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Deep versus shallow decompression stops: illustration of different decompression strategies used in technical diving

Alessandro Marroni¹ , Massimo Pieri¹ , Jean-Pierre Imbert^{1, 2}, Riccardo Pelliccia¹ , Mario Arena³,
Laura Marroni¹, Peter Germonpré^{1, 4, 5} , Danilo Cialoni⁶ , Costantino Balestra^{1, 5, 7} 

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ABSTRACT

Background: Despite evolution in decompression algorithms, decompression illness is still an issue. Reducing vascular gas emboli (VGE) production by varying decompression procedures is very common among divers. Several methods have been tried, either mechanical, cardiovascular, desaturation-aimed or biochemical, with encouraging results. In this study, we tested two different decompression methods: one called DEEP, where the decompression starts deeper, the other one SHALLOW, where shallower stops were planned, for the same dive and decompression time.

Material and methods: In total, 18 healthy, non-smoking divers participated [1 female, 17 males; mean age 44.94 ± 5.74 years; body mass index (BMI) 27.3 ± 5.9 kg/m²]. Each diver performed two standardized Open Circuit trimix (21/35) dives, decompression mix EAN50. The deep profile used stops at 21, 18, 15, 12, 9, 6, and 3 meters. The shallow profile used stops at 9, 6, 3, with the same total bottom and decompression times for both groups. All dives were done in a pool (Y-40, Montegrotto, Italy) at a depth of 40 m for 40 min of bottom time and 80 minutes of total runtime. VGE counts were recorded every 15 min from 0 (0–5 min) to 90 min by echocardiography.

Results: Vascular gas emboli were significantly reduced after the deep stops decompression procedure (DEEP: 6.7 ± 7.2 VGE per heartbeat vs. shallow: 10.7 ± 11.6 VGE per heartbeat, $p = 0.0006$). Three DCS cases were recorded after the “shallow” stop procedure ($p = 0.24$ Fisher’s exact test).

Conclusions: There are significant differences between the two tested decompression procedures. The DEEP procedure resulted in a lower production of bubbles compared to the SHALLOW procedure.

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Keywords: decompression disease, adverse effects, VGE, decompression procedures, venous gas emboli, human

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INTRODUCTION

Although self-contained underwater breathing apparatus (SCUBA) diving procedures have become safer over time, decompression sickness (DCS) remains a risk that can be life-threatening. It is commonly known that SCUBA diving can induce vascular gas emboli (VGE) during and following ascent, due to ambient pressure drop [1]. The multiple manifestations of DCS suggest that several bubble scenarios are involved in its development. However, the exact pathophysiological mechanisms linking VGE to DCS are complex and still unclear. Nonetheless, the management of ascent profile may change the development of free gas phase in tissues, the differential supersaturation in different compartments [2, 3], and possibly affect the outcome of each dive [4].

The design of decompression procedures is based on various decompression techniques [ascent rates, O₂ level, inert gas switch] and the strategy. The decompression strategy corresponds to the way the different bubble scenarios are activated during the ascent (arterial bubbles, tissue bubbles, combined arterial and tissue bubbles, etc.), and the decompression techniques are used to control these scenarios. The decompression techniques and the strategy define what can be intended as the safest ascent procedure to mitigate the stress associated with a given profile.

The role of these different ascent procedures (or 'strategies') in preventing DCS remains to be documented and fully understood. It is, however, generally accepted that the absence of detectable VGE post-dive is correlated with a low probability of DCS [5, 6].

In this study, we investigated two decompression profiles that reflect common practice in the technical diving community, characterized by dive depth, bottom time, gas protocol, stop depth distribution, and total decompression time. This study aimed to compare VGE generated on the same subject after two ascents of the same duration but with a different distribution of the decompression stop time and depth.

The first practice refers to the use of deeper decompression stops than would normally be calculated by the Buhlmann ZHL16 algorithm [7, 8] using gradient factors (GF). Such decompression profiles are provided by most dive computers or desktop applications such as DecoPlanner.

The second practice is related to the use of decompression tables, such as the US Navy 2016 or Buhlmann ZHL16 tables, that provide a much shallower first stop.

The depth of the first stop influences the decompression profile. Deep stops imply a significant decompression time spent at greater depths. Shallower stops require a longer time to be spent at stops close to the surface.

MATERIAL AND METHODS

POPULATION

After explaining potential risks and obtaining informed consent, 18 healthy, non-smoking experienced divers [1 female and 17 males; mean age 44.94 ± 5.74 years; body mass index (BMI) 27.3 ± 5.9 kg/m²] were enrolled in the study.

All recruited divers held 'Diving Instructor' certification and used the same dive equipment and Global Underwater Explorers (GUE) configuration.

All participants held a valid medical clearance for diving at the time of the study. None of them reported a history of cardiovascular pathology, patent foramen ovale (PFO), or were taking any cardio- or vasoactive medications, nor had a history of recent DCS. They were instructed to abstain from any physical activity and diving for 48 h prior to the test dives [9]. Caffeinated beverages and alcohol were also prohibited for six hours before the test.

All experimental procedures were conducted in accordance with the Declaration of Helsinki [10], and were approved by the Ethical Committee of Università degli Studi di Milano, Italy (Aut. n° 37/17 52).

STUDY DESIGN

Dive exposures

This is a cross-over prospective study. Each diver performed, in random order, two standardized dives with deep decompression stops and shallow decompression stops, making each diver his own control. Each diver performed two dives (one 'SHALLOW' and one 'DEEP') at a minimum interval of 3 to 30 days apart (29.15 ± 21.72 days).

Dive and decompression plans

The experimental dive and decompression plan was defined as follows:

- A bottom depth of 40 m in freshwater (the maximum depth of the diving pool) and a 40-minute bottom time, including descent at 20 meters per minute.
- The gas protocol included breathing trimix 21/35 (21% O₂, 35% He, balance N₂) during the bottom and initial phase of decompression, and nitrox 50 (50% O₂; 50% N₂) from 21 meters to the surface as a decompression gas mixture.
- The ascent to the first stop was performed in two or three minutes depending on the first stop's depth.
- All divers used an open-circuit breathing apparatus.

DECOMPRESSION PROFILES

To define the decompression time, we generated a decompression table using the software Deco Planner

V3.1.4, using the Buhlmann ZH-L16 B model, and GF 20/85 ($GF_{LO} = 20\%$ and $GF_{HI} = 85\%$). These settings are the standard recommendations by GUE, the subjects' dive training organization, with an alleged reported DCS incidence of approximately 2 cases per 1,000 dives. For such a dive exposure and gas protocol, the total decompression stop time calculated by the Deco Planner software is 38 minutes. From this decompression time, we generated two different decompression profiles.

Profile 1 – 'SHALLOW' – followed the original Buhlmann ZH-L16 B model, and favored more shallow stop depths. This profile roughly corresponds to the calculation of DecoPlanner using GF 100/75 and presents a first stop at 9 m. To reflect current practice in this technical diving community, the time spent at 6 m and 3 m was inverted, with 2/3 of the total time spent at 6 meters and 1/3 at 3 meters instead of the opposite. Technical divers commonly use this technique because it provides easier control of the stop depth, helps avoid the discomfort caused by the waves, and optimizes the inhaled partial pressure of O_2 (ppO_2). The resulting decompression stops are: 9 m – 5 min; 6 m – 22 min; 3 m – 11 min.

Profile 2 – 'DEEP' – roughly corresponds to the calculation of DecoPlanner using GF 30/80 and sets the first stop at 21 m. The stops times were then distributed to obtain roughly 1/3 of the total decompression time spent between 21 m and 9 m, and the remaining 2/3 between 6 m and 3 m stops. This decompression technique is taught to technical divers as a way to increase the time spent on Nitrox 50 at the 21 and 18 m stop with the objective to benefit from the high ppO_2 (1.55 bar at 21 m). Similarly, we implemented an inversion of the decompression time between 6 and 3 meters, with 2/3 of the total time spent at the 6 m stop and 1/3 at the 3 m stop instead of the opposite. The resulting decompression stops are: 21 m – 4 min; 18 m – 2 min; 15 m – 2 min; 12 m – 2 min; 9 m – 4 min; 6 m – 16 min; 3 m – 8 min.

The two actual profiles are presented in the Table 1 and Figure 1.

Dive depth control

The divers conducted their dives with a dive computer set to GAUGE mode to record the actual dive profile performed. The computer's sampling rate is fixed at 10 seconds and cannot be modified. The downloaded dive profiles were uploaded to the Divers Alert Network (DAN) Diver Safety Guardian web portal, where they were recalculated using the Buhlmann ZH-L16 C – DAN Adapted Decompression Model. The recalculated value is referred to as the DAN Surface Supersaturation Gradient (DSSG) [11].

BUBBLE ANALYSIS

It is commonly accepted that research projects can use VGE data as a surrogate endpoint for decompression stress [5, 12]. According to current recommendations, cardiac echography is the gold standard for VGE detection [13]. During field studies, bubbles are usually detected in the right atrium and graded according to different systems. In this study, during an apical 4-chamber view, echocardiographic VGE signals over the 1-minute recording were evaluated by frame-based bubble counting as described by Germonpré et al. [14].

In short, using a 2D echocardiography technique (MyLab Five, Esaote SPA, Genoa, Italy), measurements were taken every 15 minutes until 90 minutes post-surfacing at rest (lying supine) and following two deep knee bends. In total, 7 videos of 15 cardiac cycles were recorded for each dive within 5 minutes after surfacing and then at 15, 30, 45, 60, 75, and 90 minutes post-dive. At a later stage, these recordings were reviewed to analyze 10 consecutive frames in end-diastolic/protosystolic position and perform a formal bubble counting procedure. Then, the VGE peak counts per heartbeat were averaged over these 10 frames, and the resulting number was rounded to the closest digit and kept as the final result. The counting was performed independently twice by two trained scientists acquainted with the method used (CB, MP). The numbers of VGE considered for calculation were those that reached consensus.

Table 1. The two decompression schedules for 40 min at 40 m

	T21/35	N50	N50	N50	N50	N50	N50	N50	GF
Stop	ATFS [min]	21 m	18 m	15 m	12 m	9 m	6 m	3 m	–
DEEP	2	4	2	2	2	4	16	8	30/80
SHALLOW	3	–	–	–	–	5	22	10	100/75
ppO_2 [bar]	1.05	1.55	1.40	1.25	1.10	0.95	0.80	0.65	–

ATFS – ascent time to first stop; GF – gradient factors; N50 – nitrox 50; ppO_2 – pressure of oxygen; T21/35 – trimix

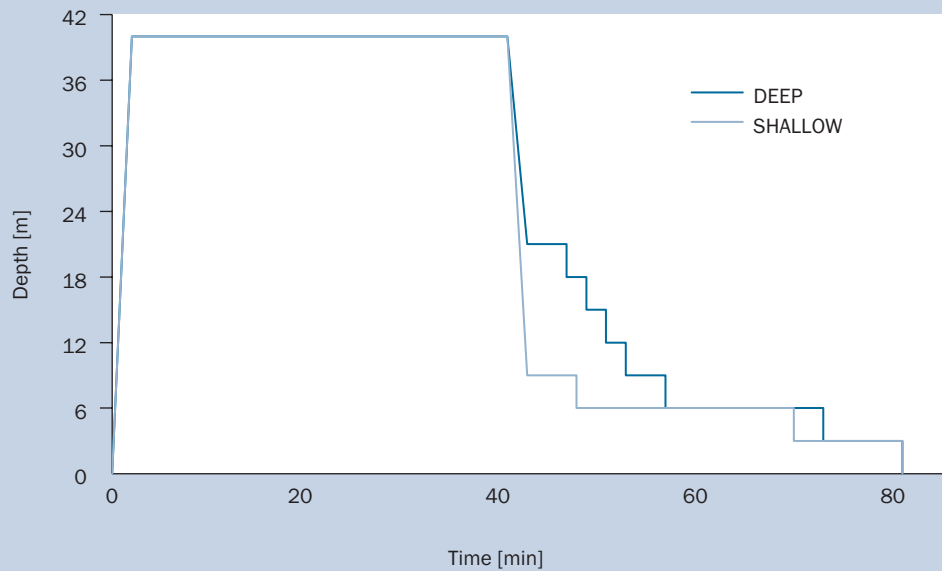


Figure 1. DEEP and SHALLOW profiles

STATISTICAL ANALYSIS

All statistical tests were performed using a standard computer statistical package, GraphPad Prism version 9.00 for Mac OS (GraphPad Software, San Diego, CA, USA).

Normality of data was assessed using the Kolmogorov–Smirnov test. When a Gaussian distribution was assumed, data were analyzed with a paired t-test (or unpaired t-test between conditions), when normality could not be assumed, the analysis was performed with a Wilcoxon test (or Mann–Whitney when non-paired).

A threshold of $p < 0.05$ was considered statistically significant. All data are presented as mean $\pm$ standard deviation (SD). Sample size was calculated setting the power of the study at 90%, assuming that variables associated with diving would have been affected to a similar extent as observed in our previous studies [15, 16].

RESULTS

SURFACE SUPERSATURATION GRADIENT

The calculated supersaturation gradient at surface (end value gradient) was significantly different between the SHALLOW and DEEP profile (1.039 ± 0.038 vs. 1.017 ± 0.031 , $p < 0.05$) (Fig. 2), but both were significantly higher than the intended $GF_{HI} - 82$ and 85 respectively (Fig. 1).

VASCULAR GAS EMBOLI DETECTION

The VGE peak count per heartbeat was analyzed for each condition. Significant differences were found between

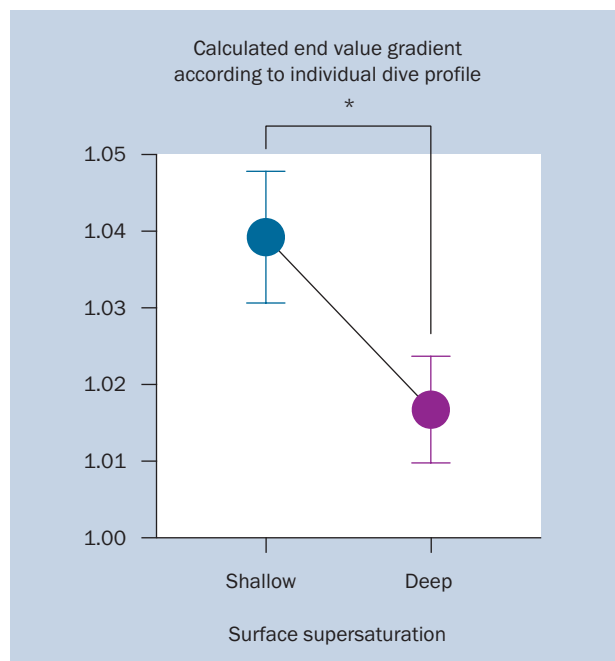


Figure 2. Comparison of calculated end value gradients [Divers Alert Network (DAN) surface supersaturation gradient (DSSG)], i.e., maximal surface saturation of the leading tissue after surfacing. Data are presented as mean $\pm$ standard error of the mean (SEM); t-test; * $p < 0.05$

the zero and 30-minute measurements when divers performed DEEP procedure compared to SHALLOW (respectively 0 minutes: 5.64 ± 7.11 vs. 14.5 ± 13.2 $p = 0.0078$,

