Vascular Ultrasonography Performed by Special Operations Forces Combat Medics

A Feasibility Study

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ABSTRACT

Introduction: Two-dimensional venous ultrasound may be a viable substitute for standard Doppler ultrasonography in monitoring and evaluating decompression stress. Preliminary data possibly show that ultrasound recordings of the inferior vena cava (IVC) and popliteal vein (PV) can indicate elevated decompression stress. This study aims to evaluate the feasibility of a microteaching program for training combat medics to conduct ultrasound measurements on the IVC and PV for self-monitoring of decompression stress on the waterside. **Methods:** A vascular surgeon provided a microteaching course to combat medics of the Netherlands Armed Forces. Two Lumify™ (Philips Medical Systems International B.V., Best, The Netherlands) handheld ultrasound devices were used, connected to a Samsung Galaxy Tab A™ (generation 10.5, Samsung, Suwon, South-Korea) or a Panasonic FZ-A2™ tablet (Panasonic, Kadoma, Japan). The IVC was examined using the C5-2 abdominal probe, and the PV was assessed using the L12-4 linear probe. Combat medics performed and recorded measurements observed by a vascular surgeon on their randomly assigned partners after 2 minutes of practice. Three outcomes were measured in this study: (1) observer assessment of the performance, (2) self-perceived procedure experience, and (3) video recording quality scored by a vascular surgeon and researcher. **Results:** A total of 25 Special Operations Forces combat medics took part in this study. All but one participant recorded the correct vessels. Recordings of the IVC and PV were achieved in a mean time of 50 (SD 26) seconds and 1 minute and 26 seconds (SD 55s), respectively. The participants didn't report a difference in difficulty of obtaining a clear image of either vessel. Both assessors assigned median and modal scores of at least 4 out of 5 for all image quality categories. **Conclusion:** This microteaching program is an effective training technique for military medical personnel with little to no ultrasound experience to obtain ultrasound images of the IVC and PV. Our findings suggest that combat medics could perform vascular ultrasound measurements, which could be used to screen for high decompression stress in the future.

KEYWORDS: *ultrasound; special operations; decompression stress; diving; microteaching*

Introduction

Descent under the water surface while diving exposes the body to external pressure. The increased pressure causes inert gases to dissolve and accumulate within tissue. When ascending to the surface, the external pressure reduces, which causes dissolved gases to emerge from solution. If depressurization happens in an unordered way, for example, during a rapid ascent, the gases can precipitate and start to accumulate, forming gas bubbles.[1] The amount of bubbles entering the bloodstream correlates to the amount of bubbles formed within the tissue, which can cause symptoms of decompression illness. Therefore, the amount of venous gas emboli can be used as a marker for the amount of decompression stress experienced by the diver.

For decades, Doppler ultrasonography of the heart and subclavian veins has been the standard to determine the post-dive bubble-load, resulting in diving tables specifying or recommending maximum dive times at certain depths.[2,3] A disadvantage of this procedure is the requirement of highly experienced professionals and a controlled, noise-free environment. Two-dimensional venous ultrasound could be a promising alternative

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to the standard Doppler ultrasonography measurements. Obtaining and scoring two-dimensional ultrasound recordings is easier to master due to its visual nature.[4] Recent developments, such as ultrasound probe connectivity to smartphones and tablets, have made ultrasound devices portable and therefore more usable in operational settings outside of hospitals, such as on the waterside. Given the strategic importance of targeting critical infrastructure in underwater operations, exploring innovative approaches to enhance operational readiness could significantly strengthen the competitive advantage of maritime special operations forces (SOF) units.

Submitted data obtained by our study group suggests that bubble scores of the inferior vena cava (IVC) and popliteal vein (PV) show a significant correlation with the bubble-load of the diver, as determined by Doppler analysis. Thus, we hypothesized that with the accumulation of additional scientific evidence, vascular ultrasonography of these vessels may become an alternative method for detection of elevated decompression stress levels in the future. This could allow military (SOF) divers to become less dependent on scarce Doppler analysis experts and enhance operational readiness.

