Original articles

Reliability of venous gas embolism detection in the subclavian area for decompression stress assessment following scuba diving

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Abstract
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Introduction: Ultrasonic detection of venous gas emboli (VGE) in the precordial (PRE) region is commonly used in evaluation of decompression stress. While subclavian (SC) VGE detection can also be used to augment and improve the evaluation, no study has rigorously compared VGE grades from both sites as decompression stress indicators.
Methods: This retrospective study examined 1,016 man-dives breathing air extracted from the Defence Research and Development Canada dataset. Data for each man-dive included dive parameters (depth, bottom time, total ascent time), PRE and SC VGE grades (Kisman-Masurel) and post-dive decompression sickness (DCS) status. Correlation between SC and PRE grades was analyzed and the association of the probability of DCS (pDCS) with dive parameters and high bubble grades (HBG III- to IV) was modelled by logistic regression for SC and PRE separately for DCS risk ratio comparisons.
Results: PRE and SC VGE grades were substantially correlated (R = 0.66) and were not statistically different ($P = 0.61$). For both sites, pDCS increased with increasing VGE grade. When adjusted for dive parameters, the DCS risk was significantly associated with HBG for both PRE ($P = 0.03$) and SC ($P < 0.001$) but the DCS risk ratio for SC HBG (RR = 6.0, 95% CI [2.7–12.3]) was significantly higher than for PRE HBG (RR = 2.6, 95% CI [1.1–6.0]).
Conclusions: The association of bubble grades with DCS occurrence is stronger for SC than PRE when exposure severity is taken into account. The usefulness of SC VGE in decompression stress evaluation has been underestimated in the past.

Introduction

To date, there have been two common ways to assess decompression-induced physiological stress for dive exposures and associated decompression procedures. The first one is the US Navy approach, which relies on statistical predictive tools calibrated with diving profile/decompression sickness (DCS) databases.[1–8] This probabilistic approach allows the construction of a DCS risk model based on gas kinetics and associated ascent criteria, linking a decompression model output to a risk. It also offers an interesting calibration possibility of the parameters for a global decompression model. The second approach is based on the detection of bubbles after diving using either Doppler ultrasound or ultrasonic echocardiographic imaging.

It is well known that the bubbles formed in the various parts of the body during a decompression can be pathogenic and may generate several forms of DCS. Even if there is no clear evidence of a causal relationship between the amount of bubbles circulating in the blood stream and DCS, numerous Doppler and ultrasonic imaging studies support the association between venous gas emboli (VGE) levels and DCS risk.[9–20] VGE is considered a relatively poor predictor of DCS (low specificity), but the absence of VGE is a good indicator of decompression safety (high sensitivity).[21,22] This is why the amount of VGE detected is believed to be a useful decompression stress indicator for comparing various decompression procedures or controlling the efficiency of a decompression procedure.[23–25] For example, the Defence and Civil Institute of Environmental Medicine (DCIEM, now Defence Research and Development Canada, DRDC – Toronto Research Centre) has used the Doppler ultrasound method to detect VGE in order to develop various decompression tables for the Royal Canadian Navy.[26–29] The potential of bubble detection to assess the relevance of decompression procedures may have been clearly pointed out using modern statistical approaches.[22,31] This offers interesting possibilities and makes feasible – in terms of cost, time, statistical relevance and health impairment control – the validation of decompression profiles to reach a given DCS risk target.

While both statistical tools and bubble detection have proven to be useful, they remain characterized by different limitations: the probabilistic approach is an *a priori* method that does not consider inter/intra individual variability with respect to DCS susceptibility while the bubble detection approach is an *a posteriori* method that does not consider pressure profile/decompression profile to assess DCS risk. However, it is well known that both VGE formation and DCS occurrence depend primarily upon the dive exposure (depth, duration, gas breathed), the decompression procedure (ascent rate, decompression stops, oxygen during stops) and potentially upon physical characteristics of the diver (age, body mass index BMI). Nevertheless, an in-depth analysis of a large dataset using a logistic regression method showed that the association between large VGE loads and the increase in probability of DCS persists after taking into account the dive parameters, such as the depth, the bottom time and the decompression time, and the individual covariates such as age and BMI.[32]

