The incidence of venous gas emboli in recreational diving.

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Dunford RG, Vann RD, Gerth WA, Pieper CF, Huggins K, Wachholz C, Bennett PB, The incidence of venous gas emboli in recreational divers. Undersea Hyperb Med 2002; 29(4):247-259- From 1989-91, the Divers Alert Network monitored recreational divers for Doppler-detected venous gas emboli (VGE) and depth-time profiles following multi-day, repetitive, multi-level exposures. A Spencer score >0 occurred in 61 of 67 subjects (91%) and 205 of 281 dives (73%). No subject developed decompression sickness (DCS) on monitored days although 102 dives (36.3%) scored at Spencer Grades 2 or 3 (High Bubble Grade, HBG). We recorded the depth-time profiles with Suunto dive computers and estimated exposure severity with a probabilistic decompression algorithm. The HBG incidence increased 53% over the range of exposure severity ($p<0.001$) in the divers, was approximately 20% higher for repetitive dives than for first dives, and decreased approximately 25% over the 6-8 days of multi-day diving ($p<0.001$) suggesting a phenomenon similar to DCS adaptation. The observed HBG incidence was approximately 20% higher for males than females. Older male divers had a 25% increase in observed incidence of HBG while older female divers showed a 55% increase when compared to their younger counterparts.

venous gas emboli, Doppler bubble detection, probabilistic modeling, multi-level diving, repetitive diving, multi-day diving, age, sex, adaptation, dive computers.

INTRODUCTION

Decompression sickness (DCS) is a pathological event thought caused by intravascular (1) and extravascular (2) gas bubbles. The bubble theory of DCS is supported by empirical evidence, and venous gas emboli (VGE) can be detected after diving using non-invasive Doppler ultrasonic methods, but the etiology of DCS is complex, and VGE are frequent after symptom-free dives (3). High VGE levels, however, are associated statistically with increased DCS incidence suggesting that VGE and DCS may share a common origin (4). Further, VGE might initiate DCS should they cross or bypass the pulmonary capillary filter and be transported by the arterial circulation to organs such as the brain or spinal cord (5-11).

While depth-time exposure is the cause of VGE, other factors may affect their occurrence

including individual susceptibility (3,12), daily variability (3,13), rapid ascent (14,15,16), exercise at depth (12), and exercise during decompression (17). Divers who were cold at depth were less likely to have Doppler-detectable VGE than warmer divers over a three-hour post dive surveillance period (18). In altitude studies, the profusion of Doppler-detectable VGE in males was greater than in females (13).

There have been studies that monitored the occurrence of Doppler-detected VGE after controlled open-water diving (19,20), but none have investigated the incidence of VGE after uncontrolled exposures that are the norm for recreational diving. Our purpose was to explore the effect of depth-time exposure on the probability of VGE. We used dive computers to record the multilevel, multi-day depth-time profiles of recreational divers and applied a probabilistic decompression algorithm to estimate the exposure severity of the dives. This measure of severity accounted for the effects of dive time, dive depth, and repetitive diving on VGE but not for the effects of sex, age, and multi-day diving that also influence VGE incidence.

METHODS

From 1989 to 1991, the Divers Alert Network (DAN) sponsored six dive trips on live-aboard dive boats in the Caribbean and Pacific to investigate the presence of VGE in recreational scuba divers at warm-water dive sites. The trips were announced in nationwide publications, and volunteer subjects paid their own expenses. Upon reporting aboard, subjects received a presentation describing the project before the first dive, and all divers willing to participate were followed for all dives undertaken during at least one day of diving. Each subject chose the day or days to be monitored depending on the availability of monitoring slots. Less than 10% of divers declined to participate.

The divers' activities were unrestricted, but they were expected to follow the guidelines of the dive operator. The Duke University Institutional Review Board approved the research protocol, and the subjects provided written informed consent.

One of two technicians accompanied each trip. Both were trained and experienced in the use of Doppler equipment for detecting VGE in the field. Doppler signals were acquired using a 2.5-MHz Techno Scientific instrument and dual-ear headphones. Signals were recorded on a Marantz model PMD430 portable tape deck, and monitoring sequences were annotated with a Shure "push-to-talk" microphone. Not more than four subjects were followed on any day to avoid congestion and technician fatigue. To increase the size of the subject population, different subjects were monitored on subsequent days.

