Review article

The need for optimisation of post-dive ultrasound monitoring to properly evaluate the evolution of venous gas emboli

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Keywords
Diving, decompression, bubbles, Doppler, review article

Abstract
(Blogg SL, Gennser M. The need for optimisation of post-dive ultrasound monitoring to properly evaluate the evolution of venous gas emboli. Diving Hyperb Med. 2011;41(3):139-46.)
Audio Doppler ultrasound and echocardiographic techniques are useful tools for investigating the formation of inert gas bubbles after hyperbaric exposure and can help to assess the risk of occurrence of decompression sickness. However, techniques, measurement period and regularity of measurements must be standardised for results to be comparable across research groups and to be of any benefit. There now appears to be a trend for fewer measurements to be made than recommended, which means that the onset, peak and cessation of bubbling may be overlooked and misreported. This review summarises comprehensive Doppler data collected over 15 years across many dive profiles and then assesses the effectiveness of measurements made between 30 and 60 minutes (min) post-dive (commonly measured time points made in recent studies) in characterising the evolution and peak of venous gas emboli (VGE). VGE evolution in this dive series varied enormously both intra- and inter-individually and across dive profiles. Median, rather than mean values are best reported when describing data which have a non-linear relation to the underlying number of bubbles, as are median peak grades, rather than maximum, which may reflect only one individual's data. With regard to monitoring, it is apparent that the evolution of VGE cannot be described across multiple dive profiles using measurements made at only 30 to 60 min, or even 90 min post-dive. Earlier and more prolonged measurement is recommended, while the frequency of measurements should also be increased; in doing so, the accuracy and value of studies dependent on bubble evolution will be improved.

Introduction

Audio Doppler ultrasound or echocardiographic imaging techniques are useful and practicable tools for the detection of venous gas emboli (VGE), often known as asymptomatic or 'silent' bubbles, following hyperbaric exposure. The techniques are important as they can help to assess the risk of decompression sickness (DCS) occurring. However, these techniques will only be of benefit so long as equipment, procedures and classification of the bubbles are effective, comprehensive and standardised, so that good-quality data are produced that can be compared across research groups.

In some recent decompression physiology studies, it seems that the advice given on the frequency and period over which bubble monitoring should take place, given by the pioneers of the techniques, is being ignored. For example, Nishi and co-workers proposed that for most non-saturation dives, monitoring should commence within 20 minutes (min) of surfacing, and then continue at 30 to 40 min intervals for at least two hours.[1] They also noted that "*in many studies*" only one monitoring session was conducted and hence, "*those studies were of limited value*". Despite these recommendations, it now seems commonplace to carry out studies investigating decompression risk with as few as two bubble measurements, usually between 30 and 60 minutes post-dive. Table 1 shows the dive profile type and Doppler measurement details for nine studies published between 2004 and the present.[2–10] It can be noted that, of the nine, the most commonly adopted time period for measurement was up to 60 minutes post-dive (five studies), while one measured up to 80 minutes post-dive and three to 90 minutes post-dive, all being less than the recommended 120 minutes.

In the studies summarised in Table 1 and in others, reference is often made to 'peak' or maximum bubble grades, and these data are then used to infer risk of one dive profile or intervention against another.[2,5] For these inferences to be comparable and correct, workers must be able to state, with a high level of confidence, that their reported values do indeed observe the peak of bubbling. Although researchers may have an informed idea of the period in which they would expect bubbles to occur post-dive, in reality, a wide range of inter- and intra-individual variation in the onset, peak and amount of VGE observed should always be expected, even while investigating sequential dives with the same profile and same subjects. Also, when the divers are subjected to various physiological or pharmacological interventions, unless pilot studies have been performed, it is not possible to state with any certainty when the bubbles will appear. In many cases, if measurements are not made soon after surfacing (within 30 min, though preferably 15 min), or are not continued after 60 min, then the onset and peak

Table 1
Reviewing the trend towards fewer Doppler/2D ultrasound measurements and reduced measurement periods

Study	Dive profile Depth (msw)	Time (min)	Number of measurements	Time period (min post-dive)	When post-dive (min)
Dujic et al 2004[2]	18	80	Four	20–80	20, 40, 60 and 80
Berge et al 2005[3]	60	45		0–60	Discontinuously
Blatteau et al 2005[4]	30	30	Two	30–60	30 and 60
Blatteau et al 2007[5]	30	30	Three	30–90	30, 60 and 90
Blatteau et al 2008[6]	30	25	Three	20–60	20, 40 and 60
Lemaitre et al 2009[7]	Children's air dive		Three	20–60	20, 40 and 60
Pontier et al 2009[8]	30	30	Three	30–90	30, 60 and 90
Germonpré et al 2009[9]	30	30	Three	30–90	30, 60 and 90
Bosco et al 2010[10]	30	20	Two	20–50	20 and 50

of bubbling might actually be missed and the monitoring rendered inadequate, particularly in studies where a full picture of bubble evolution is necessary for the interpretation of results. In truth, many diving studies now rely solely on their bubble data, be it audio Doppler or 2D-ultrasound image data, as indices for their hypothesis. Therefore, it should follow that it is sensible to collect as much VGE data post-dive as possible, in order to present the clearest picture of the subject's response to that particular exposure and/or intervention.