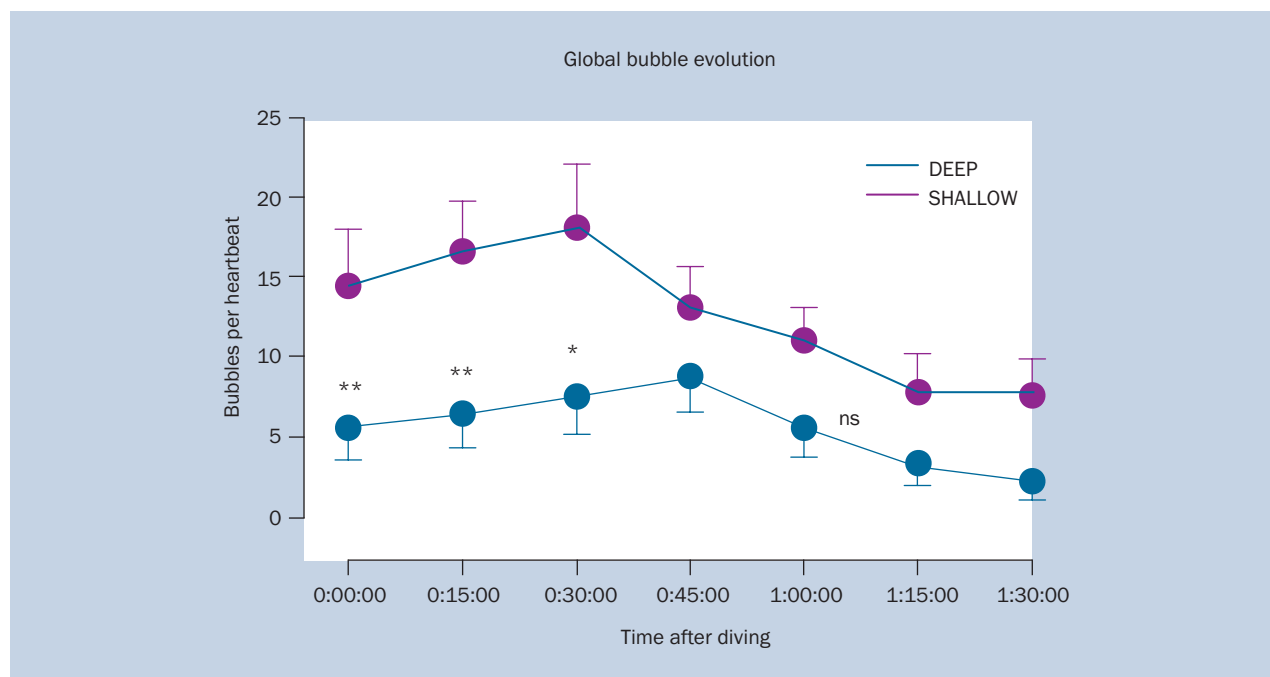


Figure 3. Effect of decompression profile on vascular gas emboli (VGE) production. Vascular gas emboli peak count per heartbeat. Total bubbles count comparing dives. Data are expressed as mean $\pm$ SEM; * $p < 0.05$; ** $p < 0.01$

15 minutes: 6.4 ± 6.9 vs. 16.6 ± 11.7 , $p = 0.0077$, 30 minutes: 7.6 ± 8.7 vs. 18.0 ± 13.7 , $p = 0.012$, mean VGE per heartbeat $\pm$ SD) (Fig. 3). Compared to SHALLOW, VGE count was significantly lower with the DEEP procedure (DEEP: 6.7 ± 7.2 VGE per heartbeat vs. SHALLOW: 10.7 ± 11.6 VGE per heartbeat, $p = 0.0006$) (Fig. 4).

DECOMPRESSION OUTCOME

We observed three cases of cutis marmorata in three divers after the SHALLOW profile, while no DCS case was observed after the DEEP profile ($p = 0.24$ Fisher's exact test). These three divers displayed more than 40 bubbles per heartbeat. The divers were immediately treated with normobaric 100% O_2 onsite for 60 minutes with complete symptom resolution. The skin manifestations are considered as mild manifestations according to the recent review by Mitchell [4], nevertheless they do indicate a significant level of decompression stress and could be also related to CNS involvement [17]. This finding appears favoring the DEEP profile as more conservative.

DISCUSSION

MAXIMUM SURFACE SUPERSATURATION

It is interesting to observe that the DSSG, the maximum surface supersaturation – also known as end value gradient – calculated from the actual dive profiles, is significantly higher than the GF_{HI} expected from the protocol (GF_{HI} 85 for DEEP and 82 for SHALLOW). This is because

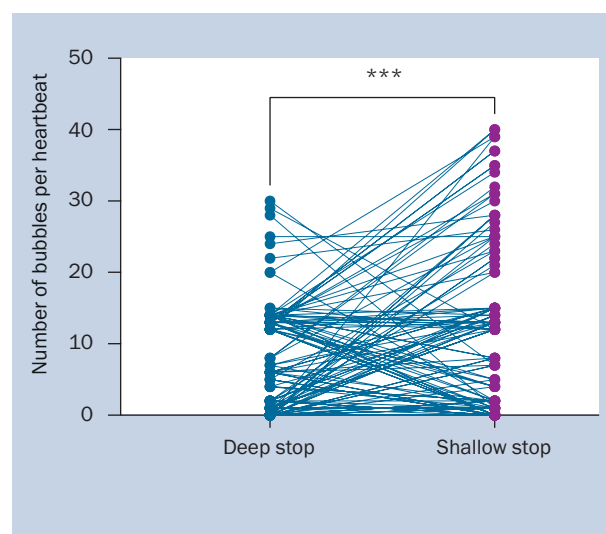


Figure 4. Effects of decompression profile on vascular gas emboli (VGE) production. Maximum number of VGE detected for each diver; *** $p < 0.001$

in today's diving computers, the decompression calculation stops when the actual depth at the last sampling interval is shallower than or equal to 0.5 meters. But the real dive ends at 0 meters (surface). Our DSSG is based on closing the calculation at 0 meters to be closer to reality.

Technical divers, by modifying stop times according to their training standard or personal decisions, may end up

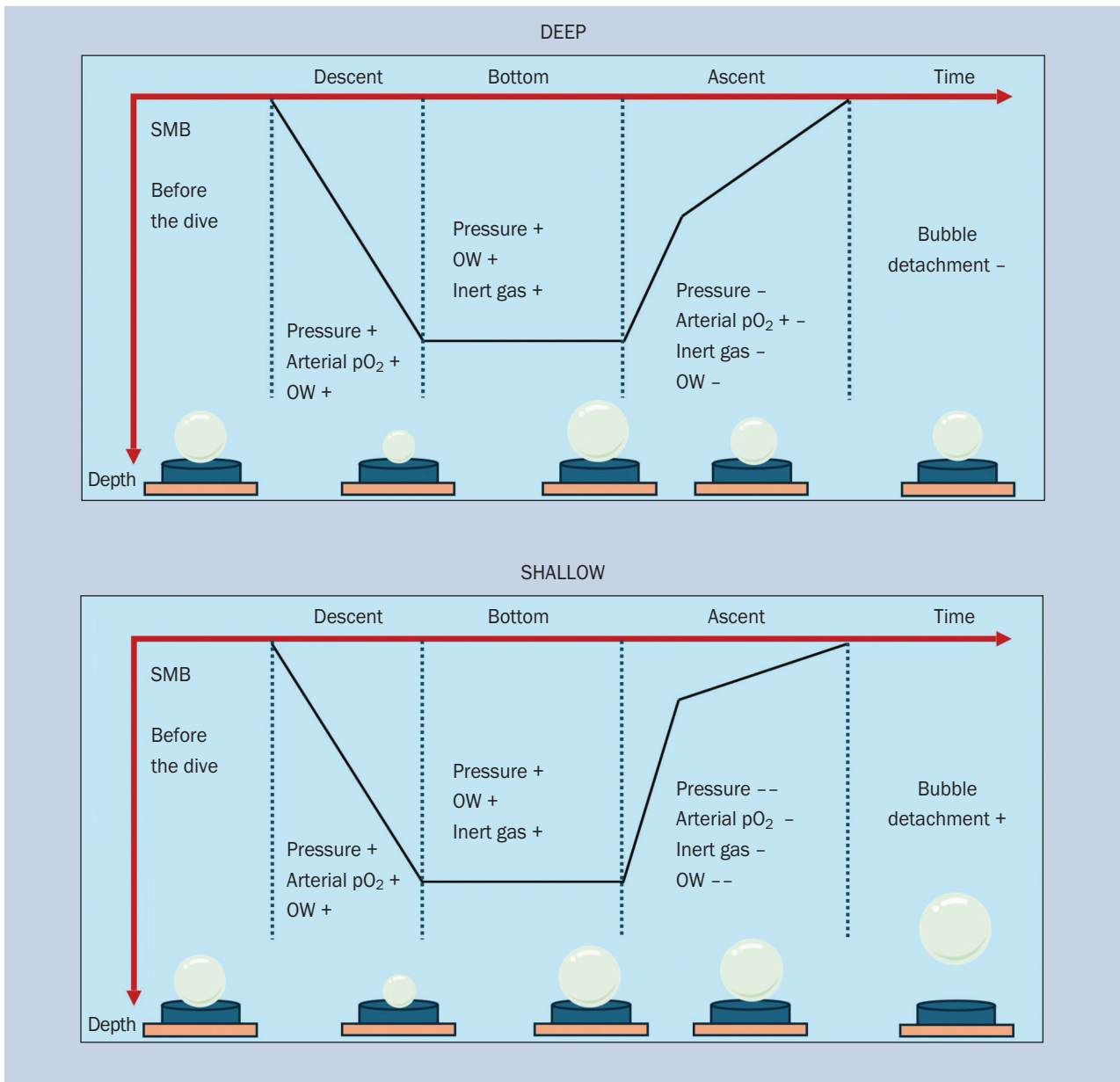


Figure 5. Tentative explanation of the differences between the two decompression stop modalities: static metabolic bubbles (SMB) and oxygen window (OW). It illustrates the interlaced mechanisms of hydrostatic pressure changes, OW variation and SMB related volume increase, which finally leads to detachment and increased bubble count

significantly increasing the final surface supersaturation of their dive compared to what they initially intended.

VASCULAR GAS EMBOLI GROWTH FROM NUCLEI

The increase of final surface supersaturation can enhance VGE growth, since they start forming during the tissue off-gassing on the ascent phase of a dive and are believed to result from the triggering of bubble precursors (nuclei), recently coined ‘static metabolic bubbles’ (SMB) [18]. The precise mechanism of micronuclei formation is long and still debated [19, 20], with possible sites being

located on facilitating endothelial areas with surfactants, hydrophobic surfaces or crevices [1, 21–23].

These nuclei have been shown to act as sites where gas can accumulate and grow into detectable bubbles [24–27]. The activation and growth of these nuclei into VGE are influenced by several factors, including the rate of ascent, the level of supersaturation, and individual physiological differences.

The concept of micronuclei-originated VGE is consistent with the observation that a specific form of acclimatization to decompression stress seems to exist, with a higher



Figure 6. Screenshot of post-decompression bubbles of one of the 3 decompression sickness (DCS) cases (30 min post-emersion) after the SHALLOW procedure: a remarkably high number of bubbles is present in the right and left parts of the heart

probability of VGE on the first dives after a period of non-diving [23, 28]. Rather than ‘acclimatization’ or ‘adaptation,’ we prefer the term ‘depletion’ of pre-existing micronuclei — and therefore of ‘bubble seeding sites’ — resulting in a reduction of VGE post-dive. This would typically reduce VGE production after a dive over the first few days of diving [29, 30]. It is assumed that these depleted micronuclei get ‘restored’ after approximately 48 hours of no diving [19, 31].

Available literature on the micronuclei-microbubble generation modalities is relatively scarce [27, 31]. Once a bubble has nucleated, its content and size will change according to the prevailing difference between the dissolved gas tension and the bubble gas pressure at the gas-liquid interface. When the inert gas partial pressure in the bubble is higher than the tissue inert gas tension, the gas diffuses from the bubble (gas phase) into the tissue (dissolved phase), finally reaching the lungs via circulation.

When living animals are in steady state, the sum of the partial pressures of dissolved gas in the tissues is usually less than atmospheric pressure, a phenomenon known as the ‘oxygen window’ (OW) or ‘inherent unsaturation’ [18]. This is because metabolism lowers the partial pressure of O_2 in tissues below the value in arterial blood, and the binding of O_2 by hemoglobin causes a relatively significant ppO_2 difference between tissues and arterial blood. Production of CO_2 is usually about the same as consumption of O_2 on a mole-for-mole basis, but there is a slight

rise of $ppCO_2$ because of its high solubility (quoted from [32]). At sea level, the inert gas partial pressure in the bubble is higher than the tissue inert gas tension, and inert gas diffuses from the bubble into the tissue, from where circulation carries it to the lungs. At depth, a higher inert partial pressure level in the lungs causes tissue to absorb inert gas, which theoretically should counteract the volume reduction of any bubble present. This would imply a longer persistence of decompression-induced VGE when executing a DEEP dive profile. However, our results seem to advocate for a relative volume reduction, which might be caused by a greater inherent unsaturation effect: at depth, the diver breathes a higher ppO_2 — and despite a partial pressure of N_2 (ppN_2), which is also higher at depth, one can hypothesize a larger inert diffusion gradient from the bubble to the tissue, causing the bubble to dissolve more rapidly.

It is possible that increased hydrostatic pressure can stimulate a collateral metabolic O_2 pathway — Wang [33, 34] showed an increased metabolism associated with mitochondrial calcium ions (Ca^{2+}) inflow by applying hydrostatic pressure to cultured endothelial cells (from 101 to 808 kPa). The hypothesized mechanism is as follows: when hydrostatic pressure is applied to the cell surface, Ca^{2+} enter the cytosol [33, 35]. At the same time, an increase in Ca^{2+} concentration is observed in the mitochondria [36]. This leads to an increase in metabolism due to the need to activate the sodium–potassium adenosine triphosphatase (Na^+/K^+ -ATPase)

pump to balance ion flow. This intracellular Ca^{2+} entry can also further increase by activation of piezo receptors [37] during decompression. A possible hypothesis is a pressure-activated mechanism, where volatile monochloramine (NH_4Cl), generated by myeloperoxidase (MPO) produced by pressure-activated neutrophils [38–40], causes cell expansion on decompression [41]. The 2-dimensional ‘pressure’ activates membrane piezo channels – mechanosensitive ion channels that convert 2-D stretch into biological signals via transient Ca^{2+} entry.

DECOMPRESSION STRATEGIES

Our results seem contradictory to recent research [42] that indicates, based on experimental studies performed by NEDU in 2011 [43], that performing a dive with identical bottom time and decompressing using ‘deep stops’ produces more VGE than using ‘shallow stops.’ The 2011 study also found significantly more cases of decompression sickness using deep stops. The difference could stem from the decompression strategy, which uses extended stop at 21 m and 18 m on nitrox 50.

Both profiles in our study had a much higher surface supersaturation gradient than the ‘original’ GF chosen for the Buhlmann ZH-L16 B-generated profile. The DSSG, as calculated by the DAN Europe software after the dive, was clearly in the ‘high risk’ range [11], where 75% of the cases of DCS occurred when the DSSG was higher than 0.7. However, the DEEP dive profile seemed to produce a lesser grade of VGE than the SHALLOW dive profile. This could be explained by different mechanisms.

First, a mitigation of the growth of gas nuclei or SMB by hydrostatic pressure [18, 44] could be achieved by starting a decompression procedure at a greater depth, allowing several minutes of respiratory exchanges under higher ppO_2 conditions. This could create a more efficient OW, reducing the initial volume of the gas nuclei, micro-bubbles, or detectable VGE, which would reduce the volume of detached bubbles at the end of the dive. In this way, the amount of circulating VGE is lower since microbubbles reach the critical radius of detachment later (Fig. 5) [18, 24, 45].

Second, the DEEP profile implemented a strategy that allowed the divers to spend more time at 21 and 18 m stop depth and, therefore, to benefit from higher partial pressure of inhaled O_2 at a critical moment of the decompression.

Third, the situation could result from a more favorable saturation distribution among different tissue compartments. In the DEEP profile, the “fast tissues” are desaturated faster and could prevent “feeding” the vascular bubbles at a later stage of decompression. In the SHALLOW profile, the conjunction of the presence of shunted arterial bubbles and supersaturated brain stem tissues could have led to the symptoms of cutis marmorata [17].