Even with recent advances in imaging technology and image quality of 2-dimensional echocardiography, Doppler ultrasound is generally considered the most popular method in field studies due to its portability and low cost.[33] The Doppler bubble signal (in the audible frequency range) is graded using either the Kisman-Masurel (KM)[34] or Spencer[9] grading systems, with grade zero for the absence of detectable bubbles and grade four for a continuous flow of bubbles.[23]

VGE detection in the precordium is considered as the gold standard in Doppler ultrasound as it takes into account bubbles from the whole body, while additional subclavian detection has been recommended to improve the sensitivity of bubble detection.[35] Nevertheless, no large study has rigorously compared data from the precordial and subclavian sites, even if some data[17] contained cases of DCS symptoms in the upper part of the body with bubbles detected in the shoulders only and not in the chest. These data motivated our study, suggesting a more in-depth examination of the sensitivity of precordial versus subclavian bubble grades in evaluation of decompression safety. It is worth mentioning that some studies have suggested that the subclavian region, as opposed to the precordium, shows more potential for automated bubble detection due to its low noise signal.[36,37]

Our retrospective analysis compared the Doppler bubble grades from precordial and subclavian regions after a wide range of dive exposures in a dataset drawn from a large prospective cohort of divers followed by DRDC. In this paper, we aimed to confirm the usefulness of Doppler VGE grades in evaluating decompression stress in air dives drawn from this DRDC dataset. For each measurement site, we examined the association between high bubble grades and the probability of DCS taking into account the dive parameters (i.e., maximum depth, bottom time, total ascent time). This analysis was intended to compare the strength of this association for subclavian versus precordial VGE grades.

Methods

DATABASE

This study forms a retrospective analysis of a subset of the DRDC database from a number of studies conducted by DRDC over a period of about 40 years. These studies were carried out to develop and validate decompression tables and diving procedures currently used in the Canadian Armed Forces. All dives in the database were approved by the DCIEM/DRDC Human Research Ethics Committee and were done in accordance with the Helsinki Declaration. Dive participants were primarily military divers, but also included civilian divers. Over 7,000 man dives have been monitored and are included in the DCIEM/DRDC Doppler ultrasound database.

The dive subjects were monitored with continuous wave Doppler ultrasonic bubble detectors (from 1979 to 1987 – "*DUG*", Soledec S.A., Marseille, France, and from 1987 to 2013 – TSI DBM 9008, Techno Scientific Inc., Concord, ON, Canada), first at the precordium with the diver standing at rest and after movement (deep knee bend), and then at the left and right subclavian veins at rest and after a specific movement (fist clench).[29] The Doppler signals were graded using the KM code[34] where bubbles are classified on a scale from 0 to 4 based on three parameters: 1) the number of bubble signals per cardiac cycle, 2) the percentage of cardiac cycles in which bubbles are observed during the rest condition, or the number of successive cardiac cycles containing bubbles starting from the initial increase in blood flow after movement, and 3) the amplitude of the bubble signal relative to the normal background cardiac sounds. The resulting 3-digit codes are then converted to bubble grades from 0 to IV, similar to the 5-point (0 to 4) Spencer bubble grades, but with finer steps based on a 12-point scale (i.e., 0, I-, I, I+, II- .., -IV, IV).

To detect the maximum bubble activity, each dive subject was monitored several times over a given period after the dive. Typically, bubble monitoring was carried out at least three times in about two hours – the first at 20 minutes (min) after surfacing and then at 40 min intervals. If bubbles were

Table 1

Dive parameters and venous gas embolism (VGE) scores for all man-dives analysed (column 2), decompression sickness (DCS) dives (column 3) and no-DCS dives (column 4); all continuous and ordinal variables are presented as median [range]; N.B. VGE scores from III- to IV were considered high bubble grade (HBG) and encoded HBG = 1; *n* (%) of the dives with a high bubble grade detected; PRE – precordial; SC – subclavian; msw – metres' sea water

