Original articles

Ocular tear film bubble counts in swimmers and snorkellers

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Key words
Recreational diving, snorkelling, swimming, tear film bubbles, decompression illness, diagnosis

Abstract

Background: The number of ocular tear film bubbles is increased following compressed air single- and multi-day diving in both sea water and hyperbaric chambers. However, the effect of sea water immersion and shallow breath-hold diving on the tear film has not been studied.
Methods: We examined the ocular tear films of 20 volunteers before and up to 72 hours following 30 minutes' exercise swimming or snorkelling in sea water.
Results: Both groups had a baseline median bubble count per eye of 0.33 (interquartile ranges, 0–1 and 0–0.9 respectively). There was no significant rise in the median bubble count following either exercise.
Conclusions: Our findings suggest that the observed increase in ocular tear film bubble counts in recreational compressed air diving is indeed related to decompression stress, and unrelated to the salt water environment per se.

Introduction

Despite the accumulating knowledge about the process of de-nitrogenation during decompression and its role in decompression illness (DCI), there still remains no test to confirm a diagnosis of DCI. Clinicians must rely on dive profile, clinical history and examination. In 1878, Paul Bert first postulated the existence of nitrogen bubbles forming in the blood and tissues following rapid decompression. Venous gas bubbles can be detected using precordial doppler ultrasound and this technique has been extensively used to assess decompression stress and validate dive tables. Venous bubbles can be detected within minutes of surfacing from a dive, reach a peak between 1 and 3 hours and are not detectable after 5 hours.[1] Unfortunately, the transient nature of venous bubbles limits their usefulness as a diagnostic test. Not only is there poor correlation between intravascular bubble counts and the presence of clinical DCI, but the majority of divers present for assessment and treatment long after venous bubbles have dissipated.[2] In one recent report, the average time from causative dive to presentation at a hyperbaric medicine unit was greater than 24 hours.[3]

The search for a diagnostic tool has led to the investigation of the ocular tear film. Although intra-ocular bubbles after decompression were first noted by Boyle in 1670, no particular clinical significance had been attributed to bubbles in the eye. Recently, a number of reports have been published suggesting that ocular tear film bubbles may relate directly to decompression stress.[4–8] However, no data exist for swimmers and snorkellers exercising in sea water. The present study has been undertaken with individuals exposed to the marine environment, in the absence of compressed air breathing, in order to establish counts for ocular tear film bubbles following marine exposure alone.

Materials and Methods

This study was undertaken at the Hyperbaric Medicine Unit, Prince of Wales Hospital, Sydney, and was approved by the South Eastern Sydney Area Health Service Research and Ethics Committee prior to volunteer enrolment.

Poster advertisements requested experienced adult swimmers and snorkellers in general good health to volunteer for participation in the study. Volunteers were excluded if they gave any history of ocular tear film dysfunction or ophthalmic disease (excepting refractory errors), or if they had undertaken compressed air diving or breath-hold diving to a depth greater than two metres in the four days prior to the study. Diving was prohibited for three days following the in-water exercise. Twenty volunteers were recruited following an explanation of the study including the slit-lamp examination procedure.

Following recruitment, a baseline examination of the ocular tear film was made with a standard slit-lamp (SL900, Haag-Streit, Switzerland) using our established protocol.[4] The volunteer subject closed their eyes for five seconds prior to each examination. The average bubble count was obtained from three sweeps of the inferior gutter of the ocular tear film, from medial to lateral (against the tear flow, which occurs from the lacrimal gland to the lacrimal canaliculi). Only bubbles in the gutter itself were counted, as small bubbles on the eyelid are not uncommon after blinking.

Volunteers were then randomly assigned to either the swimming or snorkelling group by means of a random number generator, with 10 people in each group. The swimming or snorkelling exercise was performed in enclosed sea water (either a sea pool or sheltered bay) for 30 minutes, pace being determined by the individual swimmer. To avoid the discomfort associated with swimming in salt water, the swimmers wore goggles. Snorkellers wore half-face masks and used a standard snorkel. The snorkellers were also required to perform several shallow breath-hold dives during their snorkelling exercise to a maximum depth of three metres. A member of the research team trained in adult resuscitation supervised the in-water exercise, and a public lifeguard patrolled the swim site.