The first step in evaluating the viability of self-monitoring of decompression stress, and possibly on-site titration of dive profiles, performed by dive teams on the waterside involves assessing the capacity of military combat medics to acquire proficiency in generating high-quality vascular ultrasound recordings.

The primary aim of this study was to assess the feasibility of training combat medics to perform ultrasound measurements of the IVC and the PV with the use of a microteaching program. The secondary aim was to evaluate the quality of two-dimensional recordings made by combat medics.

Methods

Participants

The group consisted of 26 SOF combat medics, some of whom were also SOF divers. Five participants were certified NATO Special Operations Combat Medics (NSOCMs). An NSOCM is a servicemember who provides TCCC and advanced tactical medical support directly to SOF units. SOF medics are SOF Operators, designated combatants, as defined by the Geneva Conventions, with specific medical education and training.

Microteaching

A microteaching course was given to combat medics of the Netherlands Armed Forces by two vascular surgeons. The course consisted of a theoretical part lasting 10 minutes, which included the basic principles and technique of ultrasonography, supported by a PowerPoint presentation. Afterwards, a 5-minute hands-on demonstration was given on how to achieve recordings of the IVC and PV.

Materials

Two Lumify™ (Philips Medical Systems International B.V., Best, The Netherlands) handheld ultrasound devices were used, connected to a Samsung Galaxy Tab A™ (generation 10.5, Samsung, Suwon, South-Korea) or a Panasonic FZ-A2™ tablet (Panasonic, Kadoma, Japan). The IVC was examined using the C5-2 abdominal probe, and the PV was assessed using the L12-4 linear probe.

Procedure

Two test stations were set up; each attended by a vascular surgeon and an assistant. The participants entered the test stations in randomly assigned buddy pairs and received instructions regarding the study protocol. The aforementioned pairs performed the measurements on each other.

First, the performing participant was allowed 2 minutes of practice time with the abdominal ultrasound probe on their buddy, receiving feedback from the instructor. The participant was then asked to remove the probe from the patient and start the official procedure. The buddy was positioned on the examination bench in the supine position. The performer was allowed a maximum of 2 minutes to obtain a 5-second video of the IVC. Subsequently, the patient stood up, and the performer was again allowed a maximum of 2 minutes to obtain a 5-second video of the PV. The performers were tasked with identifying the correct vessel themselves and did not receive any instructions regarding identification during the procedure. Once the performers stated that they felt confident that they had identified the correct vessel, they recorded and saved the 5-second video.

Scoring

Three outcomes were measured in this study: (1) observer assessment of the performance, (2) self-perceived procedure experience (supplemental Figure 1), and (3) video recording quality. Performers were assessed by a vascular surgeon on their preparation of the procedure, knowledge of materials and instruments, time and motion, the progression of the procedure and forward planning, their ability to adapt to individual anatomical circumstances, and their overall performance (Supplemental Table 1; adapted from the Objective Structured Assessment of Technical Skills [OSATS]).[5]

Participants were asked to fill in a scoring sheet about their self-perceived experience, visibility of the vessels, and opinion on performing vascular ultrasound on the waterside. Scoring options ranged from 1 (strongly disagree/very challenging) to 5 (strongly agree/very easy) (Appendix 1).

Recording quality was scored by a blinded vascular surgeon and another ultrasound specialist. An important note and subject for future research is that there is not currently a gold standard for diagnosing high decompression stress using ultrasonography in the field. We scored the videos on recording clarity, gain, brightness, anatomy, and vessel characteristics on a scoring sheet (Table 1). The full videos were assessed instead of stills to gain a better indication of the sonographer's performance.

Statistical Analysis

All analyses were performed using IBM SPSS Statistics for Mac, version 27 (IBM Corp., Armonk, NY). The observer and performer scores distribution and recording quality scores were generated. Normality was assessed using the Shapiro-Wilk test. A Mann-Whitney *U* test was performed to assess differences in recording times and scores between NSOCMs and other participants.