On the first day of a trip before diving began, one-minute precordial Doppler signals were recorded for each subject as examples of bubble-free heart sounds. These served as base line comparisons during subsequent signal grading after the trip was complete. The Doppler probe was placed at the left sternal border and manipulated until the flow sounds were strong with valve sounds audible in the background. A subject was monitored once 20-40 minutes post-dive although monitoring was sometimes delayed due to normal subject activity. During precordial monitoring, the subject stood quietly for one minute before performing three full knee-bends at 30 sec intervals. Subsequently, the subject's right and left subclavian veins were monitored for 30 sec during quiet standing followed by three hand squeezes at 20 sec intervals. Subjects used the hand on the side opposite that being monitored to steady themselves against boat movement.

On a day a subject was monitored, he or she wore a commercially available Suunto Model SML dive computer that recorded the deepest depth attained in each 3 min interval and the time of surfacing at 1 min resolution. Dive computers were calibrated and loaned by SeaQuest Industries (San Diego, CA). After the dives, the technician downloaded each depth-time profile by hand from the Suunto display. The total dive time and maximum depth were crosschecked against the subject's personal dive computer and/or watch and depth gauge. Total dive time represented the time below 5 feet of seawater (fsw) (116 kPa).

The subjects were blinded to the Doppler findings to minimize the impact of the investigation on subsequent diving. One of the two technicians analyzed the Doppler signals at least six months after the trip. Signals were scored according to the 5-point Spencer system (4). The score assigned for each dive represented the highest score at any of the three evaluation sites (precordial, left and right subclavian). A score was rejected if the presence or absence of bubbles was equivocal or if the signal was of unacceptable quality. If signals from two of the three monitored sites were rejected, the dive was removed from analysis. Four monitored dives by one subject were rejected for such reasons.

Spencer scores were collapsed into a binary outcome variable called **High Bubble Grade (HBG)** that was defined as 0 for Spencer Scores of 0 or 1 (**HBG**=0) and 1 for Scores of 2, 3, or 4 (**HBG**=1). This dichotomy was selected because higher grades were associated with a 19-fold greater DCS incidence than were lower grades (4). To explore the consistency of the data, we also tested the dichotomies: (a) no bubbles (Spencer Score 0) versus bubbles (Spencer Score 1, 2, or 3); and (b) Spencer Scores 0,1,2 versus Spencer Score 3. There were no grade 4 scores.

Statistical Analysis

Logistic regression was used to test the association of the binary outcome variable **HBG** with the main effect variable, exposure severity, and with potentially confounding covariates. A p-value <0.05 was considered significant.

The traditional, although tacit, assumption in the analysis of decompression data where subjects make multiple exposures has been that each observation for a given individual is independent of every other observation for that individual (21,22). Since Nishi indicated that individuals might have different propensities to bubble (4), we tested the validity of the independence assumption in our data where there were numerous replicate measurements.

There are standard methods that account for subject variability in balanced designs (i.e., identical observations for all individuals), but as our data were unbalanced, we used the method of generalized estimating equations (23) to extend logistic regression into a repeated measures structure that was appropriate for our non-independent, clustered observations (24). This allowed us to test the main effect variable (exposure severity) and the covariates (age, sex, etc.) for association with **HBG** while allowing for multiple observations for each person. We used step-wise selection to arrive at a final, parsimonious model and the Wald test to evaluate the statistical significance of the independent variables. The generalized estimating equations and logistic regression were implemented by Stata (Version 7, Stata Corporation, College Station, TX) and crosschecked by SAS (Version 8, Cary, NC).

The potentially confounding covariates that were tested for association with **HBG** included **Trip Number**, **Monitoring Time**, **Trip Day**, **Subject**, **Sex**, **Age**, **BMI**, and three variables representing ascent from 40, 30 and 20 fsw to the surface (**Ascent40**, **Ascent30**, and **Ascent20)**. **Trip Number** was an indicator variable to account for possible differences between trips. **Monitoring Time** represented the time in minutes at which the single post-dive Doppler

monitoring session occurred. An ordinal variable **Trip Day** accounted for the day of the trip on which monitoring took place. Because ascent rate and demographic factors appear to influence DCS and VGE susceptibility (16, 25), we tested **Sex**, **Age**, and **BMI** (weight (kg)/height $(m)^2$) as well as the three variables representing ascent from 40, 30 and 20 fsw to the surface. For subjects who made multiple trips, **Age** and **BMI** were adjusted to reflect appropriate values. **Subject** was an ordinal variable defined separately for each individual in the study. We also tested a first order interaction between **Age** and **Sex** as previous data had suggested that the relationship of age to VGE was different for males than for females (13).