In the early 1990s, the majority of Doppler monitoring made by our group and associates was carried out at relatively frequent time intervals, as the importance of regular monitoring was recognised. Measurement usually started at around 15 minutes post-dive and persisted at 15 to 30 min intervals for at least two hours or longer; for example, in the case of a saturation dive. However, given that many of the dives performed were submarine escape exposures, i.e., very rapid, deep, bounce dives with rapid compression and decompression, it soon became apparent that waiting until 15 min after surfacing would mean that the onset or peak of bubbling was quite likely to be missed. Only the tissues with very short half-times would have time to become supersaturated during an escape profile and, therefore, were likely to off-gas almost immediately after the exposure. Hence, Doppler measurements commenced as soon as possible after surfacing and were made at 5-min intervals for the first 30 min, and every 15 min thereafter for at least 120 min depending on the dive protocol and information needed, often continuing until bubble evolution had ceased. In this way, it became common practice for most post-dive monitoring, irrespective of profile, to be carried out according to this schedule whenever possible. One Doppler operator was able to attend to at least two subjects every five minutes with ease, and so there was no drawback to continuing in this way; the comprehensive information collected on the evolution of VGE in the first 30 min after surfacing for a wide variety of dives made the effort more than worthwhile.

This review presents retrospective observations on some of these data, using a number of studies that were representative of each type of dive profile, to determine the natural history of VGE evolution across all types of dives and so to indicate just how effective measurements made between 30 to 60 min post-dive are in characterising bubble evolution and peak grades.

Methods

Over the last 15 years, we have collected a large amount of post-hyperbaric exposure Doppler data from a wide variety of dive profiles, both wet and dry, using both human and animal subjects. All of the data used in the present study were taken from studies using either human or animal subjects. All human studies complied with the Declaration of Helsinki (1975) and were reviewed by a local ethics committee, while all animal work was carried out under the UK Animals (Scientific Procedures) Act (1986) and was also reviewed by a local ethics committee. The profiles include:

Simulated submarine escape exposures: usually involving a rapid compression to depth within 30 s or less, and then decompression at a rate of around 2.75 m s^{-1}. The range of depths used in studies ran from around 800 kPa (70 metres' sea water, msw) to 3,000 kPa (290 msw), with an escape from 2,500 kPa (240 msw) reported here.

Simulated saturation dives: the saturation dive reported here involved 24 h exposure to 180 kPa (8 msw).

Simulated saturation plus submarine escape exposures: these dives typically involved a 24 h, 180 kPa (8 msw) saturation exposure followed by compression to an escape depth of 2,500 kPa (240 msw) and decompression to the surface, with compression/decompression rates as for the escape profile above.

Bounce dives: of varying duration and depth that are too great in number to categorise fully here, though they may be loosely categorised into long bounce dives and short bounce dives. (see Figures 4 to 11 for examples of the profiles used in these trials).

Post-dive Doppler measurements were made using the same pool of operators (five people) for all of these exposures, and all were trained to use the Kisman Masurel (KM) grading system; their proficiency was regularly assessed at DERA/QinetiQ Alverstoke, UK.[11] The equipment used to make the Doppler measurements were Doppler Bubble Monitors (Techno Scientific, Ontario, Canada) using a 2.5 MHz transducer probe, with measurements made in the precordial area.

The animal model used was the goat; all animal Doppler measurements were made at rest out of necessity, as the goat could not be trained reliably to perform a prescribed movement. When working with human subjects, measurements were generally taken at both rest and after movement. 'Movement' measurements are usually made to help the operator; if a dynamic movement is made using large muscles, such as those in the legs, it increases venous return and so any bubbles present are likely to arrive at the heart in a flurry that is more discernable than a trickle of bubbles, as might be heard at rest. Generally, resting measurements are used when reporting the data, but movement measurements may give a more accurate picture of the onset and cessation of bubble evolution as relatively stationary bubbles, probably located in the capillaries at the periphery of the circulation, can be dislodged by the movement.

Measurements made earlier in this 15-year period of study were generally made with the subject in an upright position, where movement measurements involved the subjects making a deep knee bend, the operators then grading the resulting sound. More recently, measurements have been made with subjects lying in the left lateral decubitus position, which means that measurements made using audio Doppler are comparable to 2D-visual ultrasonic measurements using echocardiography. In this position, movement measurements were made after the subject vigorously extended and retracted their legs from the hip three times, so essentially making knee bends, but while lying down. Also, it seems that a more reliable measurement may be made from this decubitus position than when the subjects are upright. As the heart falls slightly forward in the chest in this position, operators may find that those subjects with deep chests, on whom it is often difficult to make standing measurements upon, are easier to listen to in this position.