		Total included	DCS	no-DCS
Man dives (*n*)		1,016	22	994
Maximum depth *P* (msw)		44.2 [9−79.4]	45 [18−69.1]	42.4 [9−79.4]
Bottom time *t* (min)		30 [2.6−120]	30 [6.8−120]	30 [2.6−120]
Decompression duration *tat* (min)		16.2 [0.9−89.5]	55.8 [2.5 −84.6]	14.3 [0.9−85.9]
Exposure index ($Q = P\sqrt{t}$)[38]		189 [67−296]	247 [174 −285]	186 [66−295]
PRE grades		0 [0−IV]	II+ [0−IV]	0 [0−IV]
PRE HBG = 1, *n* (%)		141 (14 %)	10 (45 %)	131 (13%)
SC grades		0 [0−IV]	III− [0−IV]	0 [0−IV]
SC HBG = 1, *n* (%)		149 (15 %)	14 (63 %)	135 (14%)
PRE bubble grades	0	634 (62.4%)	2 (9.1%)	632 (63.6%)
	I-, I, I+	123 (12.1%)	3 (13.6%)	120 (12.1%)
	II-, II, II+	118 (11.6%)	7 (31.8%)	111 (11.2%)
	III-, III, III+	138 (13.3%)	9 (40.9%)	129 (13.0%)
	IV-, IV	3 (0.3%)	1 (4.5%)	2 (0.2%)
SC bubbles grades	0	616 (60.6%)	4 (18.1%)	612 (61.6%)
	I-, I, I+	154 (15.2%)	2 (9.1%)	152 (15.3%)
	II-, II, II+	97 (9.5%)	2 (9.1%)	95 (9.6%)
	III-, III, III+	136 (13.4%)	11 (50.0%)	125 (12.6%)
	IV-, IV	13 (1.3%)	3 (13.6%)	10 (1.0%)

still present at grade III or a higher level, monitoring was continued until there was a clear indication that the bubble levels were dropping. Although there were many cases where high bubble levels were observed, recompression treatment was never initiated based on bubble grades. Treatment was always based only on DCS symptoms. However, subjects with high bubble grades were kept under observation.

We examined the data from a subset of 1,041 man dives conducted on air up to 2013 extracted from the DRDC database. Repetitive dives were excluded. Each dive record contained several post-dive Doppler-detected bubble grades at rest from both precordial (PRE) and subclavian (SC) regions (both right and left); the DCS status of the diver after exposure (Type I – musculoskeletal pain; Type II – neurologic, cutaneous, marginal, no DCS), an anonymous diver identification number and the following dive parameters: maximum depth *P* in metres' sea water (msw); bottom time *t* (minutes, min); and decompression duration (total ascent time) *tat* (min).

In an earlier study that included some of these data, it was concluded that the maximum bubble grade for all conditions, rest and movement, and all sites, precordial and subclavian, showed the strongest association of bubble grades with the risk of DCS.[17] There was a considerable reduction in sensitivity in detecting VGE if only the precordial site was monitored, 47% versus 60% for all-sites monitoring.[25]

In this study, only precordial and subclavian bubble grades for VGE detected at rest were considered for analysis and bubble grades after movement were excluded. Any records with missing precordial and/or subclavian bubble grades were excluded from the analysis. Based on these rejection criteria, from 1,041 records in our dataset, 25 man-dives (including seven cases of DCS) were excluded. As a result, 1,016 man-dives (including 22 DCS cases) were analyzed. When several bubble grades were available from a given site (precordial or subclavian), only the highest bubble grade was used in the analysis. Bubble grades from III- to IV were considered high bubble grade (HBG) and encoded HBG = 1, and bubble grades from 0 to II+ were considered low bubble grades and encoded HBG = 0.

A total of 236 divers in our study completed 84 square dive profiles covering a wide range of exposures. For each dive, we computed Hempleman's stress index.[38]

$$Q = P\sqrt{t}\ (msw{\cdot}min^{0.5}) \qquad (1)$$

This index does not incorporate any decompression information and a theoretical analysis has shown its limitations for dives requiring decompression.[39] As the dives analyzed all require decompression, we use Q as an exposure index, i.e., a measure of the severity of the exposure. It should be noted that it has been used in the past as an exposure index to limit commercial diving in the North Sea based on studies done between 1982 and 1988.[40] The main characteristics of the dive records used in our analysis are given in Table 1. Within the 22 DCS cases in Table 1, there were 15 Type I, four Type II, 1 cutaneous and two marginal cases. To increase the statistical power, we grouped all DCS types together in a dichotomized DCS variable with DCS = 1 representing all types of DCS events including marginal and cutaneous.