The second tear film examination was performed within four hours of the in-water exercise, and at 12, 24, 48 and 72 hours thereafter. All participants completed the six examinations.

Two studies performed with recreational divers using scuba equipment have previously been completed in the Prince of Wales Department of Diving and Hyperbaric Medicine.[4] In the first study, 42 single-day divers performed a dive to 25 metres for 25 minutes with a five minute safety stop. In study two, 11 divers underwent repetitive, multi-day diving exposures over five days. The median bubble counts at 24 hours for these two groups of divers were compared to the those at 24 hours of the swimmers and snorkellers.

STATISTICAL ANALYSIS

Volunteers were recruited as a convenience sample and no power calculation was made. As the results were not normally distributed, non-parametric methods were used (Shapiro-Wilks W test). Median tear film bubble counts per eye were obtained and compared using the Friedman test for multiple comparisons (a non-parametric equivalent of ANOVA). The Mann-Whitney U test was employed for individual comparisons between groups and time points. All calculations were made using StatsDirect statistical software, version 1.611, Iain Buchan, 2000.

Results

All swimmers and snorkellers completed the 30-minute exercise in salt water, either in a sheltered bay or sea pool.

FIGURE 1
MEDIAN BUBBLE COUNTS PER EYE IN SWIMMERS (AVERAGE OF THREE SWEEPS)
(error bars represent interquartile ranges) * significant difference from pre-swim ($p < 0.05$)