Most of the measurements were made at time intervals as described in the introduction, usually every 5 min for the first 30 min post-surfacing, then at 15-min intervals until at least 120 min had passed post-surfacing. In some cases monitoring continued (particularly in the case of saturation dives) every hour until bubbles ceased to be heard. Monitoring was sometimes constrained by operational limitations; for example, regular measurements could not be made at the start of the post-dive period in divers arriving back on a boat until they had returned to shore, though at least one measurement was made on the boat, as close to surfacing as possible.

Once the KM measurements were made, the resulting codes were converted into KM grades and entered into a computer spreadsheet. It must be noted that KM grades cannot be treated as numbers, as the KM scale is not an interval, but ordinal scale, producing ranked, non-parametric data. The KM scale is highly non-linear, that is, the differences between Grades 0 and I are not the same as between grades I and II, or between II and III, for example. Therefore, calculation of the mean bubble grade at a given time point is not appropriate; median values give a more conservative and statistically sound inference, particularly when using non-parametric statistics.[1] Therefore, maximum, median and minimum grades for each recorded time point across all subjects were calculated; these calculations were made separately for the resting and movement data. It is thought that using median values to report bubble evolution gives a good representation of the data for most dive profiles for comparison, with some exceptions; for example, where the median score is zero. In these cases, maximum scores may be more informative.

Care should be taken when discussing 'peak' bubble scores. In the present study, the term 'median peak' Doppler grade is used, that being the point at which the median KM grade for all subjects across the entire period over which VGE were measured, was at its highest. To use the maximum data line to describe 'peak' bubbling may be misleading, as it may represent only one individual's data.

Figures 1–11 show Doppler data from various dive profiles with maximum, median and minimum measured KM grades. All dives are dry chamber dives, unless otherwise stated. The data included are representative; they are not presented in order to be analysed statistically, but rather to illustrate the points at which the onset and cessation of VGE evolution have been observed in a number of studies.

In reporting both maximum and minimum Doppler grades across the study groups, as well as the median, these data also show that VGE evolution can vary enormously between individuals exposed to the same profile. It is also implicit that the data show the difference between dive profiles; for example, it would not be expected that bubble onset or duration would be the same following an escape and a saturation dive. Comparison of the data depicted in the plots is most usefully carried out using the line representing the median KM grades, with the maximum and minimum lines showing how large the range across subjects can often be.

KM grades in the figures that follow are referred to using Arabic rather than Roman numerals for clarity.

Figure 1
Escape dive – goats (*n* = 7) at rest;
2,500 kPa (240 msw) simulated submarine escape on air.

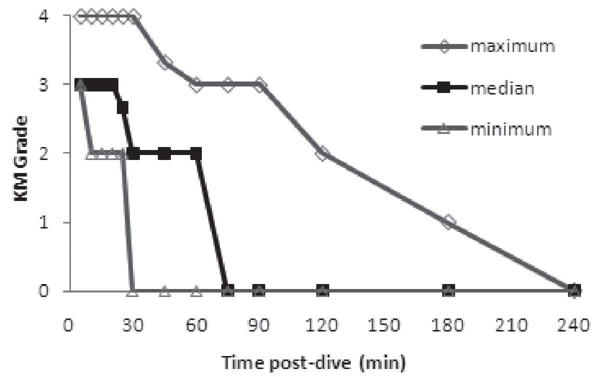


Figure 2
Saturation dive – goats (*n* = 20) at rest;
180 kPa (8 msw) saturation (24 h) on air

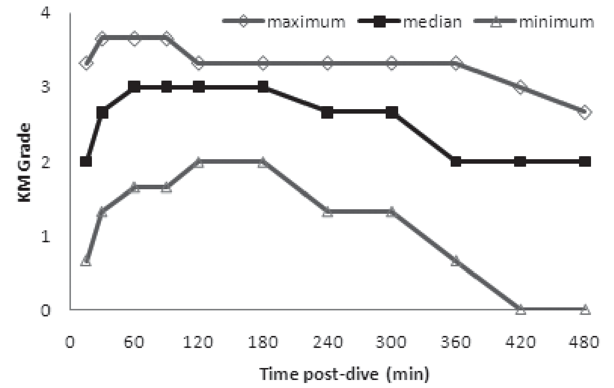
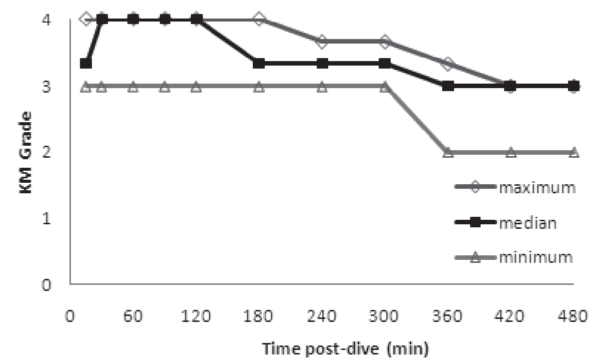