STATISTICAL ANALYSIS

VGE grades were treated as ordinal categorical data for statistical analysis. PRE and SC bubble grades for each diving exposure were considered as paired measures and the strength of correlation between PRE and SC grades was evaluated using polychoric correlation coefficient R,[41] similar to Pearson's correlation and appropriate for comparison of two ordinal measures (i.e., VGE grades) of unobserved continuous variable (i.e., bubble flow). In addition, we computed Spearman's correlation coefficient to confirm the polychoric correlation results. The relationship between measures was interpreted as distinct if $0.71 < R < 0.89$, substantial if $0.41 < R < 0.70$, and small if $0.21 < R < 0.40$. The correlation was significant if 95% bootstrap or normal confidence bounds did not contain zero. We tested for a systematic superiority of PRE or SC VGE grades with respect to each other using the Wilcoxon signed rank test[42] with a probability value (p) < 0.05, indicating a significant difference between two measures.

We examined the association between HBG and DCS incidence for different exposures by organizing dives into four severity groups based upon the exposure index Q: (1) low ($0 < Q < 150$); (2) low intermediate ($150 < Q < 200$); (3) high intermediate ($200 < Q < 250$); and (4) high ($Q > 250$). For each severity group, the DCS incidence for HBG = 1 versus HBG = 0 was compared and the associated DCS risk ratios were tested for statistical significance for both precordial and subclavian detections.

We used logistic regression to test the association of pDCS with VGE grades adjusted to dive parameters:

$$pDCS = p(DCS|x,HBG) = 1/[1+exp(-a_0 - a\ x - b\ HBG)] \qquad (2)$$

where x is a function of the dive parameters while a0, a, and b are logistic regression parameters. We first considered P, t, and tat as variables to lead the analysis, then we considered natural cubic splines transformations for adjustment for nonlinear effects of the dive parameters and compared the results. The adjusted odds ratios (OR HBG = 1 vs. HBG = 0) for PRE and SC and per 10-point increase in Q were computed from the adjusted logistic regression (2) with the Wald test for significance of covariates. Model comparison was done using the Akaike information criterion (AIC), which estimates the relative quality of statistical models for a given set of data, with smaller values of the criterion suggesting a better fit to the data. The reported risk ratios (RR HBG = 1 vs. HBG = 0) were computed from the odds ratios by using the following formula:[42]

$$RR_{HBG=1\ vs\ HBG=0} = OR_{HBG=1\ vs.\ HBG=0} /(1_{pDCS\ +\ pDCS} {*}OR_{HBG=1\ vs.\ HBG=0)} \qquad (3)$$

where pDCS = 0.014 vs. pDCS = 0.009 is the DCS incidence in the database in reference groups PRE HBG = 0 vs. SC HBG = 0. All tests were two-tailed and $p < 0.05$ was considered statistically significant.

Results

AGREEMENT BETWEEN DOPPLER MEASURES

The maximum values of VGE grade at SC were not statistically different compared to the maximum values of VGE grade at PRE (Wilcoxon signed rank test: W = 45864, probability = 0.61). The polychoric correlation coefficient for VGE from both sites R = 0.66 (95% bootstrap CI [0.57–0.69]) was significant suggesting a substantial relationship between the detections. Spearman's correlation coefficient rs = 0.53 (95% normal CI [0.47–0.69]) was also significant with the same strength of relationship.

VGE AND RISK OF DCS

Table 2 shows that with an adjustment for Q in the logistic regression, both PRE HBG and SC HBG were statistically associated with DCS risk. This association was also significant when RR were adjusted directly for the dive parameters P, t, tat (linearly) with comparable RR values and model fit as measured by AIC, which suggests the usefulness of Q in assessng the impact of bubble production on diving stress (pDCS). The adjusted risk ratios were significantly higher for SC HBG compared to PRE HBG. The model fit was better when using SC HBG (AIC = 180 for SC vs. AIC = 193 for PRE with an adjustment for Q). The logistic regression with cubic splines in P, t and tat gave similar results in terms of fit and risk ratios.