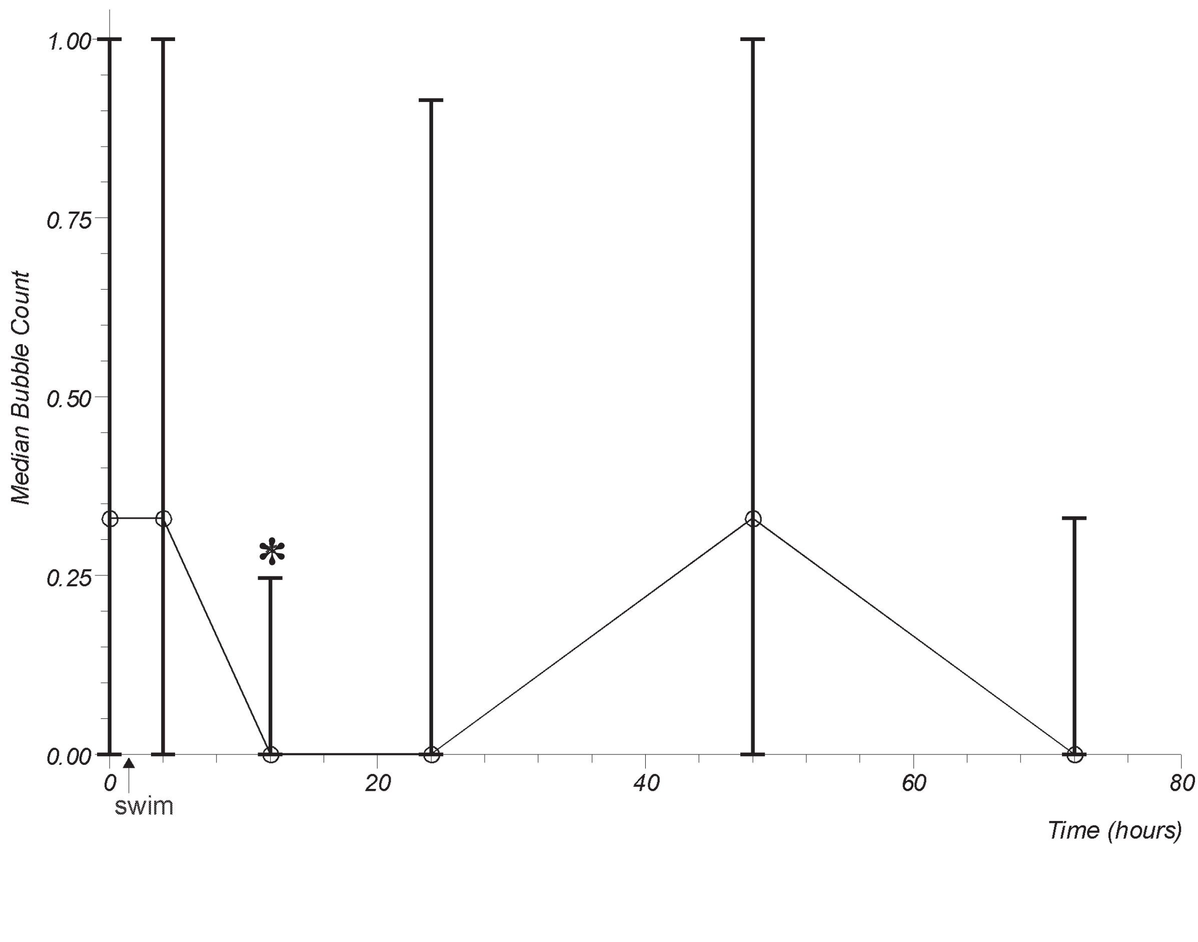
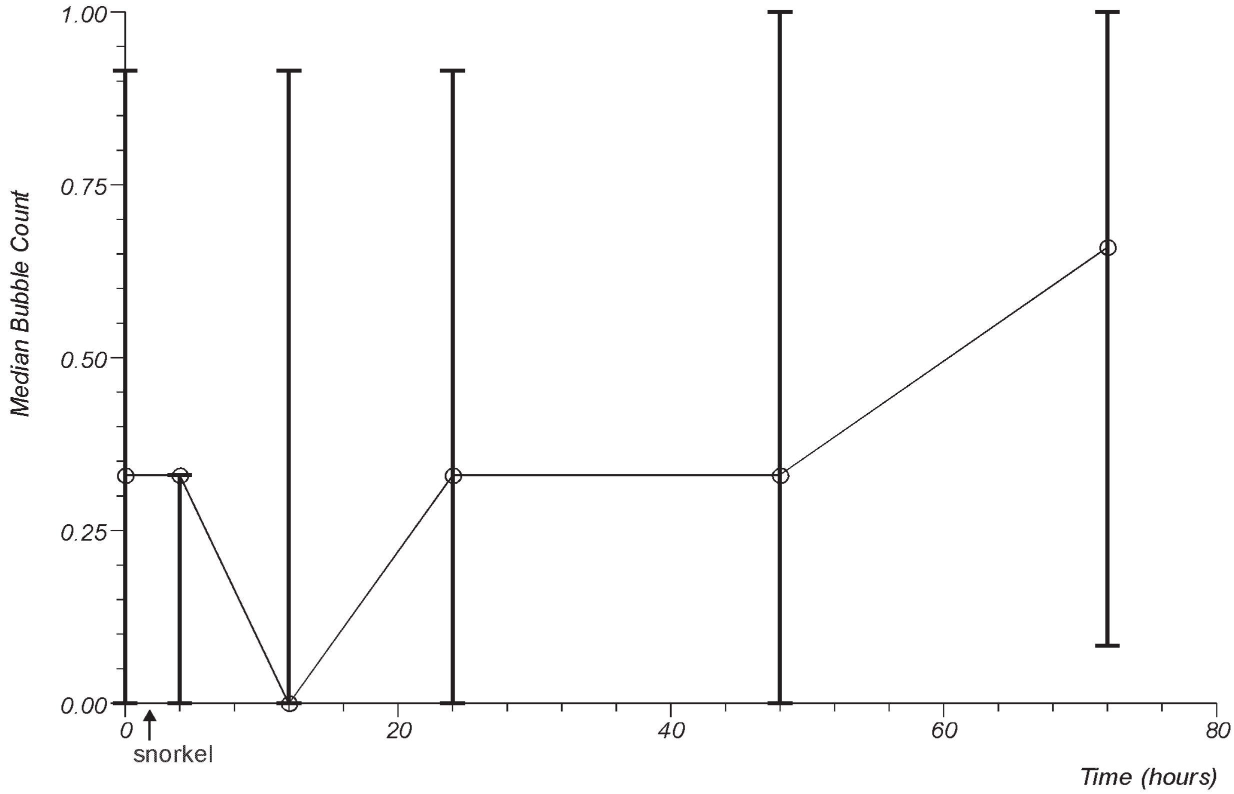


