach a consensus. The circulating bubbles were graded on the Spencer score. which applies to pulsed wave Doppler study of the blood flow in the pulmonary artery. The quality of screening was assessed for each recording and rated as satisfactory, average or poor.

It was possible to compare the two methods because the two explorations by continuous wave Doppler and pulsed wave Doppler ultrasonography were performed consecutively at an interval of less than 10 minutes. The tests were not performed in any preferential order.

Sports diving

The divers

From December 1995 to October 1997. 26 divers, average age 37 +/- 11 years (20-53 years), height 178 +/- 7 cms (168-190). weight 80 +/- 15 kgs (60-105), body mass index 25 +/- 5 kg/cm^2 (20-33) were studied. They had carried out 26 underwater SCUBA dives at a mean depth of 32 +/- 5 msw, duration 28 +/- 6 minutes. The cardiologists gave them no specific instructions, their informed consent was obtained. The decompression procedures were based on the French legal stipulations (French National Navy 1990 and Ministry of Labor 1992).

Bubble screening

The screening sessions were carried out by two cardiologists for the ultrasonography and by 2 physiologists for the continuous wave Doppler tests, 1 hour after the dive. The continuous wave Doppler and pulsed wave Doppler ultrasonography tests were performed a few minutes after each other. The screening methods were identical to those used for the saturation dives.

Statistical Study

The sensitivity and specificity of the bubble screening method by pulsed Doppler guided by 2D echocardiography was calculated using the continuous wave Doppler tests as a reference procedure.

Minor discrepancies were defined as a difference of 1 grade between the two screening methods.

In the screening tests performed on the sports divers, a Kappa test was used to assess the agreement between the results. A Wilcoxon test on paired series was used to compare the bubble grades obtained with both procedures.

RESULTS

None of the divers presented any disorders suggesting a decompression accident. Sixteen comparative screenings were performed on the professional divers (Table 2) and 26 in the sports divers (Table 3).

Saturation dives

The quality of detection was judged to be satisfactory both for continuous wave Doppler and for pulsed Doppler guided by 2D echocardiography.

Venous gas emboli were screened in 7 of the 16 continuous wave Doppler explorations. Three of the four professional divers presented circulating bubbles. A wide variability in tolerance was recorded. Diver nÐ 4 regularly presented higher bubble rates than the other divers.

Using the continuous wave Doppler procedure as a reference, we found a level of 100% of screening sensitivity and specificity for the pulsed Doppler guided by 2D echocardiography. When the results of the screening sessions were positive with continuous wave Doppler, they were always positive with pulsed Doppler guided by 2D echocardiography.

Minor discrepancies were recorded in both cases and one major discrepancy was observed. The bubble grade was higher with continuous wave Doppler in one case and in 2 cases with pulsed Doppler guided by 2D echocardiography.

Sports Diving

Twenty six comparative screening sessions were carried out.

For the continuous wave Doppler, the quality of screening was judged to be satisfactory in 20 cases, average in 2 cases and poor in 4 cases. For pulsed Doppler guided by 2D echocardiography, the quality of screening was judged to be satisfactory in 24 cases and average in 2 cases.

The screening tests were positive in 14 cases with continuous wave Doppler and in 18 cases with pulsed Doppler guided by 2D echocardiography.

Using continuous wave Doppler as a reference procedure, we found a rate of sensitivity of 93% and specificity of 58% for pulsed Doppler guided by 2D echocardiography.

The Kappa test showed a good degree of agreement between the two screening procedures (K=0.62, tv 50 = 4.7, p=0.0001)

The mean grade screened was 1.73 +/- 1.46 with pulsed Doppler guided by 2D echocardiography and 1.38 +/- 1.53 with continuous wave Doppler. The difference between the bubble grades with the two screening procedures was not statistically significant (z =1.561. p = 0.11 Wilcoxon test on paired series).

Minor discrepancies were observed in 4 cases. The bubble grade was higher with the continuous wave Doppler in 2 cases and higher with the pulsed Doppler guided by 2D echocardiography in 2 cases.

Major discrepancies were recorded in 3 cases. In these cases, the screening tests were negative with continuous wave Doppler, whereas the pulsed Doppler guided by 2D echocardiography grade was 3. These major discordant results were recorded for 3 subjects with a high body mass index (respectively 28. 32 and 33 kg/cm^2). In these 3 cases, the continuous wave Doppler screening test was judged to be of average quality in 1 case and poor in 2 cases.

DISCUSSION

The results differ according to the terrain studied : saturation diving or sports diving.

During a saturation dive, it is useful to screen for circulating bubbles to monitor decompression speed (21). The divers must go through a training period. whatever the screening method used because the investigators cannot go inside the hyperbaric chamber during the tests. The training yielded good quality screening results with both methods in athletic divers. Continuous wave Doppler and pulsed Doppler guided by 2D echocardiography are identical in terms of sensitivity to circulating bubbles. For these reasons, as the results are comparable and continuous wave Doppler is easier to perform and cheaper to run, it would seem to be the most appropriate procedure. However, pulsed Doppler guided by 2D echocardiography does provide a more comprehensive analysis of cardiac function and may prove to be advantageous as a replacement for experimental work (22).