Figure 3
Saturation + Escape dive – goats (*n* = 15) at rest;
180 kPa (8 msw) saturation (24 h) plus 2,500 kPa (240 msw) simulated submarine escape dive on air



Results

SUBMARINE ESCAPE PROFILES (essentially short, deep bounce dives)

Figure 1 shows the results for a simulated submarine escape dive series on air, to and from 2,500 kPa (240 msw), involving a rapid compression to depth within 30 s or less, then decompression at a rate of around 2.75 m s^{-1}.[12] The median peak Doppler grades occurred between 5 to 20 min post-decompression and therefore would have been missed by the normal onset of monitoring at 30 min. Median grades did not return to zero until 75 min post-dive, while some outliers continued to bubble until 4 h after surfacing.

SATURATION DIVES (long, shallow dives)

Figure 2 shows the results of saturation dives to 180 kPa (8 msw) for 24 h.[12] The median peak grades occurred from 60 to 180 min, and so the onset of the peak score would just be observed within a 30 to 60 min post-dive measurement period. However, the prolongation of the median peak and the fact that median grades had still not returned to zero within 8 h post-dive would not have been noted.

SATURATION DIVES PLUS AN ESCAPE PROFILE

Figure 3 shows the results for 24 h saturation dives to 180 kPa (8 msw) followed by simulated submarine escape to and from 2,500 kPa (240 msw) (see above for profile details) on air.[12] The peak bubble grades tended to occur between 20 to 30 min post-decompression and the median peak persisted for up to 120 min. Although the onset of the median peak grades would be noted within the 30 to 60 min monitoring period, again the entire median peak period and the fact that at 8 h post-dive, the median grades had not dropped below KM III, would not have been observed. The bolstering of the median bubble grades to such a high level for such a long period (in comparison to saturation alone) reveals the additive effect of appending an escape profile onto a period of saturation.

LONG BOUNCE DIVES

For bounce dives with longer bottom times and shallower depths (around 100 min and 280 kPa (18 msw) depth for the data reported here, Figures 4 to 8), VGE would take a little longer to appear, from around 60 min. It should be noted that movement can have a considerable effect on measurement results, returning showers of measureable bubbles that would not have reached the right cardiac chamber until later if measurements were made only at rest.

Figure 4 shows the results of resting Doppler measurements made after a bounce dive to 280 kPa for 100 min on air, with a decompression stop at 3 msw for 14 min (Swedish Navy air dive tables - based on USN 56 tables).[13] Note that the maximum peak occurred at 15 min, and that the median peak would also be missed if measurements were made only between 30 and 60 min post-dive, as it was reached at 75 min and did not decline until after 105 min post-dive.

Figure 5 shows the results of the same dive as Figure 4, but the Doppler measurements were made after movement, rather than at rest. Once again, the maximum peak occurred at 15

Figure 4
Bounce dive – human subjects (*n* = 9) at rest; 280 kPa (18 msw) for 100 min on air, 3 msw for 14 min; decompression on Swedish Navy air dive tables

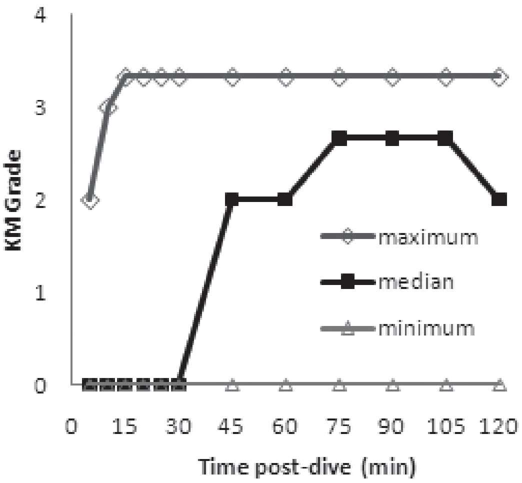


Figure 5
Bounce dive – human subjects (*n* = 9) after movement; 280 kPa (18 msw) for 100 min on air, 3 msw for 14 min; decompression on Swedish Navy air dive tables