Tables 3 and 4 present the contingency tables of HBG and DCS by exposure index (Q), for PRE and SC respectively. For both sites, Q was statistically associated with DCS risk (probability = 0.04 for PRE and 0.004 for SC), as

Table 2

The adjusted decompression sickness (DCS) odds (OR) and risk (RR) ratios from logistic regressions for precordial vs. subclavian bubble counts with 95% confidence intervals, [95% CIs]; the probability values are from Wald's test for significance of HBG = 1; the information criterion AIC is used in model comparison; reference groups for HBG are PRE HBG = 0 and SC HBG = 0 respectively; PRE – precordial; SC – subclavian; Q – exposure index; *P* – maximum depth (msw); *t* – bottom time (min); *tat* – decompression duration (min) (see text for explanation)

Adjustment	Covariate	OR [95% CI]	RR [95% CI]	p-value	AIC
Q	PRE HBG = 1	2.7 [1.1–6.7]	2.6 [1.1–6.2]	0.03	193
	SC HBG = 1	6.8 [2.8–17.6]	6.5 [2.8–15.2]	< 0.0001	180
P, t, tat	PRE HBG = 1	2.9 [1.2–7.4]	2.9 [1.1–6.9]	0.02	194
	SC HBG = 1	7.1 [2.9–18.4]	6.8 [2.9–16.2]	< 0.0001	181

Table 3

Decompression sickness (DCS) number, incidence and relative risk ratio for PRE HBG by exposure group (see text for explanation)

$Q = P\sqrt{t}$	DCS/no DCS	DCS (%)	DCS/no DCS	DCS (%)	RR	p-value
	PRE HBG = 1		PRE HBG = 0			
[0–150]	0/4	0	0/353	0	NA	
[150–200]	2/16	12.5	2/181	1.1	11.4	0.04
[200–250]	3/54	5.6	7/226	3.1	1.8	0.40
[250–300]	5/57	8.8	3/103	2.9	3.0	0.14

Table 4

Decompression sickness (DCS) number, incidence and relative risk for SC HBG by exposure group (see text for explanation)

$Q = P\sqrt{t}$	DCS/no DCS	DCS (%)	DCS/no DCS	DCS (%)	RR	p-value
	SC HBG = 1		SC HBG = 0			
[–150]	0/6	0	0/351	0	NA	-
[150–200]	3/28	10.7	1/169	0.6	17.8	0.01
[200–250]	6/56	10.7	4/224	1.8	6.0	0.007
[250–300]	5/45	11.1	3/115	2.6	4.3	0.05

Table 5

The adjusted decompression sickness (DCS) risk ratios from logistic regressions for precordial (PRE) vs. subclavian (SC) measurements; reference groups for HBG are PRE HBG = 0 and SC HBG = 0 respectively; for the exposure index Q, the adjusted RR are given per 10-point increase (see text for explanation)

Covariate	RR [95% CI]	p-value	AIC
***Q*, PRE**	1.18 [1.07–1.32]	0.04	193
***Q*, SC**	1.18 [1.06–1.33]	0.004	180

shown in Table 5. After an adjustment for HBG, RR was approximately 1.2 (95% CI [1.1–1.3]) per 10-point increase in *Q* for both sites.

Discussion

The relevance of bubble detection to assess decompression stress is routinely accepted. However, its use to characterize DCS risk is a controversial topic. This controversy could come from the fact that the severity of exposures has never been considered as a major discriminating factor in relating DCS to VGE. This study considers both exposure severity ranges and bubble grades to assess DCS risk. Although the exposure index used, *Q*, is based only on the depth of the dive and the time spent at that depth, i.e., the gas loading, and does not include any decompression information, there is an apparent correlation between the risk of DCS and increasing *Q*. This is a result of practical decompression tables based on supersaturation having an increasing risk of DCS as the exposure increases.

Analytical studies have shown that the risk increases considerably with longer bottom times and with increasing depth, although not nearly as much as with bottom time.[44,45] A survey of commercial air diving in the UK sector of the North Sea clearly showed that the severity of the exposure significantly increased the risk of DCS,[46] prompting the use of *Q* as a convenient means of limiting diving activities for safety.[40] It should be noted that since different decompression tables may have different risks of DCS, the relationship between *Q* and pDCS may differ between tables depending on the nature of the decompression profile and the decompression time. For this study, the majority of dives analyzed used air decompression tables developed by DCIEM.[26–29] Although *Q* is not intended to represent the 'quality' of the decompression as a stress index, nevertheless, by taking into account both depth and bottom time, it provides a valuable means for relating exposure to DCS risk.

