Teaching Self-Assessment of Doppler Ultrasound for Bubble Grading in Divers: Learning Curve, Reliability, and Surveying Precision.

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Abstract

Background

Observing modern decompression protocols alone cannot fully prevent Diving Accidents especially in repetitive diving. Audio Doppler bubble measurements to estimate supersaturation are done in special professional settings only, being not available for the broad community of sports SCUBA divers. In case SCUBA divers without medical and ultrasound training could learn audio Doppler self-assessment for reliable bubble grading on a stable skill level and with an efficient single teaching intervention, this skill could add significantly to diving safety.

Methods

We taught audio Doppler self-assessment of the subclavian vein and cardiac precordial probe position to 41 divers in a 45-minute standardized training session. Assessment was made of 684 audio Doppler measurements by both the trained divers and a medical professional plus additional 2D-echocardiography as reference.

Results

All air dives were within normal sports diving limits and decompression bubbles were observable via echocardiography in 32.3% of all measurements. The specificity of audio bubble detection was 96.1% but the sensitivity was low for lower bubble grades, increasing to 25%, 35% and 67% for higher echo-detected bubble grades 3, 4 and 5. The number of attempts to achieve a reliable venous signal within 30 seconds was 13 at the subclavian position and 18 at the precordial position. More bubble positive measurements could be detected at the precordial position for both self and medical professional assessment. The performance level of the taught skill remained stable over six months without further practice.

Conclusion

Audio Doppler self-assessment can be learned by people without medical and ultrasound training and a reliable venous signal can be achieved after a comparably steep learning curve. However, accurate bubble grading is not possible using audio Doppler as only higher bubble grades can be detected. Nevertheless, this qualitative finding can be important in self-evaluating decompression stress and potentially help the diver to judge on measures for avoiding decompression accidents.

Contributions To The Literature:

- Decompression accidents in SCUBA divers due to individual factors can occur despite following nowadays wrist dive computer real-time dive protocols.
- Professional post-dive ultrasound assessment to detect the actual decompression stress as inert gas bubble load is not possible to implemented in medical lay people broad SCUBA diving community.

- Using modern teaching approaches for clinical skills, medical lay people can quickly learn Doppler self-assessment and reliably derive a relevant qualitative result on major post-dive bubbling for reasonable decision making on safety measures.

Background

During ascent in self-contained unterwater breathing apparatus (SCUBA) diving, inert gases like nitrogen can become supersaturated in tissues and blood. This results in micro- and macrobubbling and finally can lead to symptoms of decompression sickness. In order to avoid that, decompression tables and dive computers provide empiric safety margins on ascent time depending on depth and dive time. However, asymptomatic inert gas bubbles occur frequently following dives and there is a broad inter- and intraindividual variety in developing bubbles and decompression symptoms. In previous studies, a high amount of detectable bubbles in dives within normal sports diving limits was related to symptoms of decompression sickness in 2−11% and up to around 40% in decompression and mixed gas commercial diving [1, 2, 3].

Audio Doppler ultrasound measurements are an established [2−8], validated [9] and standardized [10] method of monitoring the post-dive bubble load. Despite semiautomatic bubble quantification has been published [1, 11] and realized (Azoth Systems France), it is still an exclusive skill of a medical or at least ultrasound professional and therefore not implemented in sports diving. Doppler monitoring of dives could contribute significantly to individual diving safety and the technical devices needed are of reasonable cost.

However, it is not known which effort is needed to train divers without medical or ultrasound expertise to allow them a reliable self-assessment with audio Doppler and how these results are correlated with results from an experienced sonographer and echocardiographic visual bubble detection as reference. Further, for efficiently implementing this skill in the broad sports diver community, the training must be a single intervention that guarantees a reliable and sustainable skill level.

The aims of the present study were to answer the following:

1. Can SCUBA divers as lay people reliably perform audio Doppler ultrasound for inert gas decompression bubble detection at subclavian and precordial position?
2. What learning curve is required to generate reliable and consistent readings of a venous signal?
3. Are the results of audio Doppler self-measurements able to reliably determine reference bubble grades measured by visual 4-chamber echocardiography?