FIGURE 2
MEDIAN BUBBLE COUNTS PER EYE IN SNORKELLERS (AVERAGE OF THREE SWEEPS)
(error bars represent interquartile ranges). There were no significant differences between readings in this group



In the swimmers, the mean age was 29 years (SD 8.35 years, n = 10). The mean age of the snorkellers was 31.9 years (SD 6.88 years, n = 10). There were five female swimmers and four female snorkellers. Three people wore soft contact lenses while swimming and two while snorkelling. There was one smoker in each group.

The swimmers had a baseline median bubble count per eye of 0.33 with an interquartile range of zero to 1.0. The median bubble count at 12 hours was significantly lower than the baseline (Count: zero; $p < 0.02$, Mann-Whitney U test), but with no significant change from the baseline at all other times (Figure 1).

The snorkellers also had a baseline median bubble count per eye of 0.33 with an interquartile range of 0 to 0.915. Bubble counts did not change significantly for any examination time in this group (Friedman test, $p > 0.3$). The highest median bubble count per eye at any time (0.66) was noted in the snorkelling group at 72 hours (Figure 2).

One member of each group demonstrated unusually high counts. These two were the only subjects to ever have bubble counts of more than 3.0 per eye. The swimmer demonstrated high counts on three occasions with median bubble counts of 6.0 at 24 hours, 4.0 at 48 hours and 3.33 at 72 hours. The snorkeller had a bubble count in one eye of 4.6 prior to undertaking the in-water exercise and counts of one or greater on three further occasions.

Median bubble counts per person were also calculated. In both groups the highest median bubble count was 0.5 (range of 0 to 1.33). When median bubble counts per person were compared, no significant differences were seen for any time point (swimmers $p > 0.2$, snorkellers $p > 0.5$), or when the two groups were compared ($p > 0.2$). Only 12.5% of the total readings showed a tear film bubble count greater than one bubble per person; with 11 subjects (55%) never having an average count greater than one bubble at any time.

The median bubble counts per eye for the swimmers and snorkellers have been compared to those previously obtained by Bennett et al for single- and multi-day divers (Figure 3).[4] The time point of 24 hours was chosen to reflect the average time of first presentation at a hyperbaric unit for medical assessment.

INTER-OPERATOR VARIABILITY

Four slit-lamp operators were involved in the readings, although two investigators performed 96% of the examinations. Investigator 1 (KB) performed 56.6% of the readings and Investigator 2 (AD) 39.2%. Both investigators counted a median of 0.33 bubbles per person.

Discussion

Extra-ocular tear film bubbles were first noted under both hard and soft contact lenses after diving and later in the eye of a hyperbaric chamber attendant not wearing contact lenses.[5] Since this observation, research data have been accumulating to indicate that extra-ocular tear film bubbles may be a measure of decompression stress.