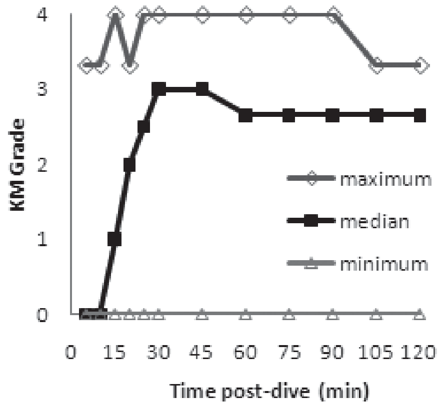


Figure 6
Bounce dive – human subjects (*n* = 8) at rest; 280 kPa (18 msw) for 100 min on air; decompression on Swedish Navy air dive tables

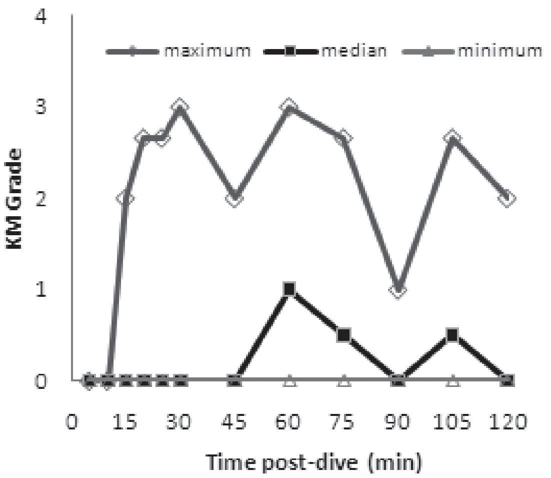


Figure 7
Bounce dive – human subjects (*n* = 10) at rest; 280 kPa (18 msw) for 100 min on air; decompression on RN Table 11 MOD.

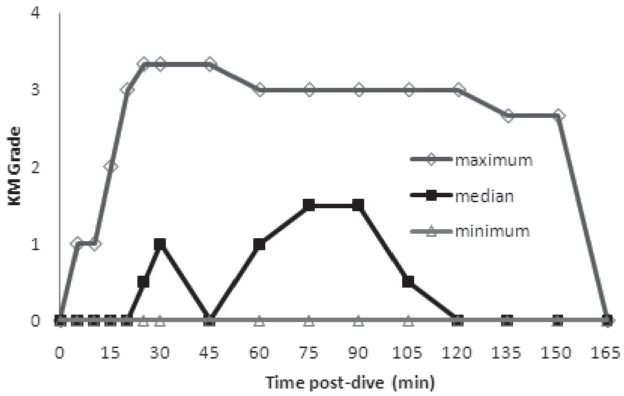
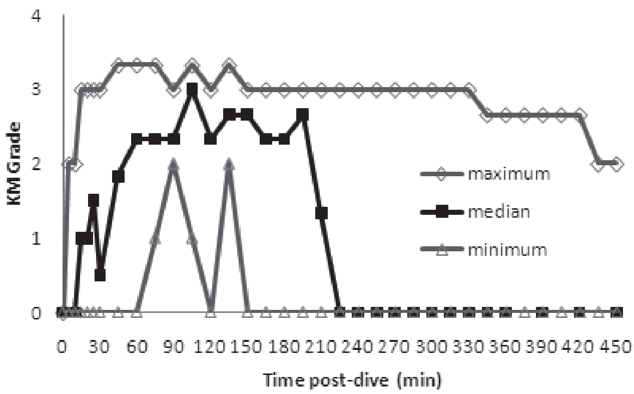


Figure 8
Bounce dive – human subjects (*n* = 10) at rest; 280 kPa (18 msw) for 100 min on air; decompression on RN Table 11 MOD



min, but movement brought the occurrence of the median peak back from 75 min (as in the resting measurements) to 30 min.

Figure 6 shows the results of another bounce dive, again to 280 kPa for 100 min on air with decompression made on the Swedish Navy air dive tables.[13] Measurements made between 30 and 60 minutes in this case would have captured both the maximum and median peak data, although bubbling continued in some subjects at a relatively high level after 60 min post-dive.

Figure 7 shows the results of a bounce dive, again to 280 kPa for 100 min or air, but with decompression on RN Table 11 MOD.[14] These data formed the control results for a trial investigating the effect of pre-dive exercise on VGE

Figure 9
Bounce dive – human subjects (*n* = 5) after movement; 700 kPa (60 msw) for 15 min on tri-mix using a semi-closed circuit rebreather in open water