Methods

We examined 41 scuba divers over a total of 342 dives and made 684 measurements (both before and after single and repetitive dives) with bubble self-recording via an 8 MHz audio Doppler ultrasound pencil probe at both subclavian and precordial (left parasternal) venous position after a single standardized, 45-

minute session of theoretical and practical training before the measurements. Starting the pretests of this study with a 4 MHz pencil probe since low-frequency Doppler examinations of divers are described for reliable signals, we recognized only minor challenges to detect a reliable venous signal in our mainly slim study population (average BMI 25) and both venous signal as well as bubble signals as High Intensity Transient Signals (HITS) were detected much better with an 8 MHz pencil probe, which was then chosen for all our Doppler recordings. All measurements were made in a mobile examination room directly at the dive site 30 minutes before and after any dive. After undressing, the divers were placed in the same beach-chair position. Audio Doppler self-measurements (DopFlow, Spead Doppler Systems Germany) were compared with those measurements made by an experienced examiner (ultrasound trained medical professional) immediately after. Without gap, 30 seconds of representative 4-chamber echocardiographic loops were recorded using the same GE Logic e (General Electrics Healthcare, Solingen) ultrasound machine with a curved array multi-frequency probe and angulation through the heart. All loops were later assessed by two independent, experienced and blinded sonographers (advanced ultrasound diploma). Detectable bubbling was recorded and graded using the Spencer Scale for audio Doppler assessments and the Eftedal-Brubakk (EB) scale for visual echocardiographic assessments, table 1:

Table 1: Spencer and Eftedal-Brubakk scales for audio Doppler and 2D Echo bubble grading. Both are categorized and non-linear scales and Spencer Grade 4 includes an unlimited amount of bubbles equivalent to Eftedal-Brubakk Grade 5 as well.

The audio recordings were made in real dive site environment without any surrounding noise reduction, the mobile examination room just provided shelter against sun and rain. The measurements were conducted over two weekends of scientific SCUBA training in a German freshwater lake and two consecutive weeks of a diving expedition in sea water of high salinity in Croatia. There were 4 weeks of no diving between all three measurement intervals.

Standardized training schedule:

1. Explanation of blood flow and established venous bubble detection sites, theoretical presentation – 10 minutes
2. Practical audiovisual demonstration of venous and arterial signals and Doppler angulation at both detection sites in human – 10 minutes
3. Explanation of the Spencer and Eftedal-Brubakk scales as well as audiovisual simulation of each grade of this scale – 5 minutes
4. Guided self-examination at both subclavian and precordial detection site until a stable venous signal was established, using a modified Peyton's Four Step Approach[12] for complex skill teaching – 20 minutes, including observation and participation of each others' guided attempts of establishing individual anatomical ultrasound windows and interpreting simulated bubble grades.

After 6 months without further practice or training, the divers were assessed again for their retention skill of Audio Doppler self-assessment.

All divers signed informed consent forms and the university ethics committee of the Bergakademie Technical University Freiberg approved the study plan. Data acquisition, storage and processing was done after anonymization and following current Ethical Standards in Sport and Exercise Science Research. Depending on direct measurement results before and after any dive, the divers received safety information on surface interval and fluid intake. The study was supported by GTÜM e.V. (German Society for Diving and Hyperbaric Medicine) and General Electric's ultrasound division in Germany regarding material provisions.

Results

The dives covered a broad spectrum of diving profiles and diving times were 4–83 minutes long with an average of 44 minutes; depth was 3–40 meters with a mean of 22 meters; all dives were made on compressed air.

From a total of 684 reference echocardiographic measurements, 221 measurements showed bubbles in the right atrium and ventricle and also in the inferior vena cava.

Bubble distribution for all dives is displayed in Fig. 1:

The sensitivity of audio bubble detection using an 8 MHz Doppler pencil probe is displayed in Fig. 2:

The specificity of audio Doppler measurements over all bubble grades was 96.1%.

False positive results (audio Doppler self-detection of bubbles but no visible bubbles in reference echocardiography) were seen in a total of 11 precordial measurements and a total of 8 subclavian measurements.

Learning curves for audio Doppler Measurements are displayed in Figs. 3 and 4:

Detection of bubbles by audio Doppler self-assessment compared to medical examiner assessment at the different locations is shown in Fig. 5:

After 6 months without any Doppler self-assessment, the divers were observed again on skill retention (Fig. 6):

Discussion

Considering our study divers following standard sports diving profiles not exceeding moderate exhaustion, no omitted safety stops and almost no decompression stops required, the observed percentage of divers with detectable bubbles in reference echocardiography was high and comparable to similar research [13]. Even before repetitive dives on the same day and despite washout during the surface interval, bubbles were still detected on a regular basis but of a lower bubble grade when

reentering the water compared to after ascending from the previous dive. However, apart from fatigue, no symptoms were recorded that could be related to a decompression incident.