VASCULAR GAS EMBOLI GRADES AND DECOMPRESSION SICKNESS RISK

Theoretical modelling of tissue compartment saturation indicates that if deeper stops during the initial phase of the ascent are used, the supersaturation may be reduced for the faster tissue compartments at the beginning of the ascent, but increased for slower tissue compartments later on in the decompression and after surfacing [42]. When shallow stops are used, bubbles may already have formed from the fast tissues during the initial ascent, persisting throughout the decompression phase. In contrast, medium and slow tissues have a lower supersaturation at surfacing.

What the primary ‘source’ of pathological bubbles precisely is, is not known. However, a detailed analysis of the DAN database shows that all cases of DCS with a DSSG > 1.0 had ‘fast tissues’ as the ‘leading’ (most saturated) compartment [11].

The DSSG value is calculated upon surfacing. Most export files from dive computers do not include a zero-depth value, as they typically stop recording at a certain depth depending on the sampling rate – in our case, 10 seconds. This calculation is performed based on the following criteria: when, by the end of the dive, the depth at the moment of the last sampling interval is less than or equal to 0.5 meters, the “virtual” (computed) dive does not end at 0 meters (surface), but at an increased depth; thus, the computed supersaturation will be lesser than the real one achieved at surfacing. The DSSG Model replaces the final ≥ 0.5 -meter value with a single value of 0 meters, maintaining the time interval defined by the sampling rate.

In this scenario, and notwithstanding the generally high level of VGE, the DEEP profile could be (a bit) safer. This is because even high grades of VGE do not always cause symptoms, and a diver without symptoms is considered ‘not to have DCS.’ However, biochemical and hemodynamic changes can be detected whenever VGE are present [46–48], and the individual’s reaction to VGE may be determined by factors that are yet unknown, some of which may be genetic [49].

The number of micronuclei acting as nucleation sites is also most likely (epi)genetically determined, explaining the large inter-individual variability in VGE after similar dives [50] as well as depending on pre-dive activities [16, 51].

Furthermore, although VGE detection techniques have improved (from acoustic Doppler to visual 2D echocardiography to second harmonics echocardiography), there is a size limit below which VGE will not be detectable [1, 22]. The limits of the sensibility of VGE detection methods imply that small, undetected VGE, less than $22\ \mu\text{m}$ [52], might pass the pulmonary vasculature (which acts as a bubble ‘filter’) [53] and exert influence on the arterial side of our cardiovascular system.

In any case, high bubble levels are generally associated with higher DCS risk [54]. In the SHALLOW profile group, three cases of cutis marmorata occurred, all showing very high bubble levels in the right cardiac cavities and VGE in the left cardiac cavities (all three divers showed mild cutaneous signs and symptoms and more than 40 bubbles per heartbeat at the 30 minutes time point) (Fig. 6). While all participating divers had declared that they did not have a PFO, the appropriate examinations had been performed by various cardiologists prior to the start of the study and a formal standardized PFO test was not imposed. It is thus possible that some of these divers did have a small PFO that was undetected. However, a repeat PFO testing was not offered to the divers with DCS, as all had extensive diving experience without DCS and the possibility of a pulmonary shunt is, with these high VGE levels, a real possibility.

STRENGTHS AND WEAKNESSES

Strengths

This study builds on established modern methods for evaluating decompression stress and current theories of VGE generation.

- As there is a possible large inter-individual variation in VGE effects after diving, the subjects served as their own controls.
- The measured effects are consistent with sound theoretical rationale.
- The equipment used for these experiments is readily available, inviting other research groups to repeat the study.

Weaknesses

- The current study only concerns a small group of subjects.
- The subjects were not homogenous or necessarily similar in body composition (age, weight, fat/lean mass distribution, sex), although this is consistent with current diving community demography.
- The subjects had not been tested to be 'consistent bubble' before the experiments (this would have required at least three extra identical 'control' dives).

CONCLUSIONS

There are significant differences between the two tested decompression procedures. The DEEP procedure resulted in a lower production of bubbles compared to the SHALLOW procedure. Three mild DCS cases occurred after the SHALLOW ascent procedure.

One possible explanation is that the strategy of using deeper stops permits breathing nitrox 50 starting at 21 m, enhances the effect of breathing high ppO_2 in decompression, and leads to a lower grade of VGE.

These results emphasize the need for further research to focus on individual data logging, exposure, and physiological monitoring, envisaging a future safer decompression and mitigation of decompression stress, i.e., what we define as the best 'economy of decompression.'

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics statement: Informed consent was obtained from all subjects involved in the study. All experimental procedures were conducted in accordance with the Declaration of Helsinki [10], were approved by the Ethical Committee of Università degli Studi di Milano, Italy (Aut. n° 37/17) 52.

Author contributions: All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Supplementary materials: None.

REFERENCES

1. Papadopoulou V, Tang MX, Balestra C, et al. Circulatory bubble dynamics: from physical to biological aspects. *Adv Colloid Interface Sci.* 2014; 206: 239–249, doi: [10.1016/j.cis.2014.01.017](https://doi.org/10.1016/j.cis.2014.01.017), indexed in Pubmed: [24534474](https://pubmed.ncbi.nlm.nih.gov/24534474/).
2. Bennett P, Marroni A, Cronje F, et al. Effect of varying deep stop times and shallow stop times on precordial bubbles after dives to 25 msw (82 fsw). *Undersea Hyperb Med.* 2007; 36(6): 399–406, indexed in Pubmed: [18251436](https://pubmed.ncbi.nlm.nih.gov/18251436/).
3. Marroni A, Bennett PB, Cronje FJ, et al. A deep stop during decompression from 82 fsw (25 m) significantly reduces bubbles and fast tissue gas tensions. *Undersea Hyperb Med.* 2004; 31(2): 233–243, indexed in Pubmed: [15485086](https://pubmed.ncbi.nlm.nih.gov/15485086/).
4. Mitchell SJ. Decompression illness: a comprehensive overview. *Diving Hyperb Med.* 2024; 54(1Suppl): 1–53, doi: [10.28920/dhm54.1.suppl.1-53](https://doi.org/10.28920/dhm54.1.suppl.1-53), indexed in Pubmed: [38537300](https://pubmed.ncbi.nlm.nih.gov/38537300/).
5. Doolette DJ. Venous gas emboli detected by two-dimensional echocardiography are an imperfect surrogate endpoint for decompression sickness. *Diving Hyperb Med.* 2016; 46(1): 4–10, indexed in Pubmed: [27044455](https://pubmed.ncbi.nlm.nih.gov/27044455/).
6. Møllerlækken A, Gaustad SE, Havnes MB, et al. Venous gas embolism as a predictive tool for improving CNS decompression safety. *Eur J Appl Physiol.* 2012; 112(2): 401–409, doi: [10.1007/s00421-011-1998-9](https://doi.org/10.1007/s00421-011-1998-9), indexed in Pubmed: [21594696](https://pubmed.ncbi.nlm.nih.gov/21594696/).
7. Bennett PB, Marroni A, Cronje FJ, et al. Effect of varying deep stop times and shallow stop times on precordial bubbles after dives to

- 25 msw (82 fsw). Undersea Hyperb Med. 2007; 34(6): 399–406, indexed in Pubmed: [18251436](#).
8. Marroni A, Bennett PB, Cronje F. A deep stop during decompression from 82 fsw (25m) significantly reduces bubbles and fast tissue gas tensions. Response by the authors. Undersea & Hyperbaric Medicine. 2005; 32(32): 89–92.
9. Obad A, Palada I, Valic Z, et al. The effects of acute oral antioxidants on diving-induced alterations in human cardiovascular function. J Physiol. 2007; 578(Pt 3): 859–870, doi: [10.1113/jphysiol.2006.122218](#), indexed in Pubmed: [17110413](#).
10. General Assembly of the World Medical Association, World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2000; 284(23): 3043–3045, indexed in Pubmed: [11122593](#).
11. Cialoni D, Pieri M, Balestra C, et al. Dive risk factors, gas bubble formation, and decompression illness in recreational SCUBA diving: analysis of DAN Europe DSL data base. Front Psychol. 2017; 8: 1587, doi: [10.3389/fpsyg.2017.01587](#), indexed in Pubmed: [28974936](#).
12. Balestra C, Germonpré P, Rocco M, et al. Diving physiopathology: the end of certainties? Food for thought. Minerva Anestesiol. 2019; 85(10): 1129–1137, doi: [10.23736/S0375-9393.19.13618-8](#), indexed in Pubmed: [31238641](#).
13. Møllerlækken A, Blogg SL, Doolette DJ, et al. Consensus guidelines for the use of ultrasound for diving research. Diving Hyperb Med. 2016; 46(1): 26–32, indexed in Pubmed: [27044459](#).
14. Germonpré P, Papadopoulou V, Hemelryck W, et al. The use of portable 2D echocardiography and 'frame-based' bubble counting as a tool to evaluate diving decompression stress. Diving Hyperb Med. 2014; 44(1): 5–13, indexed in Pubmed: [24687479](#).
15. Levenez M, Lambrechts K, Mrakic-Spota S, et al. Full-face mask use during SCUBA diving counters related oxidative stress and endothelial dysfunction. Int J Environ Res Public Health. 2022; 19(2), doi: [10.3390/ijerph19020965](#), indexed in Pubmed: [35055791](#).
16. Germonpré P, Balestra C. Preconditioning to Reduce Decompression Stress in Scuba Divers. Aerosp Med Hum Perform. 2017; 88(2): 114–120, doi: [10.3357/AMHP.4642.2017](#), indexed in Pubmed: [28095955](#).
17. Germonpre P, Balestra C, Obeid G, et al. Cutis Marmorata skin decompression sickness is a manifestation of brainstem bubble embolization, not of local skin bubbles. Med Hypotheses. 2015; 85(6): 863–869, doi: [10.1016/j.mehy.2015.09.022](#), indexed in Pubmed: [26432631](#).
18. Imbert JP, Egi SM, Germonpré P, et al. Static metabolic bubbles as precursors of vascular gas emboli during divers' decompression: a hypothesis explaining bubbling variability. Front Physiol. 2019; 10: 807, doi: [10.3389/fphys.2019.00807](#), indexed in Pubmed: [31354506](#).
19. Craig VSJ. Formation of micronuclei responsible for decompression sickness. Journal of Colloid and Interface Science. 1996; 183(1): 260–268, doi: [10.1006/jcis.1996.0541](#).
20. Walder DN, Evans A. In vivo nuclear fission in the aetiology of decompression sickness. Nature. 1974; 252(5485): 696–697, doi: [10.1038/252696a0](#), indexed in Pubmed: [4437617](#).
21. Papadopoulou V, Evgenidis S, Eckersley RJ, et al. Decompression induced bubble dynamics on ex vivo fat and muscle tissue surfaces with a new experimental set up. Colloids Surf B Biointerfaces. 2015; 129: 121–129, doi: [10.1016/j.colsurfb.2015.03.027](#), indexed in Pubmed: [25835147](#).
22. Papadopoulou V, Eckersley RJ, Balestra C, et al. A critical review of physiological bubble formation in hyperbaric decompression. Adv Colloid Interface Sci. 2013; 191–192: 22–30, doi: [10.1016/j.cis.2013.02.002](#), indexed in Pubmed: [23523006](#).
23. Arieli R, Arieli U, Marmur A. Bubble size on detachment from the luminal aspect of ovine large blood vessels after decompression: The effect of mechanical disturbance. Respir Physiol Neurobiol. 2015; 216: 1–8, doi: [10.1016/j.resp.2015.05.001](#), indexed in Pubmed: [26003848](#).
24. Arieli R. Distal arterial bubble: an alternative mechanism underlying vestibular decompression illness. J Appl Physiol (1985). 2023; 134(3): 593–594, doi: [10.1152/japplphysiol.00003.2023](#), indexed in Pubmed: [36897585](#).
25. Arieli R, Khatib S, Khattib A, et al. Is the probable spillage of the lung surfactant dipalmitoylphosphatidylcholine the ultimate source of diabetes type 1? Respir Physiol Neurobiol. 2021; 286: 103615, doi: [10.1016/j.resp.2020.103615](#), indexed in Pubmed: [33421610](#).
26. Arieli R. Taravana, vestibular decompression illness, and autochthonous distal arterial bubbles. Respir Physiol Neurobiol. 2019; 259: 119–121, doi: [10.1016/j.resp.2018.08.010](#), indexed in Pubmed: [30172778](#).
27. Arieli R. Gas micronuclei underlying decompression bubbles may explain the influence of oxygen enriched gases during decompression on bubble formation and endothelial function in self-contained underwater breathing apparatus diving. Croat Med J. 2019; 60(4): 388, doi: [10.3325/cmj.2019.60.388](#), indexed in Pubmed: [31483127](#).
28. Zanchi J, Ljubkovic M, Denoble PJ, et al. Influence of repeated daily diving on decompression stress. Int J Sports Med. 2014; 35(6): 465–468, doi: [10.1055/s-0033-1334968](#), indexed in Pubmed: [23771833](#).
29. Balestra C, Lévêque C, Mrakic-Spota S, et al. Physiology of deep closed circuit rebreather mixed gas diving: vascular gas emboli and biological changes during a week-long liveaboard safari. Front Physiol. 2024; 15: 1395846, doi: [10.3389/fphys.2024.1395846](#), indexed in Pubmed: [38660539](#).
30. Balestra C, Guerrero F, Theunissen S, et al. Physiology of repeated mixed gas 100-m wreck dives using a closed-circuit rebreather: a field bubble study. Eur J Appl Physiol. 2022; 122(2): 515–522, doi: [10.1007/s00421-021-04856-5](#), indexed in Pubmed: [34839432](#).
31. Blatteau JE, Souraud JB, Gempp E, et al. Gas nuclei, their origin, and their role in bubble formation. Aviat Space Environ Med. 2006; 77(10): 1068–1076, indexed in Pubmed: [17042253](#).
32. Van Liew HD, Conkin J, Burkard ME. The oxygen window and decompression bubbles: estimates and significance. Aviat Space Environ Med. 1993; 64(9 Pt 1): 859–865, indexed in Pubmed: [8216150](#).
33. Wang Q, Guerrero F, Mazur A, et al. Reactive oxygen species, mitochondria, and endothelial cell death during *in vitro* simulated dives. Med Sci Sports Exerc. 2015; 47(7): 1362–1371, doi: [10.1249/MSS.0000000000000563](#), indexed in Pubmed: [25380471](#).
34. Wang Q, Belhomme M, Guerrero F, et al. Diving under a microscope — a new simple and versatile *in vitro* diving device for fluorescence and confocal microscopy allowing the controls of hydrostatic pressure, gas pressures, and kinetics of gas saturation. Microsc Microanal. 2013; 19(3): 608–616, doi: [10.1017/S1431927613000378](#), indexed in Pubmed: [23590810](#).
35. Wang Q, Guerrero F, Lambrechts K, et al. Simulated air dives induce superoxide, nitric oxide, peroxynitrite, and Ca alterations in endothelial cells. J Physiol Biochem. 2020; 76(1): 61–72, doi: [10.1007/s13105-019-00715-2](#), indexed in Pubmed: [31802431](#).
36. Li X, Kordsmeier J, Nookaew I, et al. Piezo1 stimulates mitochondrial function via cAMP signaling. FASEB J. 2022; 36(10): e22519, doi: [10.1096/fj.202200300R](#), indexed in Pubmed: [36052712](#).