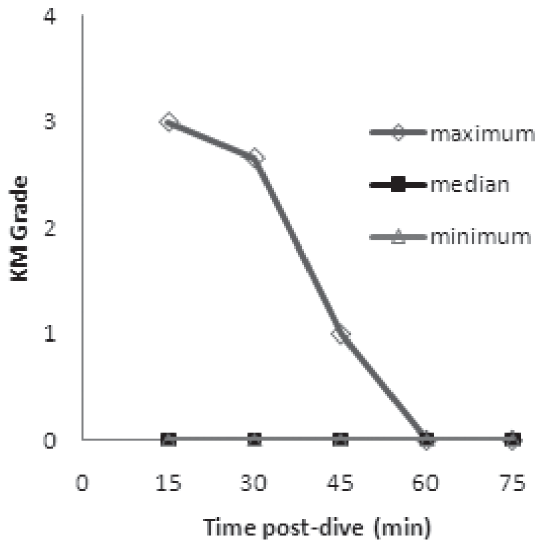


Figure 10
Bounce dive – human subjects (*n* = 3) at rest; 1,000 kPa (90 msw) for 18 min on tri-mix using a closed-circuit rebreather in open water

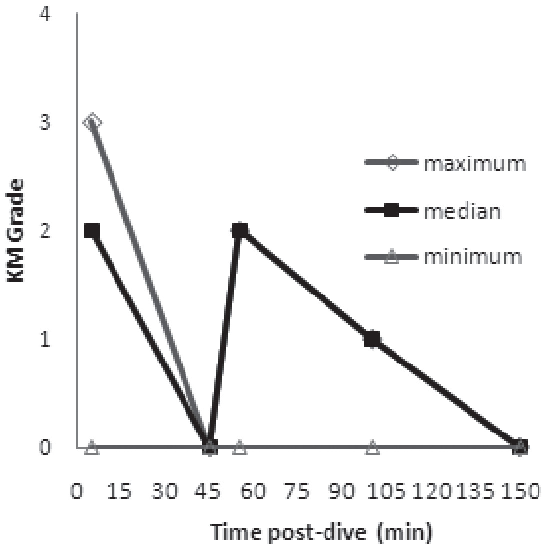
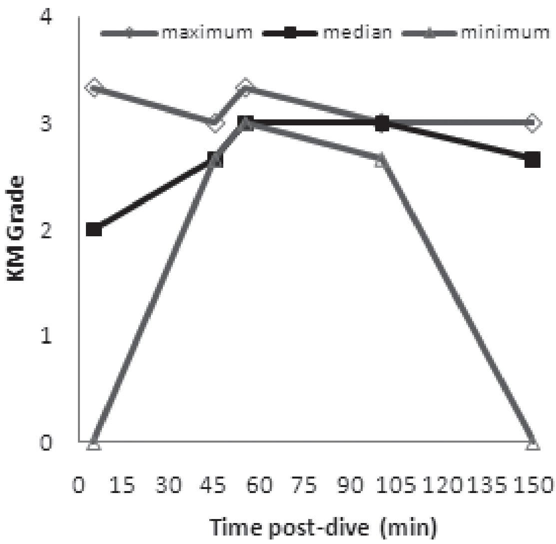


Figure 11
Bounce dive – human subjects (*n* = 3) after movement; 1,000 kPa (90 msw) for 18 min on tri-mix using a closed-circuit rebreather in open water



production. It should be noted that the maximum peak was reached at 25 min, while the median peak occurred at 75 min and did not return to zero until 120 min post-dive. All of these events would have been missed by measurements made between 30 and 60 min.

Figure 8 shows data produced after the same dive as described in Figure 7, but with exercise taken by the subjects 2 h before the dive. The median peak of bubbling was not reached until 105 min and did not return to zero until 225 min post-dive. One individual continued to produce high levels of VGE for a notable period (as described by the maximum peak data), showing the extreme of inter-individual variation. Interestingly, this subject did not produce such 'extreme' results in comparison to his peers in other sections of the trial.

SHORT BOUNCE DIVES

For bounce dives where the bottom time is short and the dive relatively deep (in the present study, between 15 and 18 min and 700 to 1000 kPa (60 to 90 msw respectively) (Figures 9 to 11), then the first appearance of VGE arrived swiftly (as soon as 5 min) after decompression.

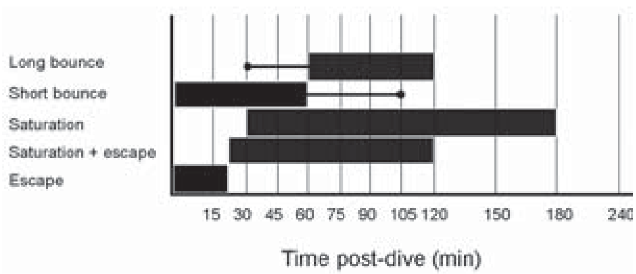
Figure 9 shows the results of a dive to 700 kPa for 15 min on tri-mix, using a semi-closed rebreather in open water. Although the median grades did not rise above zero, two subjects out of five produced maximum peak grades of KM III- and KM III at 15 min, which then dropped to zero and KM III- respectively at 30 min. Given a larger group size, it is likely that the median peak score would rise and would therefore be missed if measurements did not start until 30 min post-dive. Measurements could not be taken before 15 min for operational reasons as the divers were busy getting out of the water and shedding their equipment. Two sequential grades of zero at 60 and 75 min meant that measurement could cease before 120 min post-dive; it is thought safe to assume that if no bubbles are heard after two sequential time points of at least 15 min apart, then audible VGE are no longer present in the circulation.