Learning curve for audio Doppler self-assessment

We found that audio Doppler self-assessment can be learned to detect a reliable venous signal in the subclavian position within 1 minute after 2 attempts and within 30 seconds after 13 attempts. The self-assessment at the precordial position seemed to be more difficult and needed at least 5 attempts to detect a reliable blood flow signal within 1 minute and at least 18 attempts to manage below 30 seconds. This was mainly due to the prominent cardiac signals at this position. When self-assessment was done after the dives, more training of 2–4 attempts was needed to detect the same reliable signal within the mentioned time frame, probably due to the effects of lifting heavy diving gear while getting undressed and therefore limited fine motor skills at this moment. A limitation to generalize our results might be that we used an 8 MHz probe instead of the more commonly used 4 MHz probe for such assessments. This might influence results especially in heavier divers. Further, two tasks were learned within the same learning curve: reliably finding of a venous audio Doppler signal and recognizing bubble signals within the venous signal. This could potentially lead to missing of more bubble signals at the beginning of the learning curve and compared to the end, an effect that could lead to better results than described here. However, considering that basic skills of anesthesia and acute medicine require 50–60 trials to achieve an 80–90% success rate [14] and are a bit more complex than the skill taught here, the number of attempts needed to reliably hear and interpret a venous Doppler signal is comparably low. The same learning curve as in our study was found in beginners when performing a simple virtual surgical task [15].

Measurement results

Measurements from the precordial position showed around one-third higher occurrences of detectable bubbles in both audio self-detection and experienced examiner audio-detection, probably due to the precordial position also including blood flow from the lower part of the body with potentially higher inert gas flow due to fin swimming. This must not necessarily be contrary to previous findings of better bubble detection at the subclavian site [9], since it is easier to establish a reliable subclavian Doppler recording as also seen in our study. Further, in the precordial position, we have seen a higher amount of especially higher bubble grades. In the event that bubbles were detected by audio Doppler, the bubble grade was typically lower compared to the echocardiographic exam despite no significant time lag. The average difference in our study was 2 bubble grades lower in audio Doppler detection. Considering the number of measurements in our study, this difference can be relevant in the prediction of decompression outcomes [16]. The fact that the highest bubble grade 4 in the audio Spencer scale is not really comparable to the more differentiated high bubble grades 4 and 5 in the Eftedal-Brubakk echo scale does not create any shortcomings in our results since our divers were not able to grade correctly. In general, a reliable bubble grading using audio Doppler assessment was not possible for lay-people and for both, lay-people and

experienced ultrasonographers, underestimated compared to echocardiographic results. Especially lacking noise reduction might have influenced audio Doppler grading, but this is an important aspect of the usability of this method in dive site reality. In summary, we conclude that divers are able to learn audio Doppler self-assessment with a standardized training and a reasonable number of trials, but cannot determine their bubble grade and decompression risk reliably. However, in being able to recognize bubbling at all and especially when they have high bubble grades, they are able to generate relevant qualitative information on major bubbling for potential decision making, e.g. on safer surface intervals, in order to reduce decompression stress. Especially when they plan to reenter the water, audio-detectable bubbling from the previous dive can lead to advisable stretching of surface intervals. Specificity in general and sensitivity for higher bubble grades proved to be acceptably high to provide qualitative information on decompression stress in order to indicate measures for avoiding decompression incidents.

Skill Retention

After a gap of six months without any training, the previously achieved skill level was reliably preserved: a venous Doppler signal of good quality was self-detected within the same time compared to the end of learning curve after initial teaching and individual anatomical ultrasound windows were remembered. This long-term skill retention of a similar condensed 45-minute standardized training has already been shown in a study on teaching central line placement [17]. Hence, the training proved to be suitable enough to generate a stable practical skill level over time.

Conclusion

SCUBA divers without medical or ultrasound expertise are able to learn audio Doppler self-assessment and generate qualitative results. This skill can be reliably learned within 45minutes of focused standardized teaching and very limited practical training to allow stable results even after six months without practice. Therefore, qualitative audio Doppler self-detection could be further evaluated for inclusion in advanced SCUBA diver education.

Abbreviations

SCUBA: Self Contained Underwater Breathing Apparatus

2D: two dimensional

MHz: Megahertz (frequency unit)

HITS: High Intensity Transient Signals

EB-scale: Eftedal-Brubakk scale for ultrasound bubble grading

BG: Bubble Grade

BMI: Body Mass Index

Declarations

• Ethics approval and consent to participate

Ethical standards have been followed and written informed consent for participation and publication has been received by every participant. Ethical approval has been received by the university Ethics committee of TU Bergakademie Freiberg.

• Consent for publication

Written informed consent for publication has been received by both participants and authors

• Availability of data and materials

The source data is available on request.

• Competing interests

All authors state that there is no conflict of interest.

• Funding

• Authors' contributions

All authors state that the manuscript or data of it have not been published or submitted for publication elsewhere, every author contributed to study plan and or data acquisition and or manuscript writing.

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Table

Due to technical limitations, table 1 is only available as a download in the Supplemental Files section.