After underwater dives, a satisfactory level of agreement was observed for both screening methods (see Kappa test). Using continuous wave Doppler as a reference method, the sensitivity of pulsed Doppler guided by 2D echocardiography screening was 93%. One minor discrepancy was observed to the detriment of the pulsed wave Doppler method. Our results also show a specificity of 58% for the pulsed wave Doppler in comparison to the continuous wave Doppler. This poor specificity is secondary to 5 positive screening tests with pulsed wave Doppler, which were negative on the continuous wave Doppler. These discrepancies were major in 3 cases and minor in 2 cases.

As we had no "gold standard" procedure, we cannot exclude false positive results with pulsed Doppler guided by 2D echocardiography screening. However. we found in all positive tests accoustic bubble signals, observed with a good signal-to-noise ratios, and the associated echogenic elements in the flow spectrum (figure). This combination of acoustic and visual signals renders positive detection outcome convincing.

These results may explain why for a risk of 11% (see Wilcoxon's test) the bubble grade screened by pulsed Doppler guided by 2D echocardiography was higher than by continuous wave Doppler. The size of the sample would, however, have to be increased to confirm or infirm this trend. The subjects' morphology was in some cases detrimental to the quality of the screening tests and may be the cause of these major discrepancies. The fact the imaging is available to guide the pulsed wave Doppler facilitates good quality recordings of the blood flow in the pulmonary artery and optimizes the screening procedure which probably explains the better results obtained in comparison to continuous wave Doppler. Thus, whereas

23% of the examinations were not judged to be of satisfactory quality for the continuous wave Doppler, only 8% were sub-optimal for the pulsed Doppler guided by 2D echocardiography.

Our population, which included divers of different ages and varied morphologies was representative of the population of SCUBA divers. It appears preferable, when carrying out on site studies, to used the screening method which yields the best performance and in our study, this method appears to be pulsed Doppler guided by 2D echocardiography.

Limitations of the study

The tests were not performed simultaneously, but at intervals of a few minutes, The timing we selected, in relation to the beginning of the decompression period, was chosen because a plateau phase occurs during the desaturation process between 30 minutes and 1 hour and a half after this type of dive (23). The circulating bubble grade may vary in a very short time-frame, although the amplitude of these variations is usually low. To limit the bias, we chose to make quite long recordings, lasting 1 minute. We also detected minor discrepancies, which may be due to variations in the intensity of the desaturation process and major discrepancies which seem unlikely to be due to physiological causes and are probably due to variations in the screening sensitivity of the two procedures. If both recordings had been taken simultaneously, we would not have had this constraint, but this was impossible because the investigation site was the same for both methods : the precordial region.

CONCLUSION

Our study comparing continuous wave Doppler and pulsed Doppler guided by 2D echocardiography performed in two different environments, enabled us to draw several conclusions.

When the ultrasound exploration is easy to perform and yields a good Doppler signal, both procedures are equivalent in terms of sensitivity. This is true for athletic professional divers. Continuous wave Doppler, which is easy to implement, therefore seems appropriate to study desaturation in hyperbaric chambers for selected subjects. However, in cases for which the examination is more difficult to perform due to a reduced ultrasound window, pulsed Doppler guided by 2D echocardiography is more precise and capable of screening circulating bubbles when the continuous wave Doppler test is negative. Ultrasonography detection can be used in sports diving to evaluate the safety of a decompression profile. The method used must be sensitive. it therefore seems preferable to use pulsed Doppler guided by 2D echocardiography. The sensitivity of the screening procedure is all the more important because the population of leisure divers inevitably includes subjects with a high body mass index and these were the subjects who were difficult to screen by continuous wave Doppler in our study. An increase in the number of divers studied would be desirable to provide statistical confirmation of our observations.

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	Switch 1		Switch 2		Switch 3		Switch 4	
	Doppler	Echo	Doppler	Echo	Doppler	Echo	Doppler	Echo
Diver 1	**2**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
Diver 2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Diver 3	**1**	**3**	**0**	**0**	**0**	**0**	**0**	**0**
Diver 4	**3**	**3**	**4**	**4**	**3**	**3**	**3**	**4**

Table I : Results : Detection of circulating bubbles by Continuous Wave Doppler and pulsed Doppler guided by 2D Echography in Professional Divers (Spencer grade)

	Echo/pulsed Doppler	CW Doppler		Echo/pulsed Doppler	CW Doppler
Dive 1	**2**	**3**	**Dive 14**	**3**	**3**
Dive 2	**1**	**1**	**Dive 15**	**0**	**1**
Dive 3	**3**	**3**	**Dive 16**	**0**	**0**
Dive 4	**3**	**3**	**Dive 17**	**0**	**0**
Dive 5	**1**	**0**	**Dive 18**	**3**	**3**
Dive 6	**1**	**0**	**Dive 19**	**3**	**0**
Dive 7	**0**	**0**	**Dive 20**	**3**	**3**
Dive 8	**0**	**0**	**Dive 21**	**4**	**4**
Diver 9	**0**	**0**	**Diver 22**	**1**	**1**
Dive 10	**1**	**1**	**Dive 23**	**0**	**0**
Dive 11	**0**	**0**	**Dive 24**	**3**	**3**
Dive 12	**4**	**4**	**Dive 25**	**3**	**0**
Dive 13	**3**	**0**	**Dive 26**	**3**	**3**

Table 2. Results : Detection of circulating bubbles by Continuous Wave (CW) Doppler and pulsed Doppler guided by 2D Echography (Echo/pulsed Doppler) in Sport Divers (Spencer grade)