37. Liu H, Hu J, Zheng Q, et al. Piezo1 channels as force sensors in mechanical force-related chronic inflammation. *Front Immunol.* 2022; 13: 816149, doi: [10.3389/fimmu.2022.816149](https://doi.org/10.3389/fimmu.2022.816149), indexed in Pubmed: [35154133](https://pubmed.ncbi.nlm.nih.gov/35154133/).
38. Thom SR, Bhopale VM, Yang M. Neutrophils generate microparticles during exposure to inert gases due to cytoskeletal oxidative stress. *J Biol Chem.* 2014; 289(27): 18831–18845, doi: [10.1074/jbc.M113.543702](https://doi.org/10.1074/jbc.M113.543702), indexed in Pubmed: [24867949](https://pubmed.ncbi.nlm.nih.gov/24867949/).
39. Thom SR, Yang M, Bhopale VM, et al. Intramicroparticle nitrogen dioxide is a bubble nucleation site leading to decompression-induced neutrophil activation and vascular injury. *J Appl Physiol* (1985). 2013; 114(5): 550–558, doi: [10.1152/jappphysiol.01386.2012](https://doi.org/10.1152/jappphysiol.01386.2012), indexed in Pubmed: [23264541](https://pubmed.ncbi.nlm.nih.gov/23264541/).
40. Yang M, Milovanova TN, Bogush M, et al. Microparticle enlargement and altered surface proteins after air decompression are associated with inflammatory vascular injuries. *J Appl Physiol* (1985). 2012; 112(1): 204–211, doi: [10.1152/jappphysiol.00953.2011](https://doi.org/10.1152/jappphysiol.00953.2011), indexed in Pubmed: [21960660](https://pubmed.ncbi.nlm.nih.gov/21960660/).
41. Louarn E, Asri-Idlibi AM, Leprovost J, et al. Evidence of reactivity in the membrane for the unstable monochloramine during MIMS analysis. *Sensors (Basel).* 2018; 18(12), doi: [10.3390/s18124252](https://doi.org/10.3390/s18124252), indexed in Pubmed: [30513986](https://pubmed.ncbi.nlm.nih.gov/30513986/).
42. De Ridder S, Pattyn N, Neyt X, et al. Selecting optimal air diving gradient factors for Belgian military divers: more conservative settings are not necessarily safer. *Diving Hyperb Med.* 2023; 53(3): 251–258, doi: [10.28920/dhm53.3.251-258](https://doi.org/10.28920/dhm53.3.251-258), indexed in Pubmed: [37718300](https://pubmed.ncbi.nlm.nih.gov/37718300/).
43. Doolette D, Gerth W, Gault K. Redistribution of decompression stop time from shallow to deep stops increases incidence of decompression sickness in air decompression dives. 2011.
44. Arieli Y, Katsenelson K, Arieli R. Bubble reduction after decompression in the prawn *Palaemon elegans* by pretreatment with hyperbaric oxygen. *Undersea Hyperb Med.* 2007; 34(5): 369–378, indexed in Pubmed: [18019088](https://pubmed.ncbi.nlm.nih.gov/18019088/).
45. Arieli R. Nanobubbles form at active hydrophobic spots on the luminal aspect of blood vessels: consequences for decompression illness in diving and possible implications for autoimmune disease-an overview. *Front Physiol.* 2017; 8: 591, doi: [10.3389/fphys.2017.00591](https://doi.org/10.3389/fphys.2017.00591), indexed in Pubmed: [28861003](https://pubmed.ncbi.nlm.nih.gov/28861003/).
46. Lambrechts K, Balestra C, Theron M, et al. Venous gas emboli are involved in post-dive macro, but not microvascular dysfunction. *Eur J Appl Physiol.* 2017; 117(2): 335–344, doi: [10.1007/s00421-017-3537-9](https://doi.org/10.1007/s00421-017-3537-9), indexed in Pubmed: [28110355](https://pubmed.ncbi.nlm.nih.gov/28110355/).
47. Lambrechts K, Pontier JM, Balestra C, et al. Effect of a single, open-sea, air scuba dive on human micro- and macrovascular function. *Eur J Appl Physiol.* 2013; 113(10): 2637–2645, doi: [10.1007/s00421-013-2676-x](https://doi.org/10.1007/s00421-013-2676-x), indexed in Pubmed: [23949788](https://pubmed.ncbi.nlm.nih.gov/23949788/).
48. Arya AK, Balestra C, Bhopale VM, et al. Elevations of extracellular vesicles and inflammatory biomarkers in closed circuit SCUBA divers. *Int J Mol Sci.* 2023; 24(6), doi: [10.3390/ijms24065969](https://doi.org/10.3390/ijms24065969), indexed in Pubmed: [36983042](https://pubmed.ncbi.nlm.nih.gov/36983042/).
49. Lautridou J, Buzzacott P, Belhomme M, et al. Evidence of heritable determinants of decompression sickness in rats. *Med Sci Sports Exerc.* 2017; 49(12): 2433–2438, doi: [10.1249/MSS.0000000000001385](https://doi.org/10.1249/MSS.0000000000001385), indexed in Pubmed: [28731987](https://pubmed.ncbi.nlm.nih.gov/28731987/).
50. Papadopoulou V, Germonpré P, Cosgrove D, et al. Variability in circulating gas emboli after a same scuba diving exposure. *Eur J Appl Physiol.* 2018; 118(6): 1255–1264, doi: [10.1007/s00421-018-3854-7](https://doi.org/10.1007/s00421-018-3854-7), indexed in Pubmed: [29616324](https://pubmed.ncbi.nlm.nih.gov/29616324/).
51. Lambrechts K, Germonpré P, Vandenheede J, et al. Mini trampoline, a new and promising way of SCUBA diving preconditioning to reduce vascular gas emboli? *Int J Environ Res Public Health.* 2022; 19(9), doi: [10.3390/ijerph19095410](https://doi.org/10.3390/ijerph19095410), indexed in Pubmed: [35564805](https://pubmed.ncbi.nlm.nih.gov/35564805/).
52. Hills BA, Butler BD. Size distribution of intravascular air emboli produced by decompression. *Undersea Biomed Res.* 1981; 8(3): 163–170, indexed in Pubmed: [7292785](https://pubmed.ncbi.nlm.nih.gov/7292785/).
53. Carturan D, Boussuges A, Burnet H, et al. Circulating venous bubbles in recreational diving: relationships with age, weight, maximal oxygen uptake and body fat percentage. *Int J Sports Med.* 1999; 20(6): 410–414, doi: [10.1055/s-2007-971154](https://doi.org/10.1055/s-2007-971154), indexed in Pubmed: [10496123](https://pubmed.ncbi.nlm.nih.gov/10496123/).
54. Currrens JB, Doolette DJ, Murphy FG. Venous gas emboli (VGE) in 2-D echocardiographic images following movement: grading and association with cumulative incidence of decompression sickness. *Diving Hyperb Med.* 2025; 55(1): 44–50, doi: [10.28920/dhm55.1.44-50](https://doi.org/10.28920/dhm55.1.44-50), indexed in Pubmed: [40090025](https://pubmed.ncbi.nlm.nih.gov/40090025/).

Risk factors for decompression sickness among commercial divers in Qingdao, China — a single-center, retrospective study

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ABSTRACT

Background: Decompression sickness (DCS) is a major occupational hazard for commercial divers. This study aimed to analyze the clinical characteristics and risk factors associated with DCS severity in commercial divers in Qingdao, China.

Material and methods: A single-center retrospective study was conducted on 80 commercial divers with DCS treated at a tertiary hospital from 2017 to 2022. Demographic, diving-related, and clinical data were collected. Statistical analyses included independent-samples t-tests, chi-square tests, Mann–Whitney U test, and Pearson correlation analysis.

Results: Most patients were male (98.8%) with a mean age of 41.7 ± 10.2 years. Type I DCS accounted for 77.5% ($n = 62$) and type II for 22.5% ($n = 18$). Type II patients were significantly older (47.3 ± 7.1 vs. 40.1 ± 10.4 years, $p = 0.007$) and had longer diving experience (18.8 ± 9.6 vs. 13.7 ± 8.4 years, $p = 0.030$) than type I patients. No significant differences were found in diving depth, number of recent dives, or time to symptom onset between groups. Age strongly correlated with diving experience ($r = 0.772$, $p < 0.001$). The incidence of type II DCS was highest in the 41–50 age group (36.4%) and among divers with > 25 years of experience (50%). All patients improved with hyperbaric oxygen therapy, but full recovery was only observed in type I cases.

Conclusions: Increasing age and longer diving experience are significant risk factors for severe (type II) DCS. Targeted health monitoring and safety education for this high-risk group are critical to reduce the incidence of severe DCS.

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Keywords: decompression sickness, commercial diving, risk factors, epidemiology, retrospective study, hyperbaric oxygen therapy

INTRODUCTION

Decompression sickness (DCS) is a systemic disorder caused by the formation of gas bubbles from inert gas (primarily nitrogen) coming out of solution in tissues and blood following a rapid reduction in ambient pressure [1, 2]. The clinical manifestations of DCS are protean, ranging from mild symptoms such as skin mottling and joint pain (the “bends”)

to severe, life-threatening conditions involving the central nervous system (CNS), cardiopulmonary system, or vestibular apparatus, which can lead to paralysis, loss of consciousness, or death [2, 3]. As a significant occupational hazard, DCS poses a major health threat to individuals working in hyperbaric environments, including commercial divers, caisson workers, tunnel engineers, and astronauts [4, 5].

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Globally, both recreational and commercial diving activities are increasingly prevalent. According to the Divers Alert Network (DAN) 2021 Annual Report, which analyzed 2018 data, commercial diving carries a significantly higher risk of DCS compared to recreational diving due to greater operational depths, longer bottom times, and more complex underwater environments [6]. In China, with its extensive coastlines and inland waterways, commercial diving activities such as aquaculture harvesting, underwater construction, and salvage operations are widespread. It is estimated that there are over 50,000 active divers in China, the majority of whom are fishery divers [7]. However, due to factors such as a lack of standardized operating procedures, insufficient dissemination of diving medicine knowledge, and variable quality of diving equipment, the incidence of DCS among Chinese commercial divers has remained high [7, 8]. A large-scale study on fishery divers in northern China reported the treatment of over 5,000 cases of decompression illness (DCI) within a decade, highlighting the severity of this public health issue [9].

The risk factors for DCS are multifactorial, encompassing the dive profile (depth, time, ascent rate), individual physiological factors (age, body fat percentage, dehydration, patent foramen ovale), and environmental conditions (water temperature) [10, 11]. Previous research has explored various risk factors. For instance, a case-control study in Japan identified diving deeper than 30 meters and dehydration as significant risk factors for DCS [12]. Another study on diving fishermen in the Dalian area of China pointed to diving depth and diving method as the main influencing factors for acute DCS [13]. However, the relative importance of different risk factors and how they interact to cause varying degrees of DCS severity still require further investigation, especially within specific geographical and occupational populations.

Notably, commercial diving carries a significantly higher risk of DCS than recreational diving due to greater operational depths, longer bottom times, and more complex underwater environments [14]. Professional divers often perform repetitive diving operations under relatively fixed patterns, and this cumulative effect may result in different DCS patterns and risk factor distributions compared with recreational divers.

Although the basic pathophysiological mechanisms of DCS are well established, the epidemiological characteristics and risk factors in specific occupational groups still need further investigation. In particular, regarding the impact of age and diving experience on DCS severity, current findings are inconsistent, leading to the so-called “experience paradox”: experienced divers, despite being more skilled, may face a higher risk of severe DCS.

Qingdao, a major coastal city in eastern China, is a hub for frequent commercial diving activities, including

aquaculture and underwater engineering. The diving medicine center at our hospital, serving as a regional hyperbaric oxygen therapy facility, has treated a large number of DCS patients from this area. This study aims to retrospectively analyze the clinical and epidemiological characteristics of commercial divers with DCS treated at our center from 2017 to 2022, with a primary focus on identifying risk factors associated with DCS severity. Through this research, we hope to provide evidence-based insights for occupational health protection, DCS prevention strategies, and clinical management for commercial divers in China.

MATERIAL AND METHODS

PARTICIPANTS

This study employed a single-center, retrospective cohort design. The study population consisted of all patients who presented with diving-related illnesses at the Diving Medicine Center of a tertiary hospital in Qingdao between January 2017 and December 2022 and were ultimately diagnosed with DCS.

Inclusion criteria: 1) A clear history of hyperbaric exposure (commercial diving); 2) clinical manifestations consistent with the *Diagnostic Standard for Occupational Decompression Sickness* (GBZ 24-2025) of China [15]; and 3) relatively complete medical records.

Exclusion criteria: 1) Withdrawal of consent or refusal to provide complete information; 2) missing or unclearly recorded key data (e.g., diving depth, time); and 3) diagnosis of other diving-related conditions, such as pulmonary barotrauma or arterial gas embolism (AGE).

An initial screening identified 91 cases, of which 82 met the preliminary inclusion criteria. Two cases were subsequently excluded due to incomplete critical data, resulting in a final cohort of 80 patients for statistical analysis.

MATERIALS

Data were collected from the No. 971 Hospital of the PLA Navy's electronic medical record system and paper-based medical archives. All data were independently entered into an EpiData database by two researchers and cross-checked for accuracy. Statistical analyses were performed using SPSS software, version 26.0.

METHODS

Data collection

Detailed information was collected for each patient, including:

1. **Demographic data:** age and gender;
2. **Diving-related characteristics:** years of diving experience (total number of years engaged in commercial diving), maximum diving depth (deepest depth ever recorded, in meters), recent diving depth (depth

of the illness-causing dive, in meters), number of recent dives (dives within 24 hours before onset), and time from surfacing to symptom onset (time from final surfacing to the first DCS symptom, in hours);

3. **Clinical diagnosis and treatment information:** DCS classification (type I or type II according to GBZ 24-2025 [15] and the MSD Manual [3]; type I: skin, lymphatic, or musculoskeletal system involvement; type II: CNS, cardiopulmonary, or vestibular system involvement), treatment regimen [primarily U.S. Navy Treatment Tables, e.g., U.S. Navy Treatment Table 6A (USN TT 6A)], admission status (inpatient or outpatient), and treatment outcome (recovered or improved).

Statistical analysis

Quantitative data were expressed as mean $\pm$ standard deviation (mean $\pm$ SD), and categorical data as counts and percentages (n, %). Normally distributed quantitative data were compared using independent-samples t-tests; non-normally distributed data were analyzed with the Mann–Whitney U test. Categorical data were compared using chi-square tests or Fisher's exact test. Pearson correlation analysis was used to assess relationships between continuous variables. All statistical tests were two-tailed, with $p < 0.05$ considered statistically significant.

RESULTS

PATIENT CHARACTERISTICS

A total of 80 DCS patients were included (Fig. 1). The vast majority were male ($n = 79$, 98.8%), with only one female patient (1.2%). Age ranged from 21 to 60 years (mean: 41.7 ± 10.2 years), with the 41–50 age group being the largest ($n = 33$, 41.3%). The mean diving experience was 14.8 ± 8.8 years. The mean maximum diving depth was 35.2 ± 14.9 meters, and the mean recent diving depth was 29.6 ± 13.0 meters. The mean number of recent dives was 2.3 ± 1.3 , and the median time from surfacing to symptom onset was 5 hours (mean: 26.1 ± 75.6 hours). These findings describe the demographic and baseline characteristics of the study participants.

In terms of diagnostic classification, 62 patients (77.5%) had type I DCS, and 18 patients (22.5%) had type II DCS (Tab. 1).

RISK FACTOR ANALYSIS FOR DCS CLASSIFICATION

Patients with type II DCS were significantly older and had longer diving experience than those with type I DCS ($p = 0.007$ and $p = 0.030$, respectively). No significant differences were observed in maximum diving depth, recent diving depth, number of recent dives, or time to symptom onset between groups ($p > 0.05$).

