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Doppler bubble detection and decompression sickness: a prospective clinical trial

C. G. BAYNE, W. S. HUNT, D. C. JOHANSON, E. T. FLYNN, and P. K. WEATHERSBY

Departments of Emergency Medicine and Clinical Investigation, Naval Hospital, San Diego, CA 92134; Naval School, Diving and Salvage, Washington, DC 20374; and Hyperbaric Medicine Program Center, Naval Medical Research Institute, Bethesda, MD 20814-5055

Bayne CG, Hunt WS, Johanson DC, Flynn ET, Weathersby PK. Doppler bubble detection and decompression sickness: a prospective clinical trial. Undersea Biomed Res 1985; 12(3):327–332.—Decompression sickness in human beings exposed to high ambient pressure is thought to follow from gas bubble formation and growth in the body during return to low pressure. Detection of Doppler-shifted ultrasonic reflections in major blood vessels has been promoted as a noninvasive and sensitive indicator of the imminence of decompression sickness. We have conducted a double-blind, prospective clinical trial of Doppler ultrasonic bubble detection in simulated diving using 83 men, of whom 8 were stricken and treated for the clinical disease. Diagnosis based only on the Doppler signals had no correlation with clinical diagnosis. Bubble scores were only slightly higher in the stricken group. The Doppler technique does not appear to be of diagnostic value in the absence of other clinical information.

ultrasound
venous gas embolism
bends

Decompression sickness in deep sea divers (the "bends" or DCS) is commonly thought to follow the formation of gas bubbles in the diver's body. While at depth, inert gas from the diver's breathing gas supply, compressed to his ambient pressure, is absorbed in his tissues. Upon decompression, the gas becomes supersaturated and the return to lower pressures leads to frank bubble appearance and symptom development by mechanisms whose quantitative details are still controversial. The disease may be prevented by adherence to a controlled slow rate of decompression, commonly called a decompression schedule.

It has been proposed that early detection of bubbles in the diver's body could allow decompression schedules to be developed that would be bubble-free and thus free of DCS (1). In an operational setting, early bubble detection might allow decompression to be slowed to suppress further bubble formation, to suggest prophylactic oxygen treatment, or to signal the imminent onset of DCS. The latter point appears most important because treatment for DCS, a combination of recompression and oxygen breathing, is most successful when instituted immediately (2,3).

Detection of Doppler-shifted ultrasound reflection has many features that make it attractive for noninvasive detection of circulating bubbles in men (1,4). Numerous reports have appeared on animal and human use of Doppler devices in decompression studies (1,4–13). Many of these have used Doppler findings with other indications of DCS. Several more recent studies have cast doubt on the diagnostic capabilities of the Doppler technique (9–11). A few groups, however, have used Doppler monitoring for decisions on treatment of humans in the absence of other findings (1,7) and in one recent report Doppler results were used operationally as equivalent to clinical DCS (13). To our knowledge, only one blind clinical trial has addressed the use of this technique (8). That study claimed a statistically significant association between one set of high "bubble scores" *(see below)* and the onset of DCS symptoms. We have performed a direct clinical trial and found Doppler of essentially no value in the diagnosis of individual cases of decompression sickness.

MATERIALS AND METHODS

A standard simulated training dive at the Naval School of Diving and Salvage was chosen for trial. A series of 87 consecutive students and staff underwent a hyperbaric chamber exposure breathing air at pressure equivalent to 285 ft of sea water (gauge) for 6 to 11 min with the decompression schedule chosen according to standard U.S. Navy practice. Following the exposure, each subject who reported any symptoms was examined by an experienced clinician. Treatment decisions were based only on clinical signs and symptoms. The physician in attendance and the subjects themselves had no knowledge of the Doppler signals during the entire course of the study.

Doppler evaluation was designed to be fully blind. All subjects had sensors for a Model 1032 5.2 MHz Doppler (Institute of Applied Physiology and Medicine, Seattle, WA) attached in the recommended precordial position on the chest, which is said to be sensitive to bubbles traveling in the pulmonary artery (1,5). Signals were monitored by a technician until correct placement was obtained, then a series of subsequent audio signals were recorded on a Teac Model 2300SC recorder. Recording samples were made at the 3 decompression stops in the chamber (pressures of 30, 20, and 10 ft), and at 5, 30, and 60 min after exit from the chamber. Each sequence of 6 recording samples on a tape was labeled only by a serial number and sent in batches to one of us (D.C. Johanson) experienced in the technique for both the diagnosis of DCS and the scoring of samples by subjective criteria developed in previous work (4,5). The scorer was provided with no information on individual or overall outcome but was aware that a 10% incidence of DCS could be expected. Upon receipt, only 4 entire tapes were judged technically unsatisfactory for a decision to be made, leaving a total trial group of 83 subjects. Thirty-nine (7%) of the remaining individual samples were also unsatisfactory but these were thought not to hinder the diagnosis.