Figure 10 shows the resting Doppler results of a bounce dive made to 1,000 kPa for 18 min, again on tri-mix in open water, but using a closed-circuit rebreather. On surfacing, the divers breathed 100% oxygen for 10 min; measurements started 5 min after this period. Note the inter-individual variation in the spread of KM scores at 5 min. Despite this, the onset of both the maximum and median peak scores would have been missed between 30 and 60 min. Fewer measurements were made following this dive than would be preferable due to operational limitations – the measurements at 5 min were made on the dive boat, then the remainder made on reaching the shore. Inactivity on the boat may have been responsible for the grades dropping to zero, then rising once more following a period of physical activity as the divers moved their equipment from the boat to shore once the second measurement had been made.

Figure 11 shows results for the same dive as detailed in Figure 10, but with measurements made after movement. Note the same inter-individual spread and that the onset of the maximum peak scores still occurred at 5 min post-dive. That movement caused VGE to circulate at 45 min, while resting measurements made at this time point revealed no detectable VGE, again indicates that both rest and movement measurements should always be made in order to determine fully whether or not bubbles are present.

Collation of these data is depicted in Figure 12, which consists of a schematic diagram illustrating the typical periods over which 'median peak' resting KM Doppler grades may occur and then persist, for the differing profiles described. 'Long bounce' dives are classified here as those of duration of 100 min at depth (Figures 4 to 8). 'Short' bounce dives are those described as being 18 min at depth or less (Figures 9 to 11). Lines with circular ends extending fore or aft of the long and short bounce bars denote the extent of the range over which bubbles can be noted if movement measurements are taken into account for the data presented in the figures for the bounce dives. No movement measurements could be included for the remaining profiles, as they were made on goats for which only resting measurements are made.

Figure 12
Schematic illustrating the typical periods over which 'median peak' resting KM Doppler grades may occur



Discussion

From these data, representing nine different studies with varying dive profiles, it can be seen that there is great variation in the time of onset, peak and disappearance of Doppler-detectable VGE across individuals and across dive profiles. It appears obvious that every dive profile cannot uniformly be characterised by monitoring VGE within a short time period of between 30 and 60 minutes, or even up to 90 minutes post-dive.

Take, for example, the data reported in Figures 7 and 8. Here, the subjects performed the same dry chamber dive, compressing to 280 kPa (18 msw) for 100 minutes, then decompressing in accordance with RN Table 11 (15 msw min^{-1} ascent rate, stopping at 6 msw for 5 minutes and 3 msw for 15 min).[14] The difference between the dive protocols was a period of exercise taken two hours before compression in one instance (Figure 8), while the other dive (Figure 7) acted as a no-exercise control. Doppler measurements made between 30 and 60 minutes would have missed the median peak KM grades after both dives. The control dive produced its median peak grades at 75 to 90 minutes, while the median peak for the dive with pre-dive exercise occurred at 105 minutes. Note that in both cases, if monitoring was carried out as recommended by Nishi et al, i.e., up to 120 min post-dive, then the peaks would be observed.[1] None of the studies listed in Table 1 would have continued monitoring long enough to find the median peak grades shown in the pre-dive exercise group. The dive profile used in this case is comparable to many used in this field of study today, as it is known to elicit VGE to varying degrees in most subjects and, therefore, can be used to test the efficacy of different interventions or prophylaxes on bubble evolution.

The measurement periods of the nine studies included in Table 1 are not too dissimilar, ranging from 20 to 90 minutes at most.[2–10] However, the dive profiles range from 280 kPa for 80 minutes, to 400 kPa for up to 30 min and 700 kPa for 45 minutes. If these profiles are compared to Figure 12, then it would seem that the median peaks for the first two should be expected between 60 and 120 minutes. The final profile of 60 msw for 45 min is more complex, as it is relatively long and deep; with regard to its comparison to Figure 12, it seems that comparable median peak grades could occur anywhere between 5 and 120 min, while monitoring actually took place between surfacing and 60 minutes.[3] This study was carried out to investigate the effect of exercise or rest before a dive on VGE evolution; the comparison of the evolution of bubbles in both groups for 60 min after surfacing would provide appropriate data for that purpose, but the cessation of monitoring would not allow the complete effect of the conditions to be observed. Given the expense, both financial and in terms of time and effort, expended on organising and running such trials, it does seem to be false economy not to continue monitoring bubble evolution for at least the recommended 120 min post-dive and, therefore, collecting a more complete, and perhaps revealing, set of data.