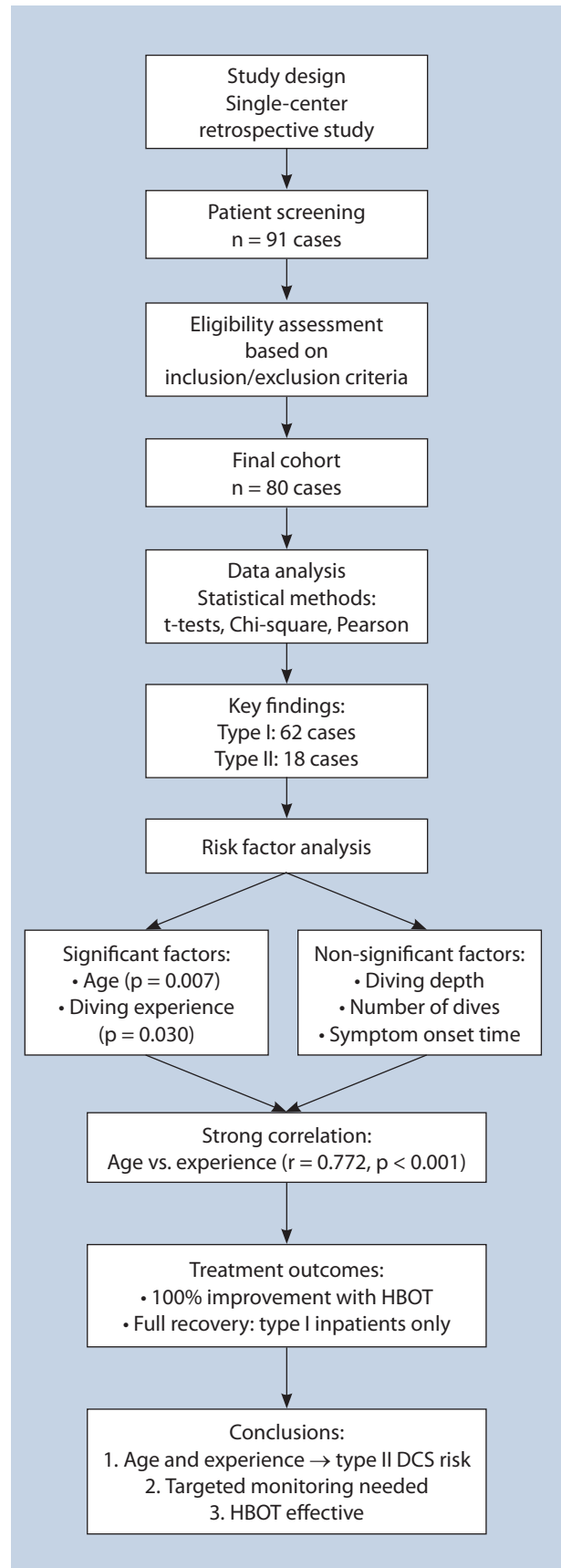


Figure 1. Flowchart of the risk factors analysis
DCS — decompression sickness; HBOT — hyperbaric oxygen therapy

Table 1. Baseline characteristics of the study participants (n = 80)

Characteristic	Overall (n = 80)	Type I DCS (n = 62)	Type II DCS (n = 18)	p-value
Age [years]	41.7 ± 10.2	40.1 ± 10.4	47.3 ± 7.1	0.007
Gender [male/female]	79 / 1	61 / 1	18 / 0	1.000*
Diving experience [years]	14.8 ± 8.8	13.7 ± 8.4	18.8 ± 9.6	0.030
Maximum diving depth [m]	35.2 ± 14.9	35.1 ± 15.7	35.4 ± 12.3	0.935
Recent diving depth [m]	29.6 ± 13.0	29.4 ± 13.9	30.3 ± 10.2	0.781
Number of recent dives	2.3 ± 1.3	2.4 ± 1.4	2.1 ± 1.1	0.402
Time to symptom onset [hours]	26.1 ± 75.6	30.8 ± 82.8	11.1 ± 28.5	0.312**

*Fisher's exact test; **Mann-Whitney U test. Bold p-values indicate statistical significance. Quantitative data are presented as mean ± SD

Table 2. Age and diving experience among different types of decompression sickness (DCS) patients (n = 80)

Stratification variable	Group	Total patients [n]	Type II DCS patients [n]	Incidence of type II DCS [%]
Age [years]	≤ 30	14	1	7.1
	31–40	18	1	5.6
	41–50	33	12	36.4
	> 50	15	4	26.7
Diving experience [years]	≤ 5	16	2	12.5
	6–15	28	4	14.3
	16–25	26	7	26.9
	> 25	10	5	50.0

Stratified analysis showed that the incidence of type II DCS was highest in the 41–50 age group (36.4%, 12/33) and among divers with > 25 years of experience (50%, 5/10) (Tab. 2).

CORRELATION ANALYSIS

Pearson correlation analysis revealed the following:

- A strong positive correlation between age and diving experience ($r = 0.772$, $p < 0.001$) (Fig. 2).
- A strong positive correlation between maximum diving depth and recent diving depth ($r = 0.735$, $p < 0.001$).
- Weak negative correlations between age and recent diving depth ($r = -0.357$, $p = 0.001$) and between recent diving depth and number of recent dives ($r = -0.342$, $p = 0.002$).

TREATMENT AND OUTCOMES

Ninety percent (n = 72) of patients received hyperbaric oxygen therapy based on USN TT 6A. The overall treatment effectiveness was 100%: 72 patients (90.0%) improved, and 8 patients (10.0%) achieved full recovery. All fully

recovered patients had type I DCS and were treated as inpatients. No type II DCS patients achieved full recovery, though all improved. The recovery rate for inpatients was 34.8% (8/23), compared to 0% for outpatients.

DISCUSSION

This retrospective study of 80 commercial divers with DCS in Qingdao identified increasing age and longer diving experience as significant risk factors for severe (type II) DCS. This “experience paradox” challenges conventional assumptions but provides new insights into occupational health risks for commercial divers.

Patients with type II DCS were, on average, 7 years older and had 5 more years of diving experience than those with type I DCS. Several mechanisms may explain this paradox. First, physiological reserve (e.g., cardiovascular function, tissue repair, gas exchange efficiency) declines with age, reducing tolerance to decompression stress [16]. DAN reports have highlighted cardiovascular health as a critical diving safety factor, with many fatalities linked to underlying conditions [14]. Second, long-term diving may cause

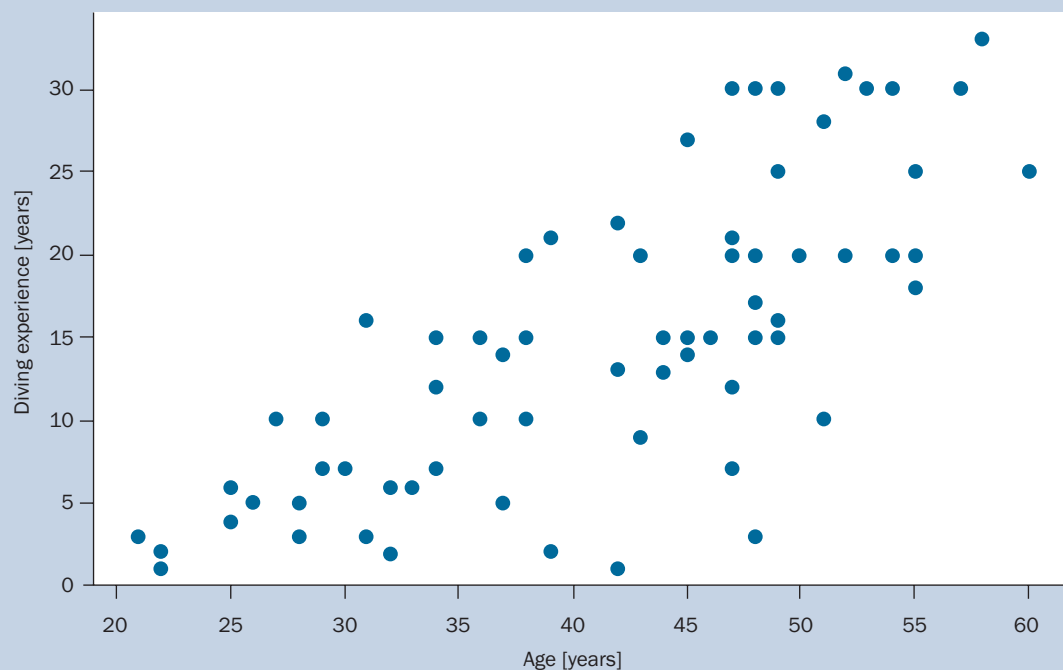


Figure 2. Scatter plot of age versus years of diving experience showing a significant positive correlation ($r = 0.772$, $p < 0.001$)

cumulative subclinical damage (e.g., asymptomatic dysbaric osteonecrosis) that alters hyperbaric stress responses [17]. Third, experienced divers may be overconfident, adopting riskier dive profiles or neglecting safety protocols [18], as supported by the 50% incidence of type II DCS in divers with > 25 years of experience.

Unlike previous studies [12, 13], we found no significant statistical association between diving depth, number of dives, and DCS severity. This may reflect sample homogeneity: all participants were commercial divers with relatively fixed work patterns, limiting variability in dive profiles. Under similar operational conditions, individual physiological factors (e.g., age) may become key determinants of severity.

Stratified analysis in this study showed that age and experience have an interactive effect on DCS severity. The incidence of type II DCS reached 36.4% in the 41–50 age group and 50% among divers with > 25 years of experience, suggesting that these two factors may synergistically increase DCS risk. This finding supports the “cumulative injury hypothesis,” which posits that subclinical damage from long-term diving, combined with age-related decline in physiological reserve, increases the risk of severe DCS.

The study population was 98.8% male, consistent with the commercial diving industry’s gender composition [9, 14].

Due to the small number of female patients, gender-related risks could not be analyzed. The literature on gender and DCS is inconclusive [19, 20], requiring larger samples for clarification. Notably, the only female patient in this study had type I DCS and improved after treatment, consistent with the findings of Webb et al. [19], who found that gender is not a factor in altitude DCS risk.

Hyperbaric oxygen therapy achieved 100% effectiveness, confirming its role as first-line treatment [21]. Full recovery was limited to type I DCS inpatients, likely due to more intensive inpatient care and the involvement of slower-healing tissues (e.g., nervous system) in type II DCS [3]. This underscores the importance of early inpatient management for severe cases. It is worth noting that this study found significantly higher recovery rates in younger patients (≤ 30 years) compared to older patients (42.9% vs. 0–11.1%), a finding with important implications for developing clinical treatment strategies.

Future research directions should include: 1) Conducting multi-center prospective cohort studies to collect more comprehensive data on potential risk factors; 2) Exploring the value of biomarkers (such as inflammatory factors and oxidative stress indicators) in predicting DCS severity; 3) Developing DCS risk prediction models based on age, experience, and other risk factors; 4) Evaluating

the effectiveness of personalized decompression protocols in high-risk populations.

LIMITATIONS

This single-center retrospective study is prone to selection and information bias. Key risk factors [e.g., body mass index (BMI), hydration status, ascent rate] were not collected [10, 11, 22]. The small sample size ($n = 80$) may have reduced statistical power, and variable symptom-onset time data may reflect recall bias. Despite these limitations, our findings align with large-scale Chinese DCS studies [9], supporting their generalizability.

CONCLUSIONS

Increasing age and longer diving experience are independent risk factors for severe DCS in commercial divers. To address this “experience paradox,” targeted interventions are needed: enhanced health monitoring (e.g., cardiovascular screening) for older/experienced divers, refresher safety education to counter complacency, and personalized decompression schedules. Hyperbaric oxygen therapy remains effective, with early inpatient treatment recommended for type II DCS to optimize outcomes. Future multi-center prospective studies should collect comprehensive risk factor data and develop predictive models to improve DCS prevention and management.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement: The source data underlying this manuscript are available from the corresponding author upon reasonable request. Data cannot be publicly shared due to institutional privacy and ethical regulations.

Ethics statement: The study protocol was approved by the Institutional Review Board of the No. 971 Hospital of the PLA Navy in Qingdao. Due to the retrospective nature and de-identification of patient data, informed consent was waived by the ethics committee. All procedures complied with relevant ethical and data protection regulations.

Author contributions: All authors meet the ICMJE authorship criteria:

- WH: Study conception/design, data acquisition, manuscript drafting.
- ZL: Data collection, critical manuscript revision.
- SQ: Statistical analysis, data interpretation, final manuscript approval.

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REFERENCES

1. Mitchell SJ. Decompression illness: a comprehensive overview. *Diving Hyperb Med.* 2024; 54(1Suppl): 1–53, doi: [10.28920/dhm54.1.suppl.1-53](https://doi.org/10.28920/dhm54.1.suppl.1-53), indexed in Pubmed: [38537300](https://pubmed.ncbi.nlm.nih.gov/38537300/).
2. Vann RD, Butler FK, Mitchell SJ, et al. Decompression illness. *Lancet.* 2011; 377(9760): 153–164, doi: [10.1016/S0140-6736\(10\)61085-9](https://doi.org/10.1016/S0140-6736(10)61085-9), indexed in Pubmed: [21215883](https://pubmed.ncbi.nlm.nih.gov/21215883/).
3. Dunford RG, Denoble PD, Forbes R, et al. A study of decompression sickness using recorded depth-time profiles. *Undersea Hyperb Med.* 2020; 47(1): 75–91, doi: [10.22462/01.03.2020.9](https://doi.org/10.22462/01.03.2020.9), indexed in Pubmed: [32176949](https://pubmed.ncbi.nlm.nih.gov/32176949/).
4. Cooper JS, Hanson KC. Decompression sickness. StatPearls Publishing, Treasure Island 2021.
5. China Diving and Salvage Contractors Association (CDSA). CDSA diver risk reduction annual report (2024) - focusing on engineering diving [Internet]. Beijing: China Diving and Salvage Contractors Association; 2025. <https://www.cdsc.org.cn/news/shownews.php?id=3586&lang=cn> (2025 Dec 6).
6. Blogg SL, Harris C, Chimiak J, et al. Diving fatalities. DAN Annual Diving Report 2021 Edition: A report on 2019 diving fatalities, injuries, and incidents. Durham (NC): Divers Alert Network; 2025. <https://www.diversalertnetwork.org/reports/annual-diving-report>.
7. Liu WW, Wang D, Chen H, et al. Current status of decompression illness in China: analysis of studies from 2001–2011. *Undersea Hyperb Med.* 2013; 40(1): 41–48.
8. Qiu S, Xue Y, Zeng Z, et al. Study of chronic health influencing factors and their preventive measures for divers based on big data analysis in diving medicine. *Applied Mathematics and Nonlinear Sciences.* 2024; 9(1), doi: [10.2478/amns-2024-2682](https://doi.org/10.2478/amns-2024-2682).
9. Xu W, Liu W, Huang G, et al. Decompression illness: clinical aspects of 5278 consecutive cases treated in a single hyperbaric unit. *PLoS One.* 2012; 7(11): e50079, doi: [10.1371/journal.pone.0050079](https://doi.org/10.1371/journal.pone.0050079), indexed in Pubmed: [23185538](https://pubmed.ncbi.nlm.nih.gov/23185538/).
10. Pińkowska O, Podstawka Z, Byś A, et al. Risk factors of decompression sickness in scuba diving. *Journal of Education, Health and Sport.* 2020; 10(9): 569–576, doi: [10.12775/jehs.2020.10.09.069](https://doi.org/10.12775/jehs.2020.10.09.069).
11. Zhou M, Zhu B, Qing L, et al. Body hydration status and decompression sickness. *J Environ Occup Med.* 2024; 41(7): 834–40, doi: [10.11836/jeom24012](https://doi.org/10.11836/jeom24012).
12. Suzuki N, Yagishita K, Togawa S, et al. A case-control study evaluating relative risk factors for decompression sickness: a research report. *Undersea Hyperb Med.* 2014; 41(6): 521–530, indexed in Pubmed: [25562944](https://pubmed.ncbi.nlm.nih.gov/25562944/).
13. Tang X, Ma X, Li Z, et al. Influencing factors of acute decompression sickness in diving fishing operators in Dalian city (in Chinese). *Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi.* 2013; 31(9): 678–680.
14. Tillmans F. DAN Annual Diving Report 2020 Edition: A report on 2018 diving fatalities, injuries, and incidents. Divers Alert Network 2021.
15. National Occupational Health Standards of the People's Republic of China. Diagnostic standard for occupational decompression sickness. <https://www.niohp.com/sndt/202511/W020251128681690880766.pdf> (23.12.2025).