The scoring system used applied a grade signifying the relationship of bubble signals to the cardiac sounds:

Grade 0—No bubbles heard

Grade 1—An occasional bubble signal

Grade 2—Frequent bubbles during less than half the cardiac cycles

Grade 3—Frequent bubbles during more than half the cardiac cycles
Grade 4—Heart sounds completely obscured by bubble signals.

RESULTS

Results of both clinical and Doppler ultrasound diagnoses are given in Table 1. In the 8 subjects who exhibited and who were treated for clinical decompression sickness, the usual range of decompression symptoms were found: pain in knee, forearm, and shoulder; radial nerve paresthesia; loss of deep tendon reflex; and cutis marmorata, an intense mottling of the skin. All victims immediately received standard U.S. Navy treatment, and all victims had complete reversal of symptoms with no apparent residual problems (2). Although 36 of the subjects were adjudged to have DCS on the basis of the Doppler tapes, only 5 of these (14%) had any clinically demonstrable signs or symptoms. Such a discrepancy would not surprise those who view Doppler as a sensitive indicator of DCS, but the 3 cases that required treatment by clinical standards without Doppler signs constitute a distressingly high ⅜ or 38% false negative rate. Overall, the Chi-square test of independence (1 degree of freedom with continuity correction) indicates a probability of between 25 and 50% that the clinical and Doppler diagnoses refer to independent processes.

The scorer assigned a numerical grade (0 to 4) to each of the Doppler tape readings. The average "bubble scores" at the 6 measurement times are plotted in Fig. 1 for the 2 groups, based on clinical outcome. There is a general tendency of the scores to increase with time after the decompression, and there is an apparent difference in scores between the 2 groups. To examine the statistical significance of the difference, the 459 raw measurements (83 subjects × 6 times − 39 missing samples) were subjected to an analysis of variance according to the following model. Six parameters were estimated for a set of symptom-free scores at the 6 measurement times and a 7th parameter was estimated for a fractional increase in bubble score (the same at each time) that occurs with clinical bends. All 459 measurements were fitted to this model by a least squares program, although each measurement only influenced the results for 1 or 2 parameters. The fractional increase parameter was estimated at 51 ± 23% ($P < 0.05$).

In an attempt to establish a temporal pattern useful for diagnosis, a further analysis was performed. In addition to the 6 no-bend averages, an additional 6 averages were estimated for the group with clinical symptoms. The standard error bars in Fig. 1 are from that analysis. For the null hypothesis, that all averages are the same in either

TABLE 1
CLINICAL SYMPTOMS AND DOPPLER DIAGNOSES OF DCS

Doppler Diagnosis	Clinical Symptoms	
	Yes	No
DCS	5	31
No DCS	3	44

$\chi^2 = 0.591$. $0.50 > P > 0.25$.