Results

Performance Assesment

One participant was excluded due to overqualification, as he was a registered nurse. Except for one participant who

TABLE 1 *Vascular Ultrasound Assessment Scoring System Used in This Study*

Criteria	Score				
	1	2	3	4	5
Recording clarity	Recording is not clear – no structures can be distinguished	Recording is slightly clear – large structures/ different tissue can be distinguished	Recording is moderately clear – small structures can be distinguished	Recording is sufficiently clear – relevant structures can be distinguished	Recording is very clear – high quality
Gain	Recording is distorted by gain	Recording is slightly distorted by gain	Recording is not distorted, but there is too much gain present	Recording is not distorted by gain and mostly clear	Recording is not distorted by gain and fully clear
Brightness	Recording is distorted by level of brightness	Recording is slightly distorted by level of brightness	Recording is not distorted, but it is too light or dark	Recording is not distorted by brightness and mostly clear	Recording is not distorted by brightness and fully clear
Anatomy	Vessel of interest is not visible	Vessel of interest is barely visible	Vessel of interest is visible	Vessel of interest is visible in full sagittal plane	Vessel of interest is visible in full sagittal plane and centered in the recording
Vessel characteristic	Proximal, middle, and distal diameter not equal	Proximal, middle, and distal diameter equal			

identified the aorta instead of the IVC, all participants managed to identify the correct vessels. The recordings of the IVC were achieved in an average of 50 (SD 26) seconds, all of which were taken within the allotted 2 minutes. Recordings of the PV were taken at an average of 1 minute and 26 seconds (SD 55s), with five performers exceeding the 2-minute mark. NSOCM-qualified participants were not significantly faster (P>.05). The total score for each category yielded a median value of 3 out of 5, with interquartile ranges spanning from 3 to 3 across all categories. There were no significant differences observed between participants who had completed the NSOCM course and those who had not (P>.05 for all questions in the questionnaire). See supplemental Figure 2 for more details.

Questionnaire

Seven participants reported having no prior experience with ultrasound procedures. Thirteen had some experience, including obtaining femoral artery access during resuscitative endovascular balloon occlusion of the aorta (REBOA) training, and five participants had taken part in extensive ultrasound training in the NSOCM course. No significant differences between these groups were found (P>.05).

The participants scored the preparation of the Lumify as easy and did not find it hard to obtain a clear image of either vessel. Furthermore, they did not find it difficult to distinguish between the vein and the artery. The reported median score on the participants' level of confidence using ultrasound on the waterside was neutral, with numerous participants reporting a wish for extra practical training and anatomical education. All except one participant, who had no diving experience, reported that they would feel confident using ultrasound recordings to determine decompression stress on their buddies if it was considered the gold standard.

Image Quality

The interobserver agreement exhibited limited consistency in evaluations related to clarity, gain, brightness, and anatomy. Assessments of vessel characteristics demonstrated a moderate level of agreement. Despite the observed disparities in agreement, both assessors assigned median and modal scores of at least 4 for all categories. Notably, the evaluations achieved a maximum score for vessel characteristics, indicated by both the median and mode.

Discussion

This study shows that this microteaching training is an effective way to train military medical personnel with no ultrasound experience in obtaining ultrasound images of the IVC and PV. This first step toward on-site dive profile titration suggests that combat medics can perform vascular imaging procedures to obtain usable high-quality images.

Obtaining recordings took significantly longer for the PV than the IVC. This was an unexpected finding, as we assumed that the PV would be easier to identify compared to the IVC. The population of military divers participating in this study, however, were all well-trained individuals with high physical fitness levels. Participants had a low amount of body fat making identification of the IVC easier. Furthermore, some participants showed signs of leg muscle hypertrophy along with prominent collateral veins around the PV presenting as spiderwebs on the ultrasound recordings, making it more difficult to identify the correct vessel.