The main effect variable, exposure severity, was taken as the conditional probability of DCS ($\mathbf{cP_{DCS}}$) for each dive, estimated using a probabilistic decompression algorithm from depth-time profiles recorded by the Suunto dive computers. The algorithm, based upon a mathematical simulation of *in vivo* bubble growth (21,26), had been calibrated by the method of maximum likelihood to the observed DCS outcomes of 3,322 chamber dive profiles completed by air- or nitrox-breathing, water-immersed, working subjects (21). Profiles that included repetitive dives were each completed within a 24 hr period.

The conditional probability of DCS for a dive is the probability of DCS during or after the dive, subject to the condition that the diver is DCS-free when first leaving the surface on the dive. For this study, an individual dive was defined as any exposure to >5 fsw after a surface interval of >10 minutes. The conditional probability of DCS for the dive was thus computed as a function of the integral of the instantaneous DCS risk over the time period beginning with first descent through 5 fsw on the dive, and ending with first descent through 5 fsw on the next dive, or with decay of the instantaneous DCS risk to zero after the last dive in a day (21,26,27). For each dive, $\mathbf{cP_{DCS}}$ increased monotonically from zero at dive start to a maximum value at start of the next dive, or at a time within 12 hrs of surfacing from the last dive of the day (Fig. 1). We used the post-dive $\mathbf{cP_{DCS}}$ maximum as the measure of each dive's exposure severity.

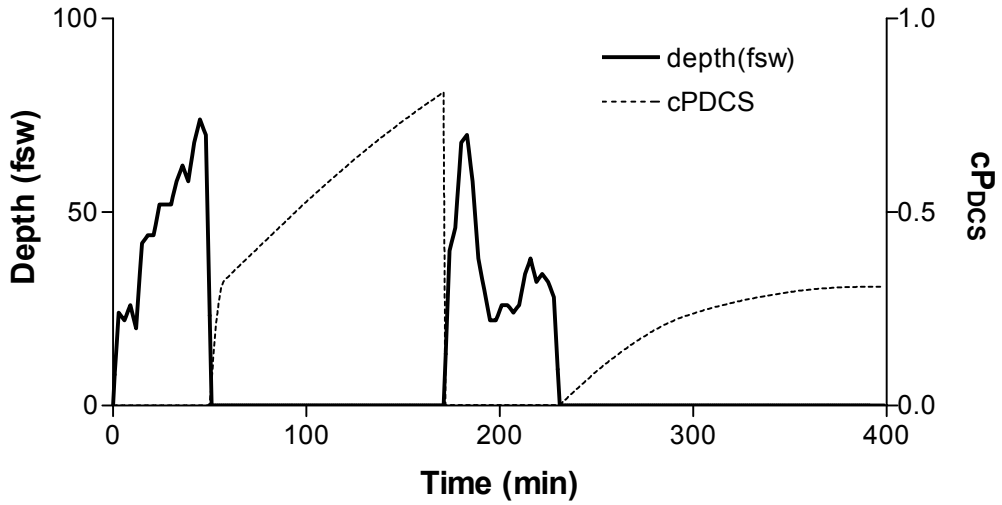

Fig. 1. Depth-time profile recorded by Suunto SME dive computers for one subject on one dive day. For dives 1 and 2, the maximum depths were 74 and 70 fsw, the dive times were 51 and 60 min, and the maximum $\mathbf{cP_{DCS}}$ values were 0.81 and 0.31. The surface interval was 120 minutes

For repetitive dives, $\mathbf{cP_{DCS}}$ took into account all prior dives and surface intervals beginning with the first dive of the day. $\mathbf{cP_{DCS}}$ for repetitive dives could be greater or less than for previous dives depending on the duration of the surface interval and the severity of the repetitive dive.

RESULTS

Table 1 lists the 6 trips undertaken in the study. A total of 281 individual dives were successfully monitored in 67 subjects during 101 exposure days out of 497 possible subject dive days. Dive trips were 6-8 days in duration and the subjects usually dived every day. Occasionally, a few divers skipped a day in mid-trip and, on one trip (Saba), there was no diving on Day 4. On rare occasions of illness or injury, more than one dive day may have been missed, but we did not keep count of non-diving days. Subjects were monitored after at least one dive and after as many as 13 dives since 12 subjects made multiple trips. There were 46 males (189 monitored dives) and 21 females (92 monitored dives). Mean age was 44.8±8.5 years (range 32-68) for males and 44.5±11.5 years (range 22-64) for females. The median BMI for males was 24.7 kg/m^2 (interquarterial range 23.6-26.0) and 21.0 kg/m^2 (interquarterial range 19.8-21.8) for females.