16. Sulaiman ZM, Pilmanis AA, O'Connor RB. Relationship between age and susceptibility to altitude decompression sickness. *Aviat Space Environ Med.* 1997; 68(8): 695–698, indexed in Pubmed: [9262810](#).
17. Bennett PB, Elliott DH, Brubakk AO. *Bennett and Elliott's physiology and medicine of diving.* Elsevier, Amsterdam 2003.
18. Pollard GW, Marsh PL, Fife CE, et al. Ascent rate, post-dive exercise, and decompression sickness in the rat. *Undersea Hyperb Med.* 1995; 22(4): 367–376, doi: [8574124](#).
19. Webb J, Kannan N, Pilmanis A. Gender Not a Factor for Altitude Decompression Sickness Risk. *Aviat Space Environ Med.* 2003; 74(1): 2–10.
20. Conkin J. *Gender and Decompression Sickness: A Critical Review and Analysis.* Houston, TX: NASA Johnson Space Center. NASA/TM-2004-212056 doi. 2004.
21. Moon RE, Mitchell SJ, Moon RE, et al. Hyperbaric Treatment of Air or Gas Embolism: Current Recommendations. *Undersea Hyperb Med.* 2025; 52(1): 41–53, indexed in Pubmed: [40249721](#).
22. Mendez-Dominguez N, Huchim-Lara O, Chin W, et al. Body mass index in association with decompression sickness events: cross-sectional study among small-scale fishermen-divers in southeast Mexico. *Undersea Hyperb Med.* 2018; 45(4): 445–451, indexed in Pubmed: [30241124](#).

Physiological and behavioral responses to extreme cold-water diving and thermal stress: recommendations for the polar diver

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ABSTRACT

As access and exploration of polar regions has expanded in the past two decades due to greater interest and technology, more recreational scuba divers are exploring these more remote cold-water locations. Polar, or extreme cold-water, diving is a more physically demanding form of scuba diving, and divers need to better understand the effect of near-freezing water temperatures on human physiology. Changes in both physiological and behavioral functions may occur quickly in these types of environments and present the scuba diver with a potentially more challenging and dangerous environment. Divers with significant experience in more temperate warm-water locations may overestimate their ability to manage extremely cold water and underestimate the effect of near-freezing water temperatures on their body and diving capacity. More scuba training organizations need to better educate and prepare divers for this type of diving and should consider adding more environmentally specific information in their educational programming. With a better understanding of how the body responds to cold-water diving and the methods utilized to manage thermal changes and stress in extreme conditions, dive safety and performance will be improved, and the increased risks associated with diving in extreme environmental conditions may be managed more effectively with the purpose of increasing diver safety.

(Int Marit Health 2026; 77, 3: 175–185)

Keywords: polar, cold-water, scuba, diving, physiology, safety

INTRODUCTION TO EXTREME COLD-WATER DIVING

Scuba diving activities are often associated with warm water locations that provide for long dives in temperate conditions with minimal concerns of temperature changes and their effect on the body. Diving associated with colder water conditions and regions is often still performed in temperatures well above freezing; diving the Great Lakes in the United States, offshore of the British Isles, and wreck diving in the Baltic are examples of dive locations considered cold-water locations. However, with greater opportunities for divers to participate in dive activities in the polar

regions due to increased tourism and scientific exploration in these parts of the world, there is a greater need for an understanding of the thermal stress that occurs when diving in waters near freezing in an effort to educate and inform divers who may not understand the specific physiological responses that occur in cold water. Many expedition companies such as National Geographic/Lindblad Expeditions and Northern Explorers are expanding their reach into more remote and extreme polar locations that allow for individuals to experience extreme cold-water diving conditions. Thus, the goal of this review is to examine research that focuses on extreme cold-water immersion and diving, with an emphasis

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on the extreme thermal conditions seen in the polar regions and provide recommendations and safety protocols for the polar cold-water diver.

Extreme cold-water diving presents multiple issues to the diver and requires both an advanced set of skills as well as a strong understanding of the effects of cold water on both human physiology and movement capabilities. Researchers have long examined the effects of cold water on physiological changes [1] and motor skill performance [2]. Changes in cardiac performance [3], respiration [4], and motor skill performance [2] are all significantly altered and typically impaired in the extremely cold water associated with polar diving [5]. Tactile ability and manual dexterity, necessary for safe diving and equipment usage, have been shown to be significantly impaired in temperatures well above those typically seen in polar diving [6]. Even a moderate decrease in water temperature can result in physiological alterations that may impair the ability of the cold-water diver to maintain optimal functioning during an extended dive [7]. In fact, survival times in water below 20° Fahrenheit (−6.7 °C) have been shown to be severely limited [8]. Therefore, divers who typically dive in the extreme cold need to understand the physiology of diving in these temperatures, understand how to mitigate the difficulties associated with this type of diving, and be aware of how to manage the thermal stress and post-dive physiological changes safely.

Some literature examines polar diving operations for the purpose of describing the specific operations needed when in a polar environment, specifically the Antarctic continent [9]. The goal of a paper by Pollock [9] was to provide the reader with an understanding of the necessary logistical processes needed for scientific diving to be safely performed at McMurdo Station, Antarctica. Scientific divers under these conditions are required to follow specific diving protocols dictated by the United States National Oceanic and Atmospheric Administration and the National Science Foundation, and they often have technical support on-site when performing Antarctic dives. The role of this current review is to examine more general considerations and recommendations for both recreational and professional divers who dive in extreme cold water but may not be supervised or guided by specific regulations and protocols from organizations, with an oversight of how dive operations may be safely conducted.

THERMOREGULATION

When examining the thermoregulatory challenges that face the extreme cold-water diver it is important to separate the body into separate areas, or compartments [10]. These functional compartments include peripheral structures

of the body, including the extremities of the body, such as the arms and legs. The core would be considered the second functional compartment and would include the structures of the head, the neck, and the trunk, or the torso. Both of these compartments play a significant role in the body's attempt to manage excessive cold during dives, and it is necessary to understand how each compartment manages a significant decrease in external thermal conditions.

Physiologically, the body will attempt to maintain internal core temperature at the expense of the extremities and other peripheral body structures. The goal during extreme cold is to maintain internal core temperatures of the critical organs (heart, brain, and lungs) of the human body by preventing significant heat loss that occurs during blood flow from the core of the body to the extremities. Thus, the goal of the brain and other thermoregulatory structures is to try to minimize blood flow from the core and central organs through specific changes in the blood vessels that redirect blood away from the periphery. Without a change in blood flow, as the blood recirculates through the core, that blood will continue to pick up heat for transport to the periphery, resulting in continued chilling of the core structures. As the core temperature drops precipitously, changes in physiological and motor function rapidly occur that will lead to severe physical and mental impairment in the diver. Although this helps manage internal core temperature during extreme cold outside of an aquatic environment, as we will see, it results in significant changes in motor function that can significantly impair a diver in extremely cold water.

Adam [11] has suggested four different stages that occur upon cold-water immersion in individuals. These include the initial responses to cold-water immersion (Stage 1), a short-term period of immersion (Stage 2), long-term immersion (Stage 3), and a period of post-cold-water immersion (Stage 4) (Tab. 1). Most research suggests that severe hypothermia occurs as the duration of the immersion reaches late Stage 2 to Stage 3 in most average human beings [11].

Table 1. Stages of cold-water immersion [11]

Stage of cold-water immersion	Time in cold water
Stage 1	0–3 minutes immersion
Stage 2	3–15 minutes immersion
Stage 3	Greater than 30 minutes immersion
Stage 4	Post immersion

This, of course, does not take into account thermal protection as worn by cold-water divers, but it provides insight into the physiological progression that occurs while diving in extreme cold. Divers in the extreme cold will vary in their physiological response based upon individual physical differences, dive time, and thermal protection.

As homeothermic (warm-blooded) creatures, human physiology is in constant flux to maintain a stable internal temperature. Most human beings have a set-point internal core temperature of 98.6° Fahrenheit (37 °C), but that internal temperature can significantly change with changes in environmental, metabolic, and physical conditions. During extreme cold-water diving the primary goal of the thermoregulatory center of the brain is to maintain internal core temperature by minimizing heat transfer and heat loss to the environment. The thermoregulatory center of the brain is located in the preoptic-anterior hypothalamus and acts as the body's thermostat. The primary role of the preoptic-anterior hypothalamus is to activate and control the various mechanisms that the human body utilizes to regulate both the heating and cooling of the human body. The preoptic-anterior hypothalamus initiates its control of body mechanisms as a result of information it receives from thermoreceptors located throughout the body. These peripheral thermoreceptors are specialized cells that are stimulated by changes in both internal and external temperature variations and act as the initial stimuli that ultimately result in thermoregulation of body temperature. The specialized cells are located throughout the entire body but are most densely concentrated in the skin and the central nervous system. The brain also houses what are called central receptors that respond to the temperature changes of the circulating blood. As the blood circulates through the blood vessels of the brain and increase or decrease in the temperature of the circulating blood, it results in the initiation of reflexive changes that act to conserve or help eliminate heat within the blood and human body. It is both these peripheral and central receptors that ultimately allow for the fine-tuned regulation of internal core temperature.

MECHANISMS OF HEAT TRANSFER

As previously stated, as a homeothermic organism, the human body is constantly trying to manage changes in internal core temperature. The human body has four specific mechanisms that play a role in heat transfer and maintenance. These include conduction, convection, radiation, and evaporation. Each one of these processes plays a significant role in maintaining internal core temperature when diving in extreme polar conditions. Conduction refers to the mechanisms of heat transfer due to direct contact between the body and another solid object in the environment. A diver sitting directly on a bench or other type

of platform while either gearing up before a dive or on a boat on the way to a dive site is a scenario in which there is direct heat transfer between the diver and the environment. While diving, most of the heat loss will occur through conduction due to direct contact between the diver's body and the water. Convection is related to the process of heat transfer that occurs due to the movement of a gas or liquid across the human body. Wind chill is an example of this process: as the wind increases in speed and strength across the body, an increase in the gradient between the temperature of the body and the air increases and more heat is directly lost. A diver in a windy environment would have greater heat loss than if there was no wind present. More significantly, a diver performing a dive with a significant current can also see a significant shift in their body's ability to maintain core temperature. The greater the movement of the water across the body during a dive, the faster heat loss will occur. Radiation is the process of transferring heat through infrared waves. A diver sitting in the warm sun will feel an increase in temperature due to the direct light energy that is transferred to the body through the skin. Finally, evaporation refers to the transfer of heat due to the change of molecules from liquid form to a gas. During that transfer, heat is lost and emitted into the environment. For the diver in an extreme cold-water environment, it is imperative for the diver to avoid sweating and create a scenario where evaporation may occur inside of a drysuit. Excess sweat in a drysuit during a polar dive will quickly lead to significant body chilling. In fact, managing exertion and sweat production is one of the most important considerations for polar divers.

PHYSIOLOGICAL CHANGES AS A RESULT OF EXTREME COLD-WATER EXPOSURE

When the thermoregulatory mechanisms of the body begin to fail to manage temperature changes effectively, the body can potentially reach a hyperthermic or hypothermic state. Hyperthermia occurs when the body is unable to regulate and dissipate internal heat and the body cannot manage this extra heat stress effectively. This is not typically a concern for the polar diver in extreme cold. Hypothermia is a condition that all divers need to manage, especially when diving in extremely cold conditions (Tab. 2). Hypothermia occurs when the body is faced with a significant imbalance between internal core temperature and environmentally cold conditions. Clinical hypothermia occurs when the body's internal core temperature goes below 95° Fahrenheit [12]. This does not include the lowering of the skin temperature however, thus initial responses to extreme cold water may not be indicative of a true hypothermic condition.

As the body begins to chill during a cold-water dive, significant changes in physiology and behavior will begin

Table 2. Symptoms of hypothermia [from National Oceanic and Atmospheric Administration (NOAA) Diving Manual — Diving for Science and Technology, 2013]

Core temperature	Physical and cognitive symptoms of potential hypothermia
Below	Chilling
C (F) [°]	
37 (98.6)	Cold sensations, skin vasoconstriction, increased muscle tension, increased oxygen consumption
36 (97)	Sporadic shivering suppressed by voluntary movements, gross shivering bouts, further increase in oxygen consumption, uncontrollable shivering
	Moderate hypothermia
35 (95)	Voluntary tolerance limit in lab experiments, mental confusion, impairment of rational thought, possible drowning, decreased will to struggle
34 (93)	Loss of memory, speech impairment, sensory function impairment, motor performance impairment
33 (91)	Hallucinations, delusions, partial loss of consciousness, in shipwrecks and survival history, 50% do not survive, shivering impaired
	Severe hypothermia
32 (90)	Heart rhythm irregularities, motor performance grossly impaired
31 (88)	Shivering stopped, failure to recognize familiar people
30 (86)	Muscles rigid, no response to pain
29 (84)	Loss of consciousness
27 (80)	Ventricular fibrillation, (ineffective heartbeat), muscles flaccid
26 (79)	Death

to occur to the unprepared diver (Tab. 1). Two of the initial changes that the cold-water diver will notice are the increase in physical fatigue with continued physical effort and changes in manual dexterity. Along with these initial physical changes, the diver may begin to experience problems with cognitive attentional capacity and may begin to lose the ability to focus on diving tasks. Shivering may also begin to occur that can impact the ability of the diver to manage functional motor skills needed to dive safely, manage equipment, or more importantly, allow them to physically exit the cold-water conditions. As body temperature continues to drop during an extreme cold-water dive, further decreases in core temperature result in more severe physiological and behavioral changes that significantly increase diver safety (Tab. 3).

How does the extreme cold-water diver manage their susceptibility to hypothermia during an extended period? The first obvious factor is the temperature of the water to which the diver is exposed. Polar diving typically occurs in water temperatures close to freezing (32 °F/0 °C). Before a cold-water dive the diver needs to assess whether these conditions can be managed and whether he/she has the ability to deal with those extreme temperatures safely and effectively. Some of the questions that the diver needs

to ask themselves include the following: Am I comfortable with the exposure protection (drysuit) that I'm wearing? Do I feel I have the ability to remove myself quickly from the water when needed? Does the dive actually need to occur under extreme cold-water conditions? Do I have surface support in case of an emergency?

The second major factor that plays a role in hypothermia during extreme cold-water diving is the type of exposure protection the diver is wearing during the dive. Polar diving mandates a drysuit as the type of exposure protection required for these extreme conditions. Research has shown that specialized clothing or suits designed for the extreme cold provide much better thermal protection by reducing the loss of heat and slowing the rate of temperature loss [13]; drysuits offer the best possible thermal protection in these environments. A wetsuit, even of significant thickness, will not prevent hypothermia from occurring within a short period of time in water temperatures just above freezing. Thus, a drysuit with the appropriate undergarments is necessary. The primary role of the drysuit is to prevent direct contact of the skin and body with the water; thus, as long as the diver is dry, the material used for the drysuit is sufficient in warmer water. In extreme cold-water diving,

Table 3. Hypothermia and diving tasks

Symptoms of hypothermia in the extreme cold-water diver	Impaired dive-specific tasks
Loss of manual and finger dexterity	Inability to manage equipment or communicate with other divers
Shivering	Diver may uncontrollably shake while at depth
Confusion	May not understand proper signaling, may perform inappropriate tasks, or lack an understanding of simple instruction
Behavioral changes	May demonstrate poor diving technique or poor judgement when performing dive-related tasks
Poor motor response times	Inability to manage diving-related tasks quickly and safely
Loss of coordination	Inability to maintain mouthpiece in the mouth during a dive

undergarments are the key to maintaining internal core temperature and preventing the onset of hypothermia. These undergarments should be designed and layered in such a way as to trap the metabolic heat produced by the body during the dive and prevent its transfer to the environment. A secondary purpose of these types of undergarments is to prevent the buildup of perspiration by the body in an effort to prevent heat loss due to evaporation and conduction. This is accomplished by the design of both synthetic and wool garments that transfer moisture from the surface of the skin to the outermost layer of the undergarments. When used correctly, it is not unheard of for a diver in extreme cold-water conditions to exit a dive and find their undergarments extremely wet to the touch when removing their drysuit; if the undergarments are appropriate for the diver and the conditions, the diver's skin should still be dry to the touch and their internal core temperature should still be near normal.