Although a large amount of vascular gas emboli on Doppler recordings has been shown to correlate with higher decompression stress, further research is required to develop scoring systems to measure the severity decompression stress based on vascular ultrasound recordings.[6,7] This feasibility study represents the first necessary step to proceed to a study assessing the correlation between bubble observations in the IVC and PV and high decompression stress and risk of decompression illness.

Despite expressing confidence in their ultrasound recordings, the majority of participants expressed a desire for additional training in both the use of ultrasound devices and understanding of anatomy. A structured training system would improve the medics' ultrasound performance and could also explore possible applications of simultaneous telemedicine, allowing for consultation with physicians (including dive medicine physicians) located elsewhere. Further research should also be performed to determine the usability of specific ultrasound devices in maritime settings, due to its specific requirements, such as the study by Karimpour et al.[7] To determine whether images obtained using handheld ultrasound devices can be used for diagnosis of decompression stress, future research should also focus on the possible difference in image quality between those obtained by handheld ultrasound devices as compared to standard ultrasound machines.[7,8] Future studies should evaluate how performing ultrasound procedures in outdoor settings with external distracting factors, such as on the waterside, affects the quality of recordings.

The prevailing conditions in maritime combat zones, including the Red Sea and the Somali coast, underscore the significance of military operations and the critical need for ongoing advancements in technical and medical domains. Additionally, the 2022 sabotage incident involving the Nord Stream Pipeline highlights the relevance of underwater warfare. Increasing medical equipment availability and applicability for skilled end users, the operators at sea, facilitates earlier identification of hazardous physical conditions, allowing for earlier medical screening to prevent medical emergencies.

Limitations

One study limitation is the use of a non-validated scale, possibly prone to subjectivity, to assess ultrasound recording quality. Despite this, we believe our results suggest that the recordings were generally of good quality. Another limitation of this study pertains to the homogeneity of the participant population, consisting exclusively of physically fit, military personnel with low body fat. Consequently, the generalizability of the findings to civilian demographics is limited.

Conclusion

This microteaching program is an effective training technique for military non-medical personnel with little to no ultrasound experience to obtain usable ultrasound images of the IVC and PV. This suggests that combat medics could perform vascular ultrasound measurements on the waterside, which could be used to screen for high decompression stress in the future, if a validated scoring system was to be developed, enhancing operational readiness.

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Author Contributions

BT designed this research, collected, and analyzed the data and drafted the original manuscript. JvdV designed this research, collected the data, reviewed, and edited the manuscript. BBB led the experiment, reviewed, and edited the manuscript. CM assisted the experiment, collected data, and reviewed and edited the manuscript. PJvO designed this research reviewed and edited the manuscript. RH designed this research, led the experiment, and reviewed and edited the manuscript. All authors read and approved the final manuscript.

Disclosures

The authors have nothing to disclose.

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SUPPLEMENTAL FIGURE 1 *Participant performance questionnaire score.*

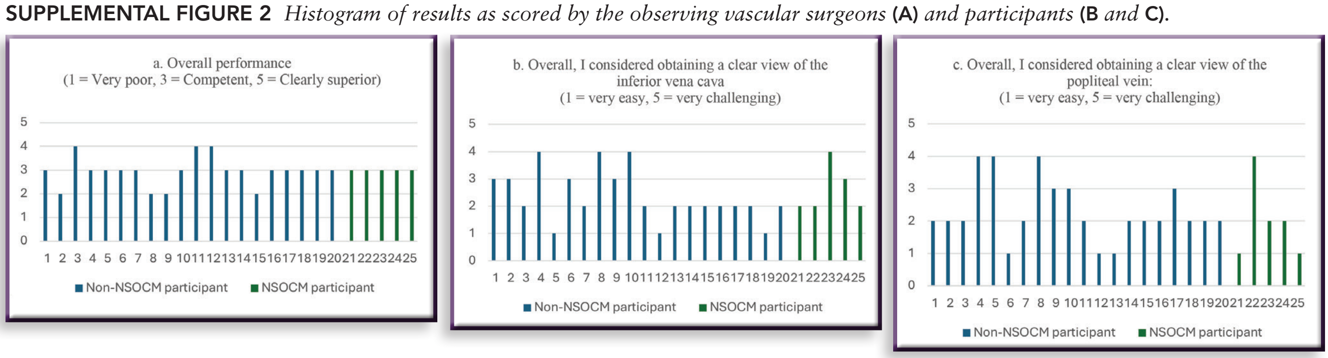
Participant Performance Questionnaire Score
Vascular ultrasound performance
Participant number: ____________________