Table 1. Trip location, total subjects and total dives monitored in this study by trip and number of trip days available for monitoring.

Trip	Subjects	Dives	Trip Days
Galapagos Is., Ecuador	11	43	8
Cayman Is., British West Indies	13	45	5
Cocos Is., Costa Rica (1)	14	47	6
Cocos Is., Costa Rica (2)	15	50	7
Saba Is. Netherlands Antilles	13	44	6*
Truk Lagoon, Federated States of Micronesia	15	52	6

* Day 4 of this 6-day trip involved no diving for all divers.

Table 2 lists parameters for the 281 monitored dives. The maximum depth and dive time were measured by the computers and also by the subjects' personal watches and depth gauges. The measurements agreed within 0.2±2.2 fsw and 0.1±2.6 min except for one time discrepancy (9 min) and three depth discrepancies (8, 9, and 12 fsw) that were beyond three standard deviations and were unexplained. These may have represented typographical errors or errors in the subjects' personal depth gauges since SeaQuest Industries provided calibrated dive computers.

As illustrated in Fig. 1, the dive profiles were multilevel. In dives to >50 fsw, for example, 27% of the 3 min recording intervals were within 10 fsw of maximum depth, and 24% occurred on the final ascent from 40 fsw to the surface. The remaining 49% were to depths shallower than maximum depth by 11 fsw or more. Only 22 (8%) of exposures were ≤50 fsw. Of 183 surface intervals between repetitive dives, 33% were 1-2 hrs, 42% were 2-3 hrs, and none were longer than 6-7 hrs. Few surface intervals were shorter than one hour.

Table 2. Median (interquartile range) for maximum depth (fsw), dive time (min), and $\mathbf{cP_{DCS}}$ by sex, age, and first or repetitive dives.

	Males	Females	First Dives	Repetitive Dives
N	189	92	101	180
Maximum Depth	90 (74 -107)	77 (62 - 92)	95 (74 - 111)	80 (68 - 99)
Dive Time	42 (36 -51)	42 (33 - 48)	39 (30 - 45)	45 (36 - 51)
cP_{DCS}	0.8 (0.5 - 1.3)	0.6 (0.4 - 1.0)	0.5 (0.4 - 0.7)	1.1 (0.6 - 1.5)

The median of the maximum depth for all subjects was 85 fsw (interquartile range 70-130 fsw). The median maximum depth for males was 13 fsw deeper than for females (Table 2), and males accounted for 29 of the 30 exposures in excess of 120 fsw. For depths to less than 120 fsw, the median maximum depth for males was 8 fsw deeper than for females. The median maximum depth for the first dive of the day was 15 fsw deeper than for repetitive dives.

Table 3 lists the Spencer Doppler scores by sex for the 281 exposures. A score greater than 0 was noted for 61 of 67 subjects (91%) and after 205 of the 281 dives (73%). Doppler signals were graded as 2 or 3 for 102 dives (36.3%). No Grade 4 VGE was detected. The median post-dive time of Doppler monitoring was 43 min (interquartile range 35-54 min).

No subject developed DCS on any monitored day although one subject was treated for suspected DCS following several dives on a day that was not monitored.

Table 3. Distribution of Doppler scores by sex.

Spencer Score	Male	Female	Total
0	38 (20%)	38 (41%)	76 (27%)
1	70 (37%)	33 (36%)	103 (37%)
2	61 (32%)	10 (11%)	71 (25%)
3	20 (11%)	11 (12%)	31 (11%)
Total	189	92	281

Associations with HBG

Variables significantly associated with **HGB** included the main effect, $\mathbf{cP_{DCS}}$, and the covariates **Trip Number**, **Age**, **Sex, Trip Day**, and **Monitoring Time**. A square root transformation of $\mathbf{cP_{DCS}}$ improved its association with **HGB**. There was a first order interaction between **Age** and **Sex** and a small but significant association with two of the six trips. **HGB** was not associated with **BMI**, or with ascent time from 40, 30 or 20 fsw. The Suunto computer recorded ascent time to the nearest minute and may have been too imprecise to show any effect.