EXTREME COLD-WATER DIVING PHYSIOLOGICAL RESPONSES AND ADAPTATIONS

Although significant research has examined the effects of cold-water immersion, there is limited research that has examined scuba diving in extreme cold water specifically. Researchers have demonstrated that prolonged cold-water immersion significantly impairs physical movement capabilities as well as cognitive factors and significantly increases the safety of the individual [14]. Another factor that is associated with increased risk during cold-water conditions is the effect that the cold water has on the possibility of decompression illness in divers [15]. Decompression illness, also known as decompression sickness (DCS), occurs when the body is unable to eliminate the elevated levels of nitrogen that saturate the cells of the body during either long or deep dives. Although DCS is most often associated with the overall time and depth of a dive, extreme cold increases

the risk due to the slowing of blood flow through the vascular system as a result of increased vessel vasoconstriction (narrowing of the arterioles) and changes in blood hemodynamics. Slower blood flow results in slower off-gassing of saturated nitrogen and may lead to DCS symptoms, which can range from joint pain and ear issues to loss of motor and sensory function, and ultimately, death.

When examining data on scuba diving injuries and accidents, changes in cardiovascular function during diving activities are often implicated in severe injury or death [16]. Heart attacks and related events are the primary factors that play a role in most diving deaths. This may be due to multiple factors, including the age of the diver, overall physical health, number or risk factors related to cardiovascular disease, or changes in environmental conditions that result in extreme metabolic demands and stress. Therefore, examining the effect of extreme cold on cardiovascular function is essential for the diver who participates in extreme environments.

Heart rate and cardiac contractility of the heart are partially controlled through mechanisms of the autonomic nervous system, specifically the sympathetic and parasympathetic systems that help regulate heart rate variability. Activation of the sympathetic system, also known as the "fight or flight" system, acts to increase contractility and blood flow while the parasympathetic system works in opposition and, when activated, lowers heart rate response and related cardiac functions. During extreme cold-water diving, there is the potential for these systems to be activated concurrently, increasing the potential for cardiac arrhythmia and sudden death during a dive [17].

One of the well-known effects of immersion in humans is the diving reflex that occurs upon entry into water [18]. This reflex response occurs once an individual begins to immerse themselves underwater and the water stimulates the skin thermoreceptors of the face. The primary role of the diving reflex is to maintain oxygen levels in the blood

in an effort to provide the metabolic energy sources necessary for sustaining life during prolonged periods underwater without access to air. Apnea, (breath-holding), decreased respiration rate, decreased blood pressure, lowered heart rate (bradycardia), and peripheral vasoconstriction are all immediate physiological changes that occur as a result of water immersion [10]. Although cold-water divers are typically wearing exposure protection during a dive, entry into extreme cold will still reflexively result in a varied physiological parasympathetic response.

Conversely, during sudden immersion in cold water, the human body will also demonstrate the cold shock reflex [18], which is an autonomically controlled response to sudden immersion in cold water. The cold shock response is also known as a part of cold-water immersion syndrome. Upon sudden entry into cold water and immediate cooling of the skin, the sympathetic nervous system causes uncontrollable respiratory inhalation (gasping), a rapid increase in heart rate (tachycardia), hyperventilation, and ultimate vasoconstriction in the blood vasculature to prevent immediate heat loss from the core [19, 20]. Cardiorespiratory responses to sudden cold-water immersion present minimal risk to healthy individuals; however, the risk of a cardiac event increases in people with hypertension or coronary artery disease. Because many divers that participate in extreme cold-water diving are older (due to both time and financial considerations) and may have these types of cardiac conditions, immersion in the extreme cold should be reconsidered or at a very minimum, appropriate exposure protection needs to be strongly considered and used to minimize a cold shock response. The use of full-face masks (FFM), instead of a standard face mask that only partially covers the face, has been shown to potentially attenuate the potential for a cold shock response in extreme cold [4], although a FFM does not appear to prevent respiratory issues such as the narrowing of the airway.

Although both the diving reflex and cold shock response are both normal physiological responses to immersion in cold water, these two conflicting reflexive mechanisms may lead to potential significant cardiovascular and cardiac events that may result in significant injury or death. Lundell et al. [21] examined the effects of cold-water diving in the Arctic region on heart rate variability in navy divers. Their results suggest that although the diving reflex occurs immediately upon entry into the cold water, the associated changes decrease very quickly, suggesting that the parasympathetic activity associated with the diving reflex is altered due to a concurrent increase in sympathetic activity. As both systems within the autonomic nervous system are being activated nearly at the same time, this coactivation of both branches of the autonomic nervous system may potentially

lead to alterations in the electrical cardiac cycle of the heart and potentially cause cardiac arrhythmias that can lead to sudden death [17]. Thus, it is important for the polar cold-water diver to understand both of these mechanisms and adjust their diving behavior accordingly in an effort to minimize the cardiac risks.

PRE-DIVE RECOMMENDATIONS FOR THE EXTREME COLD-WATER DIVER

There are many obvious ways that a cold-water diver can manage the extreme thermal stress that they face during diving operations. Before even beginning a dive, the diver needs to pay particular attention to the dive conditions. This includes knowledge of the water temperature but should also include an understanding of any current or surge conditions that may be present. Significant current can add to the thermal stress through an increase in cold stress occurring from the process of conduction of heat away from the body during dives. Additionally, increased current may make exiting the water significantly more difficult and time consuming; this concern is particularly important because a flooded drysuit or dry glove may make a quick exit imperative. Any significant ingress of water during an extreme cold-water dive should be considered an immediate reason for ending a dive. Unlike temperate conditions, even a small amount of water can cause significant chilling of the body and result in potential hypothermic conditions.

Selecting the correct undergarments is critical for proper temperature regulation under extreme cold conditions. Many manufacturers provide significant options for the cold-water divers; most of these provide high loft (for trapping air) and moisture wicking properties to help remove perspiration from the skin. In addition to the type of garments, the diver needs to be particularly cognizant of the fit of the undergarments and drysuit. Too large of a fit may increase the amount of air trapped within the suit and therefore negatively affect the inherent buoyancy of the diver and cause an increase in energy expenditure (and resultant perspiration), while too tight of a fit increases the restriction that the drysuit imposes on functional movements during a dive. As extreme cold results in impaired motor function, the diver needs to make sure no impairments in the fit of the drysuit limit movements, especially movements that are necessary for exiting the water. More recently, undergarments have been manufactured that produce warmth through an electrical heating element built into the clothing. These provide significant warmth during a cold-water dive, but there is a potential for the electrical elements to fail, possibly increasing the risk of DCS due to sudden changes in core temperature. More research examining the efficacy and safety of these types of garments needs to be

conducted before they are considered a standard piece of cold-water diving equipment.

Along with the appropriate drysuit and undergarments, the extreme cold-water diver needs to consider the type of head and hand protection most appropriate for their specific diving needs. A neoprene hood is the standard type of head protection that is used in cold water, and the diver typically needs to simply decide how much thermal protection is needed for comfortable diving; the level of thermal protection is dictated by the thickness of the neoprene layer used for construction of the hood. Typically, in polar waters, a 7–8 mm hood thickness would be recommended for most divers and types of diving operations. Choosing the proper hand protection provides more options and potential choices for cold-water conditions. Divers can choose between neoprene gloves of varying thickness or dry gloves that prevent direct contact with the water. Dry gloves typically consist of an outer waterproof glove that is paired with an inner liner that provides greater warmth by staying dry; however, if the interior gets wet it loses thermal protection quickly. Considerations regarding the manual dexterity needs of the diver during diving will often dictate the type of hand protection used. Dry gloves often provide more tactile “feel” for the diver, depending on the level of protection under the waterproof glove while diving, but they risk complete loss of function due to a leak. Polar divers should practice with both types of glove systems and determine what is more practical for their specific diving needs and choose the appropriate form of thermal protection accordingly.

Time and depth considerations are important to minimize the risk of diving in extreme cold conditions. Time considerations are often variable depending on the specific requirements of the dive itself. If diving with a particular goal or “mission,” the dive time may be dictated by the need to accomplish specific tasks. However, dives of over 30–40 minutes should be avoided, even when the diver feels that the thermal protection is adequate. Although they may not be feeling chilled, their internal core temperature will have dropped, and they most certainly will be more physically fatigued from the cold; any sudden emergency that requires significant changes in the dive plan or major energy expenditure requirements may result in an increased risk for the diver.

Depth limitations should also definitely be considered and utilized under most polar-type conditions. Any extreme depth potentially increases the thermal stress on the diver, but more likely, it will present increased challenges on the dive equipment, and any equipment malfunction, most importantly a free-flowing regulator, will create inherent risk to the diver. A free flow in a regulator would typically result from the freezing of internal components and result in an uninterrupted release of air (or gas) that the diver may not be

able to turn off, resulting in a rapid loss of breathing gas. This can quickly result in a life-threatening situation and needs to be managed quickly and efficiently. Although equipment configurations can be used to increase redundancy in that type of emergency event (two independent tanks and regulator systems) in polar conditions, the diver should try to limit depths to no more than 60 feet (18.7 meters), unless mission requirements require greater depth. The United States Navy limits diving depths to no more than 60 feet, and the National Oceanic and Atmospheric Administration also limits maximal diving depths for the safety of their polar divers [12].

Excessive metabolic heat production occurs as a result of the energy needs of the body. Cold-water divers need to avoid any excess movements prior to a dive in an effort to limit metabolic energy use and the resultant heat production. Although it may sound counterintuitive, excess heat production before a drive leads to excessive perspiration. Even with the proper undergarments that are designed to wick perspiration away from the skin, increased sweating will lead to significant chilling and potential hypothermia. Thus, extreme cold-water divers need to manage pre-dive energy expenditure and excessive heat by minimizing unnecessary movements, moving in a slow and controlled manner when putting on gear and preparing for the dive, and using the assistance of others to help with any movements or needs prior to entering the water. Excess sweating should be avoided at all costs, and if it occurs, the dive should be called off or the diver should take time to dry off and prevent chilling before continuing with dive operations.

The cold-water diver should also be educated about the role that body structure plays on heat transfer in an effort to manage excess heat loss. Research into thermoregulation and the human body has long examined the role that a specific body type plays on thermal stress and transfer of heat [22]. Body type is often classified using a specific somatotype [10]. These somatotypes include the ectomorphic body type, which is usually classified as a tall, lean body, with minimal body fat or excessive musculature. The mesomorphic body type describes a more muscular and strong type of structure, while the endomorphic body is usually described as being short with greater amounts of body fat. When it comes to diving in cold water, the diver with the mesomorphic or endomorphic somatotype will have less heat loss when compared to the ectomorphic diver due to the insulative properties of both muscle and body fat. Therefore, understanding one’s personal body composition and structure will help the diver determine the level of layering needed under a drysuit in an effort to retain heat. Additionally, with exercise and physical training, a diver may also be able to increase musculature in an effort to naturally improve the functional insulative capacity of their body, as well as

increase their functional fitness for diving. Researchers have suggested that one of the additional benefits of regular exercise for cold-water divers is that regular exercise may alter the responsiveness of the autonomic nervous system during cold-water immersion, thus potentially decreasing the “strength” of the cold shock response and minimizing autonomic conflicts that may lead to a cardiac event [23].

Along with the physical changes that occur with increased exercise and physical training in the polar diver, increased physical fitness also needs to be considered when planning extreme cold-water dives. Increased physical fitness will result in less metabolic energy being used before, during, and after the dive and result in less perspiration and potential chilling of the body. Additionally, improved cardiorespiratory and muscular function will result in increased efficiency when diving and make exiting the water much more manageable and efficient. Finally, improved physical fitness will decrease the risk of excessive breathing during periods of increased physical exertion during a dive and prevent the potential of “overbreathing” the regulator. When energy demands increase during a dive, the body will increase blood flow and breathing rate in an effort to circulate oxygen in the body quickly and meet the energy needs of the body at that time. Overbreathing the regulator occurs when a diver continues to breath heavily and rapidly during the dive. This places stress on both the body and the regulator. Under polar-like conditions, this increase in respiration rate may result in a rapid freezing of the regulator, leading to a malfunction and free-flow scenario. Improved physical fitness will allow the cold-water diver to avoid overbreathing a regulator and may prevent an unsafe free-flow scenario from occurring during the dive due to increased respiratory stress on the regulator.

Finally, extreme cold-water divers should try to avoid using breathing gas that may lead to a more rapid loss in body heat, such as helium. Commercial and technical divers often use helium to replace some of the oxygen present in normal atmospheric air due to oxygen becoming toxic to the body at deeper depths (over 180–200 feet). Helium significantly increases thermal conductivity and results in faster chilling of the body. As deep extreme cold-water diving should typically be avoided due to the increased risks associated with equipment failure and hypothermia during potentially required decompression stops, these types of breathing gases need not be considered. Polar divers should avoid using helium or any other gas that results in rapid heat loss, even if wearing significant thermal protection.

IN-WATER RECOMMENDATIONS FOR THE EXTREME COLD-WATER DIVER

As previously noted, there are significant precautions the cold-water diver can take prior to the dive to help manage

the thermal stress they will face when diving in water near freezing. However, there are also significant actions that need to be taken in the water during the dive. The most important is that the diver needs to be focused on their internal body temperature throughout the dive and limit the dive based on the severity of the cold. Many divers may continue the dive until they feel chilled before exiting the water. Under extreme cold conditions, the diver needs to end the dive prior to any significant chilling if safety is of utmost importance. When diving in extreme cold-water temperatures, particularly in the high Arctic or Antarctica, many dives take place from smaller dive platforms or boats that are used to navigate the typical icy conditions. Usually this necessitates that the diver backrolls into the water at the start of the dive but will need to remove his/her gear and exert significant energy to propel them out of the water into the side of the boat. Although assistance is usually available, extreme cold-water divers need to maintain the manual dexterity and energy to exit the water and enter the boat at any time. Thus, if the diver waits too long and is significantly chilled, or mildly hypothermic, they may lack the necessary motor abilities to get themselves out the water. If they cannot exit the water efficiently and quickly, continued immersion may rapidly lead to the continued onset of hypothermia and increase the risk of severe impairment or even death. Divers under these types of environmental conditions need to be extremely self-aware of their body and temperature changes during the dive and have the ability to “turn” a dive earlier than others might expect. Self-discipline in these situations is the key to safe diving in extreme cold.

Full-face diving masks have become more popular over the last 10 years due to greater coverage of the face and potential communication capabilities for divers. Unlike standard masks, the majority of the face is covered by the FFM during dive operations. By decreasing the cold sensations against the skin thermoreceptors in extremely cold water, the cold shock response may be lessened and both the physical discomfort of the diver and the potential for concurrent autonomic nervous system stimulation leading to potential cardiac issues may be decreased. Although the use of FFM requires additional training and requires the cold-water diver to develop new skills in the event of a flooded mask at depth, extreme cold-water divers may want to consider their usage due to the effects on thermal stress and physical comfort in the extreme cold.

The selection of a regulator specifically designed for cold water and Arctic-types of environments is critical for safety and performance in extreme cold [24, 25]. Many of the scuba regulators on the market today are designed to perform in more typical tropical and temperate environments because most active scuba divers are more inclined to undertake warm-water diving. Although most of these

regulators are designed for high performance and safety, they often lack the engineering needed to avoid freezing in the extreme cold. Most cold-water regulators that are used in polar environments are designed to enhance the warming of the regulator during breathing in an effort to decrease the risk of freezing the internal mechanism. Additionally, these polar-type regulators are environmentally sealed, a method of design and manufacture that minimizes or prevents direct contact with the freezing water, thus decreasing the risk of freezing and a subsequent free flow scenario. Although trained divers are prepared for free flow situations, when diving in Arctic or Antarctic regions, and potentially under the ice, a free flow at depth can quickly develop into a significant emergency situation. Proper scuba regulator selection is important to prevent technical issues that can result in major injury or death in the extreme cold of the polar regions.