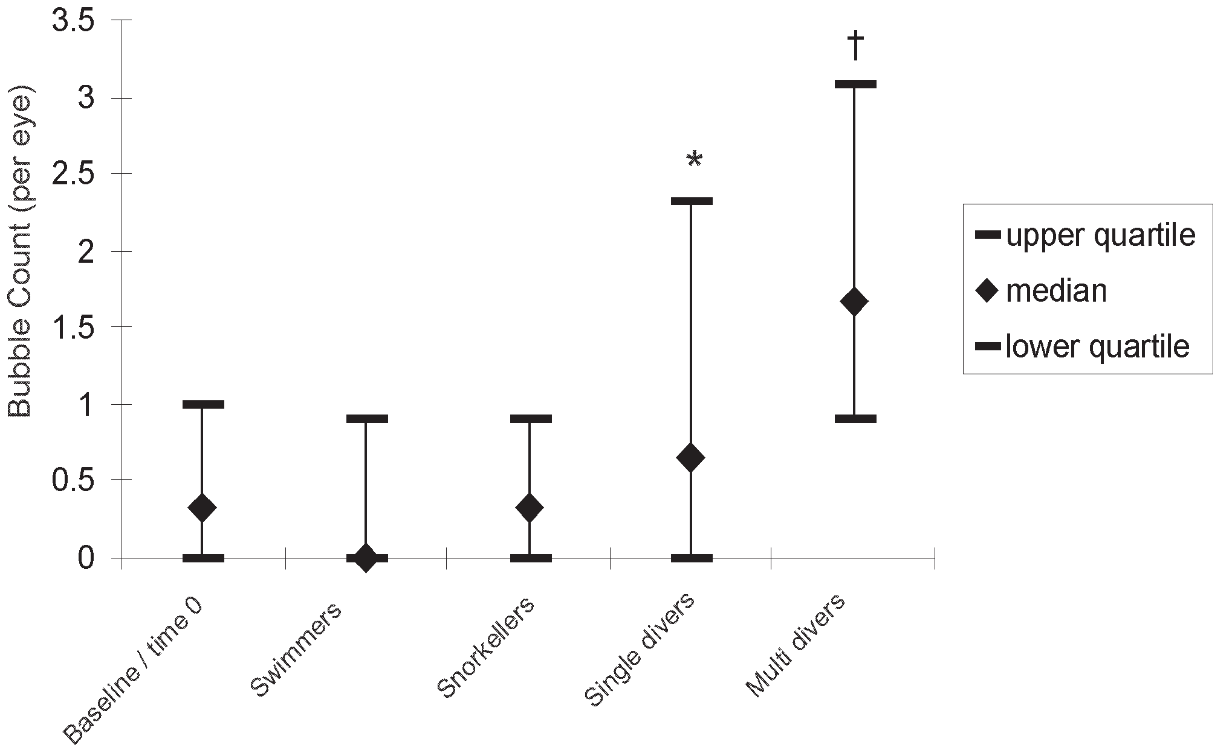
Tear film bubble counts were increased when volunteers underwent dry hyperbaric chamber air breathing dives[6,7] but not oxygen breathing dives.[8] A similar increase in ocular tear film bubble counts was noted following open water compressed air dives in the Prince of Wales studies.[4] This is not matched in the present study by swimmers and snorkellers exercising in the marine environment.

Tear film bubble counts from the swimmers and snorkellers were compared with the divers' counts at 24 hours post-exercise or dive, a time when patients commonly first present to a hyperbaric unit for medical assessment with symptoms of decompression illness.[3] Median bubble counts in the swimmers were significantly lower than both the single- and multi-day divers at 24 hours. The snorkellers were also significantly different from the multi-day divers but not the single-day divers ($p > 0.05$). The difference between the snorkellers and single-day divers may have reached significance with a larger sample.

The tear film bubble counts at baseline in this study are very similar to those in the previously reported studies in recreational divers.[4] This study, therefore, further confirms the low baseline median count and range that we can expect in the general diving population. The failure to demonstrate any significant change from baseline following swimming and snorkelling compared with diving, strengthens the case for a causal relationship between compressed air diving and increased tear film bubble counts.