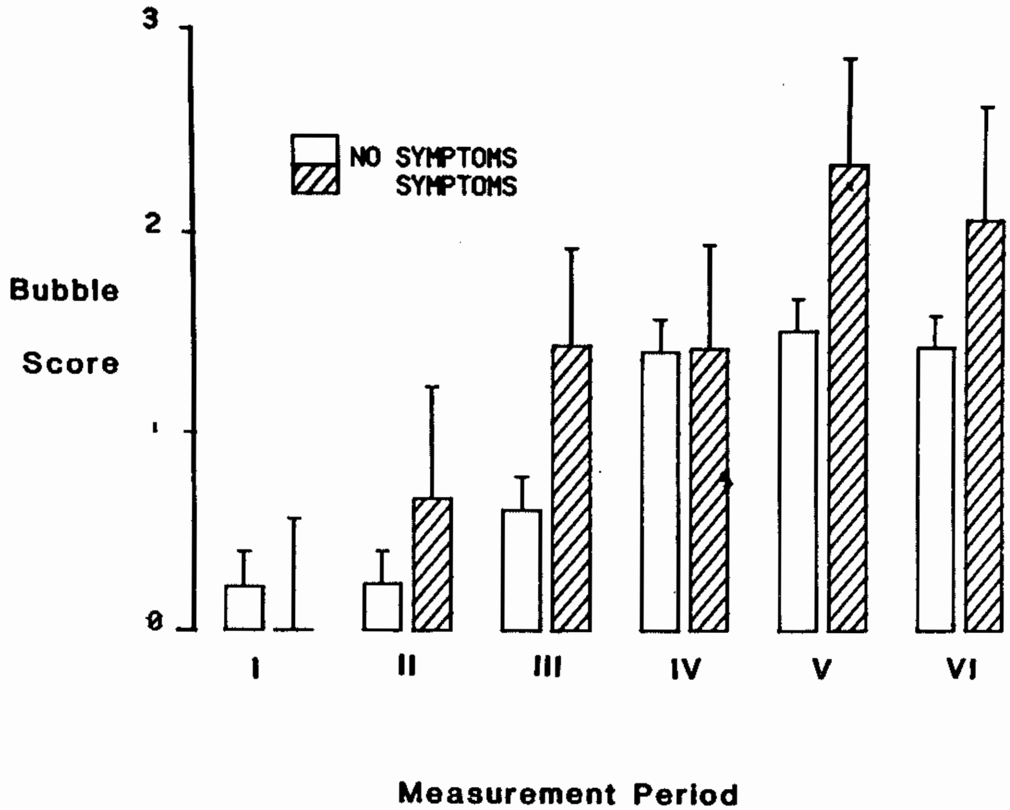

Fig. 1. Histograms of the average "bubble score" of subjects separated by clinical outcome; no symptoms (75 subjects) and treatable decompression sickness (8 subjects). Error bars are 1 SE of the mean scores estimated by the second analysis of variance described in the text. Samples were obtained at 6 sequential times as described in the text.

group, an F statistic of 1.172 was calculated with 6 and 447 degrees of freedom. Such an F statistic could happen by chance more than 25% of the time. The 39 missing values that occurred were distributed over all outcome categories, and a more conservative treatment of the missing data would only tend to diminish the significance of the increments.

DISCUSSION

The various statistical answers are consistent. In a sample of nearly 500 bubble scores, an average increase of 51% can be discerned. This difference is actually small compared to individual subject variability and differences over time, both span several hundred percent. Thus a 6-parameter pattern in score differences is lost in the "noise," and a series of 83 subjects is insufficient to detect the very weak correlation between the diagnoses. The various results can be summarized by stating that bubble scores may be weakly related to clinical symptoms, but far too little to be of diagnostic value in individual cases.

This study attacks the simplistic theorem that intravascular bubbles cause DCS. If such were the case, we would have to postulate that the bubbles we monitored over the precordium were different from "symptomatic" bubbles. Perhaps precordial bubbles only represent those smaller packages of saturated gas able to exit the peripheral vascular bed. Perhaps the symptoms of DCS are caused more commonly by extravascular or stationary intravascular bubbles which are missed by precordial monitors. Perhaps DCS is the result of more complex rheological or tissue biochemical changes, of which venous gas emboli are only an associated phenomenon. Certainly the diagnosis of DCS by precordial monitoring requires further study and technological improvement before widespread use is justified.

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Bayne CG, Hunt WS, Johanson DC, Flynn ET, Weathersby PK. Détection de bulles par effet Doppler et maladie de décompression. Un essai clinique longitudinal. Undersea Biomed Res 1985; 12(3): 327–332.—Il est pensé que la maladie de décompression chez les humains exposés aux pressions ambiantes élevées provient de la formation et de la croissance de bulles gazeuses dans le corps au cours de la remontée. La détection des réflexions ultrasonique du déplacement par effet Doppler dans les grands vaisseaux sanguins a été reconnue comme un indicateur nonenvahissant et sensible de l'imminence de la maladie de décompression. Nous avons mené un essai clinique longitudinal, à double-insu, de la détection de bulles par effect Doppler ultrasonique dans des plongées simulées avec 83 hommes dont 8 furent atteints par et traités pour la maladie clinique. Le diagnostic, basé seulement sur les signaux à effet Doppler, n'avait aucune corrélation avec le diagnostic clinique. Les comptes de bulles étaient légèrement plus élevés chez le groupe atteint. La technique à effet Doppler ne paraît pas avoir de valeur diagnostique en l'absence d'autre information médicale.

ultrason
embolie gazeuse veineuse
mal de caissons

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