1. Do you already have experience with ultrasound? If yes, please specify what and how?

____
____
____
____
____

2. Overall, I considered preparing the Philips Lumify probe and software for imaging to be:
   a. Very easy
   b. Easy
   c. Neutral
   d. Challenging
   e. Very challenging
3. Overall, I considered obtaining a clear view of the inferior vena cava:
   a. Very easy
   b. Easy
   c. Neutral
   d. Challenging
   e. Very challenging
4. Overall, I considered obtaining a clear view of the popliteal vein:
   a. Very easy
   b. Easy
   c. Neutral
   d. Challenging
   e. Very challenging
5. It was challenging to distinguish the vein from the artery:
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree
6. I feel confident using ultrasound vascular imaging on the waterside:
   a. Strongly disagree
   b. Disagree
   c. Neutral
   d. Agree
   e. Strongly agree
7. Would you perform ultrasound vascular imaging on your dive buddy on the waterside if it was considered the best tool to determine decompression stress? Why (not)?

SUPPLEMENTAL FIGURE 2 *Histogram of results as scored by the observing vascular surgeons* **(A)** *and participants* **(B** *and* **C)**.



SUPPLEMENTAL TABLE 1 *Objective Structured Assessment of Technical Skills (OSATS) Adjusted for Ultrasound Procedure*

General					
Number participant: Total time procedure (min:s):					
Difficulty of case					
How technically difficult was this case based on the patient's anatomy and disease process?					
0	1	2	3	4	5
Unable to assess	Minimally difficult		Moderately difficult		Very difficult
Please rate the participant's performance throughout the procedure					
Preparing for ultrasound procedure					
0	1	2	3	4	5
Did not perform this step	Demonstrates little or no knowledge of elements required to prepare the procedure	Demonstrates knowledge of most elements required and/or prepares the procedure following direct instructions	Demonstrates all elements required to prepare the procedure and/or prepares the procedure with some direct instruction	Prepares for the procedure using own judgment with only minimal adjustments by supervisor	Independently prepares for the procedure
Time and motion					
0	1	2	3	4	5
Unable to assess	Many unnecessary moves		Efficient time and motion, but some unnecessary moves		Economy of movement and maximum efficiency
Knowledge of materials and instruments					
0	1	2	3	4	5
Unable to assess	Frequently asked for the wrong materials or used an inappropriate instrument		Knew the names of most materials and used appropriate instrument for the task		Obviously familiar with the materials required and their names
Flow of procedure and forward planning					
0	1	2	3	4	5
Unable to assess	Frequently stopped imaging and needed to discuss next move		Demonstrated ability for forward planning with steady progression of imaging procedure		Obviously planned course of procedure with effortless flow from one move to the next
Ability to adapt to individual pathological circumstances					
0	1	2	3	4	5
Unable to assess	Demonstrates knowledge of normal anatomy/physiology	Demonstrates knowledge of abnormal pathologies	Adjusts plan and procedure with direct guidance and instruction	Adjusts plan and procedure with minimal guidance and instruction	Can independently adjust plan and procedure with awareness of how it will affect the overall course of the procedure
Overall performance					
0	1	2	3	4	5
Unable to assess	Very poor		Competent		Clearly superior
Correct vessel identified					
0	1				
No	Yes				

Note: Adapted from the OSATS scoring system for ultrasound procedures as used in this study.

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