When we repeated the above analysis for Spencer Score 0 versus Spencer Score 1, 2, or 3, the results were similar as for **HBG** (Spencer Scores 0 or 1 versus 2 or 3) indicating that the observed relationships of **HGB** to $\mathbf{cP_{DCS}}$ and covariates were applicable at several levels of bubbling. There was an insufficient number of Grade 3 scores to assess Spencer Scores 0,1, or 2 versus Spencer Score 3.

Dive Profile Severity

The observed incidence of **HBG**=1 (expressed in percent as the number of dives with **HBG**=1 divided by total dives) against the quartile medians of $\mathbf{cP_{DCS}}$ is shown in Figure 2. The incidence of **HBG**=1 increased over the range of $\mathbf{cP_{DCS}}$ from 13% to 56%. The relationships of $\mathbf{cP_{DCS}}$ to **HGB**=1 were coincident for first and repetitive dives (Fig. 2) indicating that $\mathbf{cP_{DCS}}$ successfully accounted for **HBG**=1 after repetitive diving during a single day. While $\mathbf{cP_{DCS}}$ was generally greater for repetitive dives than for first dives (Fig. 2), this was not necessarily so (see Fig.1) and may have reflected the diving style of the observed population sample rather than a general characteristic of repetitive diving. The relative odds of **HBG**=1 increased 2.04 times (95% CI=1.38-14.20) for each unit increase in $\mathbf{cP_{DCS}}$ ($p<0.001$).

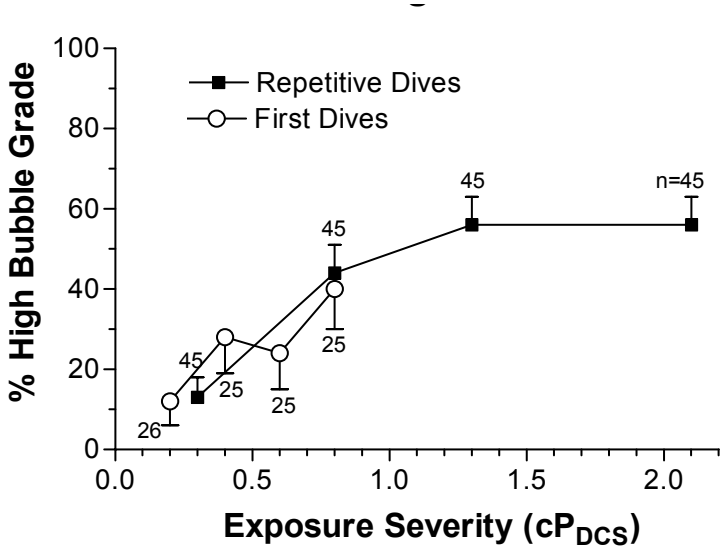

Fig. 2. The relationship of exposure severity ($\mathbf{cP_{DCS}}$) to the observed incidence of **HBG**=1 for first and repetitive. Bars represent the standard error of the binomial distribution. The number of dives on which each point is based is noted next to the bar.

Multiday Diving

The observed incidence of **HBG**=1 for each **Trip Day** is shown in Fig 3. (**Trip Days** 7 and 8 were omitted as there were only 9 total dives on **Trip Day** 7 and 6 dives on **Trip Day** 8.) **HBG**=1 was about 20% greater for repetitive dives than for first dives on all but **Trip Day** 4. The crossover on **Trip Day** 4 is unexplained as the first dives on that day appeared similar to first dives on other days. For both first and repetitive dives, the % **HBG**=1 decreased by 20-30% over the duration of the trip. The relative odds of **HBG**=1 decreased 0.68 times (95% CI=0.56-0.84) for each succeeding **Trip Day** ($p<0.001$).

The observed incidence of **HBG**=1 decreased for a given $\mathbf{cP_{DCS}}$ as **Trip Day** increased is shown in Fig 4. In other words, $\mathbf{cP_{DCS}}$ did not account for the decrease in **HBG**=1 that occurred with **Trip Day**. At a given $\mathbf{cP_{DCS}}$, the incidence of **HBG**=1 was always lower for **Trip Days** 5-8 than for **Trip Days** 1-2 with the highest observed incidence in **Trip Days** 5-8 approximately equal to lowest for **Trip Days** 1-2.