Although dry chamber dives produced significant increases in bubble counts after only 15 minutes of exercise,[7] in the present study an exercise period of 30 minutes was chosen to provide a meaningful comparison with the Prince of Wales studies in compressed air divers.[4]

FIGURE 3
MEDIAN BUBBLE COUNTS AND INTERQUARTILE RANGES AT 24 HOURS FOR SWIMMERS, SNORKELLERS AND DIVERS[4]
baseline shows pooled data for median and interquartile ranges at time zero
*** significant difference from baseline and swimmers ($p < 0.02$)**
† significant difference from baseline, swimmers ($p < 0.0001$) and snorkellers ($p < 0.0001$)



The reason for the significantly lower bubble count at 12 hours in the swimmers remains unclear. It is conceivable that the wearing of goggles may have an effect on the tear film not seen with the half-face mask worn by snorkellers and divers. The snorkellers had the highest (non-significant) median count of 0.66 at 72 hours. While it is unlikely that this increase relates to gas accumulation from shallow breath-hold diving, as bubble numbers would be declining by 72 hours, it is possible that some increase may have occurred due to mask squeeze even though the dives were limited to three metres. It is more likely that both results represent the normal range and are due to random variation in small sample sizes.

Two people demonstrated unusually high tear film bubble counts on three occasions. One examination was performed by Investigator 1 (KB), the others by Investigator 2 (AD) and confirmed by a third person. The two highest single readings obtained were 6 and 4.6 bubbles per eye respectively. While no formal attempt was made to identify any factors that may be associated with high counts, we noted that these readings were on volunteers who reported lack of sleep and a high alcohol intake in the preceding 12 hours. These same two volunteers were the only persons to average a bubble count greater than three bubbles per eye. The association between high bubble counts and fatigue or high ethanol intake may merit further investigation.

In order for ocular tear film bubble counts to be clinically useful in the diagnosis of DCI, the number of bubbles must be greater for divers with decompression illness and they would need to persist long enough to be detected on presentation to the evaluating physician. As noted previously, this time to presentation is rarely less than eight hours and averages over 24 hours.[3] Mekjavic demonstrated persistence of ocular tear film bubbles following chamber dives, with peak bubble numbers for up to two days but declining on the third day.[9]

The Prince of Wales Hyperbaric Unit is currently assessing the tear film of divers presenting with symptoms of DCI, and early results suggest bubble numbers are related to decompression stress. This would confirm the previous research data in which ocular tear film bubble numbers were increased following chamber dives to PADI no-decompression limits at differing depths.[6] In addition, tear film bubble formation displayed a dose-related rise with increasing duration of dives to 70 feet of sea water. Morariu also demonstrated a significant increase in tear film bubble counts following exercise in a hyperbaric chamber, which would correlate with increasing nitrogen uptake.[7] In keeping with the view that ocular bubbles are being formed in the process of de-nitrogenation, Jaki et al showed that the observed increase in bubble numbers following compressed air breathing was not matched by a similar increase after breathing 100% oxygen via a hood.[8]

This study's results show little inter-operator variability, with the two principal investigators recording a median count of 0.33 bubbles per person. Inter-operator variability will assume some importance if reliable readings are to be obtained and used as the basis for the decision to transfer to a hyperbaric facility. It may be that a technique using photography or assessing bubble volume, as suggested by Morariu should be developed to standardise results.[10]

However, our consistent results are encouraging and would allow for remote clinical use, as most emergency departments possess a slit-lamp. It may also provide a convenient method of monitoring hyperbaric exposure for attendants working in hyperbaric chambers. Although we have reported both bubble counts per person and per eye, the significant results and trends between groups were only apparent using median bubble counts per eye, suggesting this may be the more sensitive method of data analysis.

The next step is to investigate patients presenting to hyperbaric units with symptoms of decompression illness and this is now underway at the unit in the Prince of Wales Hospital. It is our hope to clearly define the place, if any, of tear film bubble counts in the quantification of decompression risk following compressed air diving, the monitoring of individuals subject to frequent compression and, finally, in the diagnosis of decompression illness.

Conclusion

Swimming in sea water and shallow breath-hold diving do not lead to an increase in ocular tear film bubble numbers. Therefore, the significant rise in tear film bubble numbers seen in recreational divers using scuba equipment is most likely to be due to decompression stress and unrelated to the salt water environment.[4] We have also confirmed the likely normal variation in the diving population.

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Declaration

The authors declare they have no financial interest in any commercial product involved in this research and received no financial assistance for the conduct of this study.

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