We examined the Doppler VGE grades from the chest and shoulders and the DCS data from a large DRDC dataset of air dives. Our results seem to confirm the observations that without subclavian bubble detection, a number of DCS cases would not have been associated with bubbles based on precordial monitoring alone.[17] Thus it was important to monitor both sites. Overall, no site provided systematically higher bubble grades and both PRE and SC bubble grades were in substantial agreement. However, after taking into account the severity of exposure with the *Q* index, there was a minimum six-fold increase in the probability of DCS for high subclavian bubble grades compared to an approximately three-fold increase for high precordial bubble grades (Table 2). It was also noticeable that high SC bubble grades were particularly associated with a significant DCS risk ratio when compared to low SC bubble grades for a large spectrum of dives in terms of the severity of exposure. This was less pronounced for PRE bubble grades (see Table 3 vs. Table 4).

Until now, subclavian detection has been used as supplementary or complementary information to precordial detection to assess the physiological stress induced by decompression.[47,48] This study is the first to quantify comparison of subclavian and precordial bubble grades and suggests that the usefulness of subclavian Doppler detection in evaluating decompression stress has been underestimated in past studies. This result could be seen as unexpected as the subclavian sites can only reveal bubbles produced in the upper part of the body, while the precordial site reflects that of the whole body. However, bubbles in the precordial region can be masked by the heart (background) noises, and audio artefacts from the valves of the heart may mislead the operator and cause them to register false positive grades. This is not the case for bubbles flowing in subclavian veins where the background noises are minimal and bubble signals are relatively unambiguous.

Our study has some limitations. Firstly, we did not consider the different types of DCS or symptoms but grouped them all together, including marginal and cutaneous events. If a larger number of marginal and cutaneous events were available, they might be better treated independently.

Secondly, as the data analysed were collected over a long period (from 1979 to 2013) by several different raters, there may be some inter-rater variability in bubble detection and grading of the many divers included in the study. Assessment of the inter-rater agreement on grading bubbles, demonstrated that DRDC had effective, practical techniques to ensure comparable grades when Doppler data from several raters were combined.[49] For example, each rater was evaluated prior to any new study, and the raters often worked in pairs. In cases where there were doubts about grading difficult bubble signals, the two scorers (often including DRDC's senior Doppler rater in practically all the cases) would review these signals and reach a consensus on the correct grade. New raters would work with all the other raters and grade a number of previously graded signals until a high degree of comparability with the other raters was reached.

Thirdly, only the results for precordial and subclavian VGE for the resting condition (a steady state condition) were looked at; taking into account the movement condition that results in a transient increase in VGE levels was not considered.

Modern decompression models and algorithms developed for decompression tables or for implementation in diving computers can certainly help to reduce the risk of DCS. Nevertheless, there is a high inter- and intra-individual variability of risk and no guidelines have been provided for individualized choice of diving practices, for example, when more or less conservative procedures should be selected.

To improve diving practices and reduce DCS risks, divers need an objective measure of individual decompression stress. VGE grades could be used to provide such a measure if an individual's history of VGE is known. In a study on no-decompression limits for compressed air, graphic methods were used to develop isopleths of equal occurrence of VGE and DCS pain and it was recommended that DCS and VGE-prone divers should dive only in shallow waters and should be rejected as candidates for occupational diving.[50] In a series of decompression-required dives tested at DCIEM, it was found that a depth-bottom time limiting line could be established beyond which high VGE grades and DCS would result, leading to the conclusion that 'high bubblers' should avoid diving at or near the limiting line and that only 'low bubblers' should dive above the limiting line.[51] More recently, it has been suggested that a modification of some of the diving practices of divers producing high VGE grades could potentially decrease their DCS risks since it was observed that divers having a history of mild DCS were more prone to VGE formation than divers without a DCS history.[52] Another suggestion made is that with a good method of interpreting VGE data, there is a possibility of long-term monitoring of an individual's susceptibility to DCS to derive individualized decompression schedules to reduce the risks of DCS.[53]

Conclusions

In general, low bubble grades are associated with lower risks of DCS. When exposure severity is taken into account, this association was stronger for bubble grades from the subclavian sites than from the precordial site. For high bubble grades, the probability of DCS with high subclavian bubble grades was much greater than that for high precordial bubble grades. These findings suggest that the usefulness of subclavian VGE detection using Doppler ultrasound in the development of safer diving has always been underestimated in the past. Doppler VGE detection could be a valuable tool in the improvement of diving practices through the reduction of bubble grades.

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