Fig 3

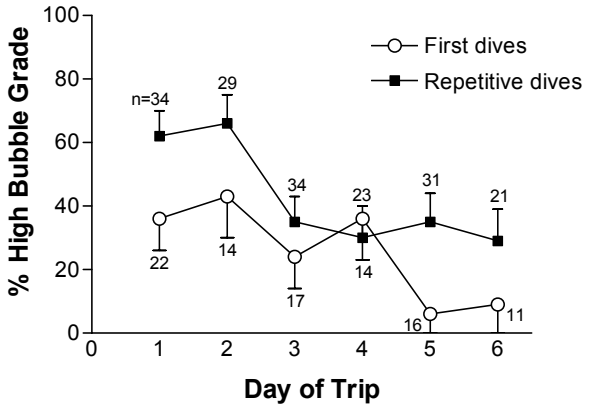

Fig. 3. Effect of multi-day diving (**Trip Day**) on the observed incidence of **HBG**=1 for first and repetitive dives. Day 7 and 8 were omitted as there were only 9 dives on Day 7 and 6 dives on Day 8.

Fig 4

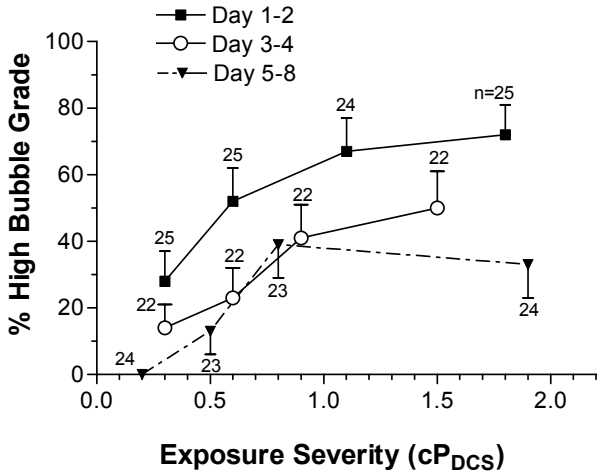

Fig. 4. Effect of exposure severity ($\mathbf{cP_{DCS}}$) on the observed incidence of **HBG**=1 by **Trip Day**.

Age and Sex

The observed incidence of **HBG**=1 for males and females against age is shown in Fig 5. The incidence of **HBG**=1 increased from 0-52% for (quartile mean age range 31-57) and from 35-60% for men (quartile mean age range 36-54). There was an effect of age on gender (p=0.02) such that the relative odds of **HBG**=1 was significantly greater for women at 5.85 fold per decade (95% CI=2.57-13.32) compared to a 1.53 fold increase per decade for men (95% CI=1.2-1.95).

As the mean maximum depth for males was 13 fsw greater than for females and since males undertook 29 of the 30 dives >120 fsw, we repeated the analysis after removing all dives

to >120 fsw. We found no substantive change in the results indicating that $\mathbf{cP_{DCS}}$ successfully accounted for changes in exposure severity due to depth.

To estimate the amount of unique subject variance, we computed a coefficient of determination (R^2) for the **Subject** variable and contrasted this with R^2 computed for the demographic variables **Age** and **Sex**. The R^2 due to **Subject** was 0.533 while that due to **Age** and **Sex** was 0.12. This indicates that 22.5% of the explained variance was attributable to **Age** and **Sex** while the remaining 77.5% was unique to the individual or due to factors not in the model.