Given the difficulty in forecasting accurately the behaviour of VGE evolution, long intervals between measurements are also not ideal. For example in Figures 10 and 11, Doppler monitoring was constrained by the fact that the dives had taken place in open water off a dive boat and that the primary aim of the divers was to test a closed-circuit rebreather. Doppler data collection was a secondary objective and so had to fit in around the divers getting back on the boat, attending to their equipment and getting back to base. It was only possible therefore to make five measurements, and only two of these were made in the first 45 minutes. Although it appeared that the median peak grades were recorded, the lack of measurement points between 5 and 45 min mean that we cannot say for certain that the peak was observed and the value of the data suffers because of this.

Of course, it could be argued that Doppler monitoring would have to occur continuously to be able to say definitively that the true peak had been observed. However, without the use of implanted Doppler probes, this would be completely impractical. Given the biological nature of the system in question, if the type of dive profile to be used is considered carefully and if the optimal bubble monitoring frequency and measurement period, drawn from the guidelines established here or from similar articles in the literature, is implemented, then that should allow some confidence in reporting the onset, peak and disappearance of VGE from the venous system.

Conclusion

Ultrasound monitoring of post-dive VGE needs to become more standardised across research groups in order for the data to be comparable. Both earlier and more prolonged monitoring is recommended, while the frequency of measurements should also be increased. As trials are expensive in every sense, it is logical to collect the most complete set of data possible in order to validate the results and allow accurate comparison across studies.

Acknowledgements

We thank all involved in helping to collect the data reported in this review.

Conflict of interest: none

References

1 Nishi RY, Brubakk A, Eftedal O. Bubble detection. In: Brubakk A, Neuman T, editors. *Bennett and Elliott's physiology and medicine of diving*, 5th ed. Edinburgh: Saunders; 2003.
2 Dujic Z, Duplancic D, Marinovic-Terzic I, Bakovic D, Ivancev V, Valic Z, et al. Aerobic exercise before diving reduces venous gas bubble formation in humans. *J Physiol*. 2004;555(Pt 3):637-42.
3 Berge VJ, Jorgensen A, Loset A, Wisloff U, Brubakk AO. Exercise ending 30 min pre-dive has no effect on bubble formation in the rat. *Aviat Space Environ Med*. 2005;76:326-8.
4 Blatteau JE, Gempp E, Galland FM, Pontier JM, Sainty JM, Robinet C. Aerobic exercise 2 hours before a dive to 30 msw decreases bubble formation after decompression. *Aviat Space Environ Med*. 2005;76:666-9.
5 Blatteau JE, Boussuges A, Gempp E, Pontier JM, Castagna O, Robinet C, et al. Haemodynamic changes induced by submaximal exercise before a dive and its consequences on bubble formation. *Br J Sports Med*. 2007;41:375-9.
6 Blatteau JE, Gempp E, Balestra C, Mets T, Germonpre P. Predive sauna and venous gas bubbles upon decompression from 400 kPa. *Aviat Space Environ Med*. 2008;79:1100-5.
7 Lemaitre F, Carturan D, Tourney-Chollet C, Gardette B. Circulating venous bubbles in children after diving. *Pediatr Exerc Sci*. 2009;21:77-85.
8 Pontier JM, Guerrero F, Castagna O. Bubble formation and endothelial function before and after 3 months of dive training. *Aviat Space Environ Med*. 2009;80:15-9.
9 Germonpre P, Pontier JM, Gempp E, Blatteau JE, Deneweth S, Lafere P, et al. Pre-dive vibration effect on bubble formation after a 30-m dive requiring a decompression stop. *Aviat Space Environ Med*. 2009;80:1044-8.
10 Bosco G, Yang ZJ, Di Tano G, Camporesi EM, Faralli F, Savini F, et al. Effect of in-water oxygen prebreathing at different depths on decompression-induced bubble formation and platelet activation. *J Appl Physiol*. 2010;108:1077-83.
11 Kisman K, Masurel G. *Method for evaluating circulating bubbles detected by means of the doppler ultrasonic method using the 'K.M. code'*. Toulon: Centre d'Etudes et Recherches Techniques Sous-Marines; 1983. English translation of 283 CERTSM 1983.
12 Blogg SL, Gennser M, Loveman GAM, Seddon FM, Thacker JC, White MG. The effect of breathing hyperoxic gas during simulated submarine escape on venous gas emboli and decompression illness. *Undersea Hyperb Med*. 2003;30: 163-74.
13 Swedish Navy. *Dyk:R Säk, Safety Regulations for Swedish Navy Diving*. in: M7744-390002, Swedish Navy; 1989.
14 UK Navy. *BR2806 - UK Military Diving Manual*. In: CINCFLEET/FSAG/P2806, Vols I and II ed: Royal Navy UK; 1999.

Submitted: 30 March 2011
Accepted: 25 June 2011

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