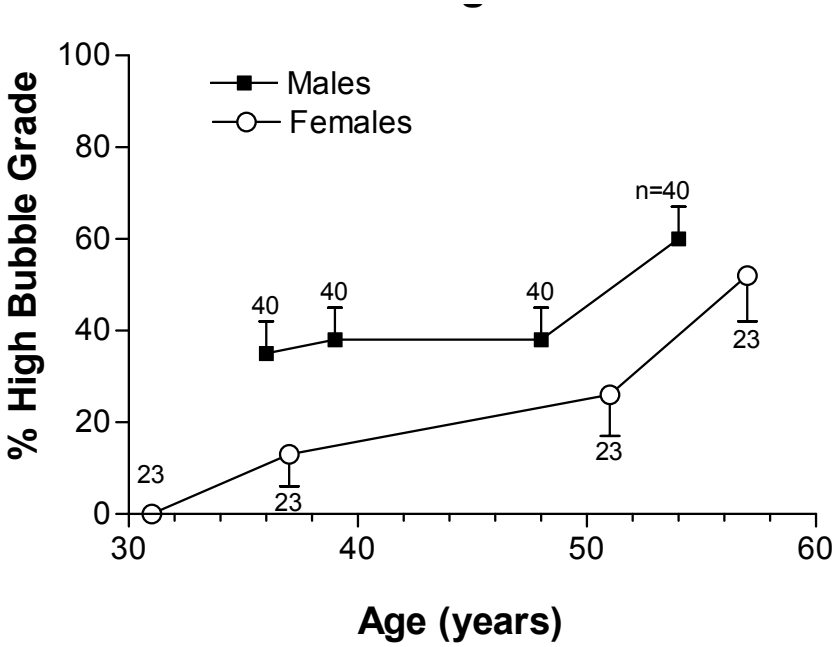

Fig. 5. Effects of age and sex on the observed incidence of **HBG**=1.

Delay to monitoring

The observed incidence of **HBG**=1 as a function of quartile medians for time to Doppler monitoring is shown in Fig 6. As before, the incidence of **HBG**=1 was greater for repetitive dives than for first dives. The relative odds of **HBG**=1 decreased by a factor of 0.78 for each 10 minute increase in **Monitoring Time** (p=0.019; 95% CI 0.63-0.96). The maximum observed incidence of **HBG**=1 occurred at 35-45 minutes after surfacing, in agreement with published reports that maximum Doppler scores occurred within the first hour (4). Figure 6 indicates that if monitoring is delayed 25-30 min after peak VGE occurrence, the VGE incidence could be underestimated by as much as 20%.

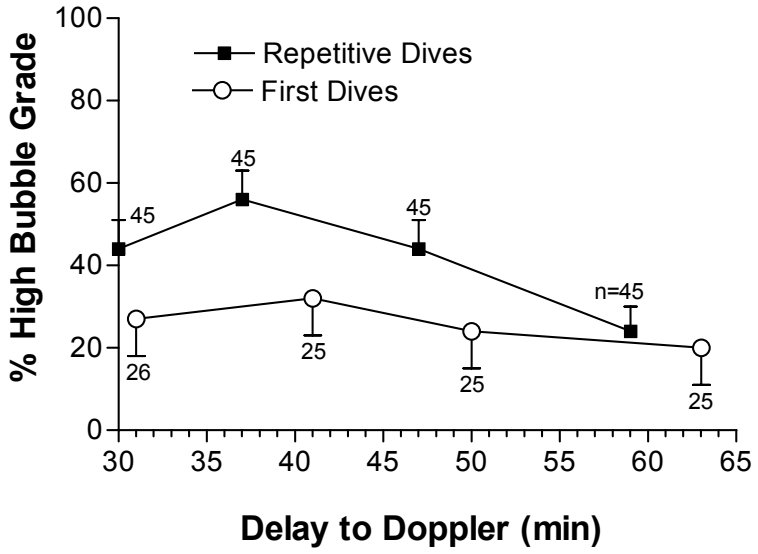

Fig. 6. Effects of time to Doppler monitoring on the observed incidence of **HBG**=1 for first and repetitive dives.

DISCUSSION

We used dive computers to record the depth-time profiles of recreational divers and monitored the divers with Doppler ultrasound for post-dive VGE. VGE signals were detected in 91% of the divers and in 73% of the monitored dives.

In 1,726 DCIEM dives (4), the DCS incidence was 1.1% DCS for Spencer Grades 1 or 2, 6.3% for Grade 3, and 9.7% for Grade 4. If the same relationship of VGE to DCS had held in our study, we would have expected about four DCS incidents. However, many of these DCIEM dives required decompression stops, while our dives required no stops. Thus, the type of diving may condition the relationship of VGE to DCS.

cP$_{DCS}$ was associated with **HBG** ($p<0.001$) despite being based on DCS data from chamber dive trials rather than on VGE data. While **cP$_{DCS}$** was predictive of VGE, we do not suggest a physiological relationship between estimated DCS probability and Doppler score although the two may be related to a common third entity such as depth-time exposure. **cP$_{DCS}$** was equally successful in describing VGE after first and repetitive dives in a single day (Fig. 2), and **cP$_{DCS}$** was higher for repetitive dives than for first dives indicating that repetitive dives, as conducted in the study, had greater exposure severity than did first dives. The 1.5-fold decrease per day in the incidence of **HBG**=1 for a given **cP$_{DCS}$** over the 6-8 days of the trips, on the other hand, demonstrated that **cP$_{DCS}$** could not account for the effects of multi-day diving (Fig. 3). This was not unexpected since the model used to estimate **cP$_{DCS}$** was calibrated to data that included no multi-day profiles of this kind (21).

The observed decrease in incidence of **HBG**=1 recalls the daily reduction in DCS incidence reported for repeated exposures of compressed air workers (28) and suggests a similar phenomenon for VGE. Our observations disagree with a previous experiment that failed to find reduced Doppler scores in subjects who dived each day for 12 consecutive days (29). This

discrepancy may reflect the different nature of the dive exposures that were single-level chamber dives to 148 fsw for 28 minutes followed by 32 minutes of decompression.

Figure 5 indicates that males and older divers had a higher incidence of **HBG**=1 than did females and younger divers. This agreed with previous reports that males have higher Doppler scores and that Doppler scores increase with age (30,31). We also found an interactive effect of age on gender suggesting that the increase in incidence of HBG=1 in females with age is higher than that for males. In this study, subjects differed in age from other diving populations. For example, our subjects were older (mean age 45 years) than 1,111 patients treated for diving injuries in 1989-91 (mean age 36 years) (32,33,34).

BMI was not associated with **HBG**=1 although other reports have shown bubble score to be associated with weight, percent body fat, and maximum oxygen uptake (19). Age was found to be positively associated with BMI (Spearman rho=0.123, $p<0.05$), suggesting that age and BMI were collinear and that age absorbed the variance contained in BMI.

The practical significance of Doppler-detected bubbles in the etiology of DCS has been debated since the 1970s when VGE were first shown to be common after diving. Patent foramen ovale (9,10,11) or other routes of VGE passage into the arterial circulation (5,6,7) are potential mechanisms linking VGE with neurological DCS, and observational studies of VGE such as reported here might ultimately prove useful for decreasing the incidence of neurological DCS. In addition, we suggest that confounding variables age, sex or multi-day diving found to be associated with VGE incidence here might also be useful in improving the predictive power of DCS probability models.

Limitations

In this field study, we did not follow the same divers on consecutive days, we monitored the divers only once after each dive and minimally interfere with divers' activity. In doing so, we widen the sample of divers who could be studied and observed divers close to their normal activity. However, we were then unable to employ methodological design controls as would be in found in a laboratory study but, instead, used statistical methods to account for the variations inherent in field studies.

Subjects were monitored only once after each dive which might have underestimated the maximum bubble score when delay to monitoring exceeded 30-45 minutes (Fig. 6). As subjects were not monitored every day, the effects of multi-day diving could not be observed directly, although statistical analysis allowed indirect assessment.

Estimated cP_{DCS} values are based on a probabilistic model of DCS incidence in which DCS risk is a function of prevailing bubble volumes in a series of modeled tissue compartments. These volumes, and the associated DCS risk, decay to zero within any 12-hour post-dive surface interval, but some modeled tissue compartments may remain gas-supersaturated beyond 12 hours. Such "residual gas" effects would increase the risk of a given dive from day-to-day, and thereby worsen the model's agreement with the observed decrease in **HBG**=1 incidence by **Trip Day** (Figure 3). However, only single-day data were available from any given diver to make the cP_{DCS} estimates, which required the assumption that a given day's diving was independent of previous days' diving. This obviated the influence of any potential day-to-day residual gas effect in the estimates.

Subjects occasionally skipped a day of diving (most often mid-week) although we did not keep track of days that were skipped. The effect of a skipped day would have been to lessen the decrease in the incidence of **HBG**=1 that was observed to occur during successive **Trip Days**

(Fig. 3). That a significant multi-day effect was apparent despite skipped days is evidence of the strength of the effect.

The Suunto decompression computers recorded the deepest depth every three minutes and produce a reported mean depth greater than true mean depth. Resulting cP_{DCS} estimates were based on the assumption that all the time in any 3 min segment was spent at the maximum depth recorded of that segment.

The results were based on a small population sample in an uncontrolled study design and require independent verification.

CONCLUSION

Recreational divers were monitored for Doppler detected venous gas emboli following multi-day, multi-level, repetitive dive exposures. A probabilistic model of DCS risk provided an estimate of decompression stress based on depth-time profiles recorded by dive computers. VGE increased with decompression stress as well as diver age but females showed a stronger age effect than males. Detectable bubbles decreased with multi-day diving suggesting an adaptive effect.

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