Finally, even before participating in extreme cold-water diving, trained and safety-conscious scuba divers will benefit from a specific acclimatization program designed to prepare them for extremely cold conditions. Acclimatization to the extreme cold experienced in polar diving has long been shown to be possible with the right methods and training [26]. Acclimatization is a long-term physiological process that occurs over many weeks and months, as opposed to physiological acclimation, which is a shorter-term adaptation to extreme cold [27]. Extreme cold-water divers should spend time diving in progressively colder water over months of preparation prior to diving in polar regions. Through progressive cold-water adaptation, the chilling effect of the extreme cold will be attenuated and slower under actual Arctic conditions. Progressive acclimatization will not prevent chilling or hypothermia, but it will allow a cold-water diver to maintain core temperatures longer, thus expanding the ability

to remain in extreme cold water as well as increasing both the safety and performance of the diver.

RE-WARMING AFTER EXTREME COLD-WATER DIVING

Upon the conclusion of a polar dive, regardless of the time in the water and chilling effect, the diver needs to be aware of the thermal effects of the dive and manage the rewarming process effectively. All cold-water divers need to be aware of the afterdrop effect following a cold-water dive. Following immersion in cold water, it is not uncommon for a person to notice a continued decrease in core temperature and cooling of the body even after exiting the cold water and during the initial stages of rewarming. Current research suggests that afterdrop in temperature is thought to be due to heat convection changes immediately post-immersion [28]. Rewarming following an extreme cold-water dive should include structured exposure to warmer conditions, such as drying off and removing wet garments as soon as possible, immediate removal from the wind, and post-dive immersion in a tub of warm water (Tab. 4), and it should continue until the body core temperature returns back to normal.

CONCLUSIONS

Extreme cold-water diving continues to grow in popularity due to advances in dive equipment, training, and improved access to polar-type environments. More and more divers with little cold-water experience are diving in polar environments due to increased travel opportunities that allow access to these remote locations. Because many of these divers are not trained by or associated with agencies that prepare divers specifically for polar diving, a greater understanding of the physiological and behavioral changes that occur due to the thermal effects of immersion in extreme

Table 4. Rewarming considerations for the extreme cold-water diver

Rewarming post-dive recommendations (assuming the dive occurs from a Zodiac or similar type of small craft typically used in polar regions)
1. Exit water as quickly as possible. Remove diving equipment, leave in the water, and retrieve once onboard craft. Dive equipment typically makes it more difficult to exit the water, and decreasing maximum time spent in extremely cold water is important
2. If excess sweating has occurred, remove thermal protection to prevent continued sweating
3. If possible due to environmental exposure (open watercraft), dry the body off as quickly as possible, particularly the head and extremities
4. Remove wet undergarments and replace with dry moisture-wicking clothing in multiple layers
5. If in open watercraft, get out of the wind and into the sun for gradual rewarming
6. Drink warm (not excessively hot) liquids such as tea. Coffee is not recommended
Do not try to rewarm the core excessively fast as this can cause significant physiological changes that can lead to thermal stress and potential injury or death. Gradual rewarming is the key

Table 5. General recommendations for the extreme cold-water/polar diver

1. Educate oneself about basic cold-water physiology and how the human body reacts to immersion in extremely cold water
2. Train with different types and configurations of cold-water exposure protection (including gloves and hoods) to determine what works best for you, and master the skills needed for safe diving. Drysuit expertise takes time and training
3. Dive and train in progressively colder water to habituate and acclimate to diving under extreme conditions. Do not make your first cold-water dive a polar dive. Master diving skills in that type of environment well before the extreme cold of polar regions
4. Master physical self-awareness and limit the dives to a maximum of 30 minutes. Exit the water before you become significantly chilled. Depending on exposure and mission requirements, these times may be lengthened as a diver's comfort in the extreme cold increases
5. Exercise. Improvements in strength and cardiovascular efficiency increase diver safety, cold habituation, and overall performance
6. Limit the total number of dives done per day. Even though a diver may feel capable of multiple dives, extreme cold can severely impact fatigue levels and cognitive performance when diving. Do not overestimate your capabilities. Dive conservatively
7. Limit maximum dive depths to no more than 60 feet, and then only when absolutely necessary. Equipment issues are more common in arctic-like conditions, and added depth only increases the risk of equipment failure
8. Never push physical and mental limits. Manage the increased risk and be aware of any physical and environmental changes that occur that can impact your dive. Do not dive beyond your personal capabilities and training

cold environments is needed. There are many considerations for this type of diving and cold-water divers need to specifically prepare for such a challenging environment (Tab. 5). Along with increasing their knowledge of these types of physiological adaptations, divers need to be prepared for how to manage these changes, particularly because this type of scuba diving is done in remote areas with limited access to logistical assistance and emergency care. With a greater understanding of thermoregulatory changes in extremely cold water, diver safety and performance while diving in these types of environments can be further improved and any risks associated with this type of scuba diving may be mitigated.

ARTICLE INFORMATION AND DECLARATIONS

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REFERENCES

1. Keatinge WR. Survival in cold water: the physiology and treatment of immersion hypothermia and of drowning. Blackwell Scientific, Oxford, Edinburgh 1978.
2. Bowen HM. Diver performance and the effects of cold. Hum Factors. 1968; 10(5): 445–464, doi: [10.1177/001872086801000501](https://doi.org/10.1177/001872086801000501), indexed in Pubmed: [5717310](https://pubmed.ncbi.nlm.nih.gov/5717310/).
3. Tso JV, Powers JM, Kim JH. Cardiovascular considerations for scuba divers. Heart. 2022; 108(4): 1084–1089, doi: [10.1136/heartjnl-2021-319601](https://doi.org/10.1136/heartjnl-2021-319601), indexed in Pubmed: [34670825](https://pubmed.ncbi.nlm.nih.gov/34670825/).
4. Uhlig F, Muth CM, Tetzlaff K, et al. Lung function after cold-water dives with a standard scuba regulator or full-face-mask during wintertime. Diving Hyperb Med. 2014; 44(2): 70–73, indexed in Pubmed: [24986723](https://pubmed.ncbi.nlm.nih.gov/24986723/).
5. Stang PR, Wiener EL. Diver performance in cold water. Human Factors. 1970; 12(4): 391–399, doi: [10.1177/001872087001200405](https://doi.org/10.1177/001872087001200405).
6. Laden GDM, Purdy G, O'Reilly G. Cold injury to a diver's hand after a 90-min dive in 6 °C water. Aviat Space Environ Med. 2007; 78(5): 523–525, indexed in Pubmed: [17539448](https://pubmed.ncbi.nlm.nih.gov/17539448/).
7. Tetzlaff K, Friege L, Koch A, et al. Effects of ambient cold and depth on lung function in humans after a single scuba dive. Eur J Appl Physiol. 2001; 85(1-2): 125–129, doi: [10.1007/s004210100421](https://doi.org/10.1007/s004210100421), indexed in Pubmed: [11513305](https://pubmed.ncbi.nlm.nih.gov/11513305/).
8. Xu X, Giesbrecht GG. A new look at survival times during cold water immersion. J Therm Biol. 2018; 78: 100–105, doi: [10.1016/j.jtherbio.2018.08.022](https://doi.org/10.1016/j.jtherbio.2018.08.022), indexed in Pubmed: [30509625](https://pubmed.ncbi.nlm.nih.gov/30509625/).
9. Pollock NW. Scientific diving in Antarctica: history and current practice. Diving and Hyperbaric Medicine. 2007; 37(4): 204–2011.
10. Strauss MB, Aksenov IV. Diving science: essential physiology and medicine for divers. Human Kinetics, Champaign 2004.
11. Adam J. Hypothermia: ashore and afloat. Aberdeen University Press, Aberdeen 1981.
12. Joiner J. NOAA diving manual: diving for science and technology. Best Pub. Co, Flagstaff 2001.
13. Tipton MJ, Golden FS. The influence of regional insulation on the initial responses to cold immersion. Aviat Space Environ Med. 1987; 58(12): 1192–1196, indexed in Pubmed: [3426494](https://pubmed.ncbi.nlm.nih.gov/3426494/).
14. Jones DM, Bailey SP, Roelands B, et al. Cold acclimation and cognitive performance: a review. Auton Neurosci. 2017; 208: 36–42, doi: [10.1016/j.autneu.2017.11.004](https://doi.org/10.1016/j.autneu.2017.11.004), indexed in Pubmed: [29158117](https://pubmed.ncbi.nlm.nih.gov/29158117/).
15. Gerth WA. On diver thermal status and susceptibility to decompression sickness. Diving Hyperb Med. 2015; 45(3): 208, indexed in Pubmed: [26415073](https://pubmed.ncbi.nlm.nih.gov/26415073/).
16. Denoble PJ, Petar J. DAN Annual Diving Report. Divers Alert Network, Durham 2019.
17. Shattock MJ, Tipton MJ. 'Autonomic conflict': a different way to die during cold water immersion? J Physiol. 2012; 590(14): 3219–3230, doi: [10.1113/jphysiol.2012.229864](https://doi.org/10.1113/jphysiol.2012.229864), indexed in Pubmed: [22547634](https://pubmed.ncbi.nlm.nih.gov/22547634/).

18. Tipton MJ, Stubbs DA, Elliott DH, et al. The initial responses to cold-water immersion in man. *Clin Sci (Lond)*. 1989; 77(6): 581–588, doi: [10.1042/cs0770581](https://doi.org/10.1042/cs0770581), indexed in Pubmed: [2691172](https://pubmed.ncbi.nlm.nih.gov/2691172/).
19. Schipke JD, Pelzer M. Effect of immersion, submersion, and scuba diving on heart rate variability. *Br J Sports Med*. 2001; 35(3): 174–180, doi: [10.1136/bjism.35.3.174](https://doi.org/10.1136/bjism.35.3.174), indexed in Pubmed: [11375876](https://pubmed.ncbi.nlm.nih.gov/11375876/).
20. Noh Y, Posada-Quintero HF, Bai Y, et al. Effect of Shallow and Deep SCUBA Dives on Heart Rate Variability. *Front Physiol*. 2018; 9: 110, doi: [10.3389/fphys.2018.00110](https://doi.org/10.3389/fphys.2018.00110), indexed in Pubmed: [29535634](https://pubmed.ncbi.nlm.nih.gov/29535634/).
21. Lundell RV, Räisänen-Sokolowski AK, Wuorimaa TK, et al. Diving in the Arctic: cold water immersion's effects on heart rate variability in navy divers. *Front Physiol*. 2019; 10: 1600, doi: [10.3389/fphys.2019.01600](https://doi.org/10.3389/fphys.2019.01600), indexed in Pubmed: [32082177](https://pubmed.ncbi.nlm.nih.gov/32082177/).
22. Nunneley SA, Wissler EH, Allan JR. Immersion cooling: effect of clothing and skinfold thickness. *Aviat Space Environ Med*. 1985; 56(12): 1177–1182, indexed in Pubmed: [4084171](https://pubmed.ncbi.nlm.nih.gov/4084171/).
23. Clausen JP. Effect of physical training on cardiovascular adjustments to exercise in man. *Physiol Rev*. 1977; 57(4): 779–815, doi: [10.1152/physrev.1977.57.4.779](https://doi.org/10.1152/physrev.1977.57.4.779), indexed in Pubmed: [333481](https://pubmed.ncbi.nlm.nih.gov/333481/).
24. Ward M. Diving facts & risks associated with cold water diving. Dive Lab, Inc, Panama City Beach 2014.
25. Ferris V. Unmanned evaluation of select commercially available open circuit scuba regulators for cold water diving. 2010.
26. Skreslet S, Aarefjord F. Acclimatization to cold in man induced by frequent scuba diving in cold water. *J Appl Physiol*. 1968; 24(2): 177–181, doi: [10.1152/jappl.1968.24.2.177](https://doi.org/10.1152/jappl.1968.24.2.177), indexed in Pubmed: [5637680](https://pubmed.ncbi.nlm.nih.gov/5637680/).
27. Castellani JW, Young AJ. Human physiological responses to cold exposure: acute responses and acclimatization to prolonged exposure. *Auton Neurosci*. 2016; 196: 63–74, doi: [10.1016/j.autneu.2016.02.009](https://doi.org/10.1016/j.autneu.2016.02.009), indexed in Pubmed: [26924539](https://pubmed.ncbi.nlm.nih.gov/26924539/).
28. Romet TT. Mechanism of afterdrop after cold water immersion. *J Appl Physiol* (1985). 1988; 65(4): 1535–1538, doi: [10.1152/jappl.1988.65.4.1535](https://doi.org/10.1152/jappl.1988.65.4.1535), indexed in Pubmed: [3182516](https://pubmed.ncbi.nlm.nih.gov/3182516/).

Challenges to remote medical support at sea in Bulgaria — legislative gaps, operational needs, and integration of the TMAS–SAR system

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ABSTRACT

Background: Remote medical assistance at sea is a critical component of maritime safety. Bulgaria's Telemedical Maritime Assistance Service (TMAS) framework remains underdeveloped despite new national telemedicine laws in 2025. The aim of this paper is to evaluate the effectiveness, efficiency, and compliance benefits of a unified TMAS–Search and Rescue (SAR) system in Bulgaria, assessing its impact on medical care access, coordination between maritime and healthcare authorities, and the economic and safety outcomes of maritime emergencies.

Material and methods: A policy and systems analysis reviewed Bulgarian legislation, EU and IMO/ILO conventions, and operational case records from Maritime Regional Coordination Center (MRCC) Varna (2018–2025). Comparative benchmarking was performed with Romania, Greece, Turkey, and Germany. International “one-door” TMAS–SAR models were reviewed. Findings are supported by six data tables.

Results: Bulgaria's 2025 telemedicine law regulates remote care but provides no TMAS-specific provisions, no designated provider, and no legal integration with SAR. Best-practice “one-door” systems abroad enable faster, better-coordinated medical and SAR responses. Bulgarian case series illustrate delays and fragmented responsibilities. Comparative countries show functioning TMAS–SAR structures even without dedicated TMAS legislation.

Conclusions: Bulgaria needs supplementary maritime-specific provisions, formal TMAS provider designation, SAR integration, and quality monitoring to align with international standards and protect seafarer health.

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Keywords: maritime medicine, TMAS, SAR, telemedicine, Bulgaria, legislation, maritime safety, medical evacuation

INTRODUCTION

Maritime transport is the backbone of international trade, with nearly 90% of goods carried by sea. Seafarers, fishers, and offshore workers operate in environments of extended isolation, unpredictable weather, and limited access to advanced medical care. Hazard profiles include traumatic injuries, cardiovascular events, infections, exposure to

hazardous materials, and long-term mental health strain [1–3]. The ability to deliver timely, high-quality medical assistance at sea is therefore a cornerstone of maritime safety and public health.

In many situations, vessels do not carry a qualified medical officer; onboard care is often delivered by the captain or a designated crew member trained only to the Standards

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of Training, Certification and Watchkeeping (STCW) medical first-aid level. In the absence of specialist advice, decisions on treatment, diversion, or evacuation may be delayed or incorrect, potentially worsening outcomes and risking the ship, cargo, and environment.

Telemedical Maritime Assistance Service (TMAS) bridges this gap by connecting shipboard personnel with shore-based doctors, historically via radio but now through digital broadband, satellite, and multimedia channels. TMAS physicians can remotely guide diagnosis, stabilization, and treatment, and determine the need for medical evacuation. In many maritime nations, TMAS is integrated with search and rescue (SAR) coordination, enabling concurrent initiation of rescue resources and medical consultation via a “one-door” system [4–13]. This integrated model reduces communication delays, improves accuracy of information transfer, and matches the operational rhythm of maritime emergencies.

The importance of TMAS has grown alongside changing maritime patterns: larger crew complements on cruise and passenger ships, greater public scrutiny of seafarers’ welfare, and lessons from the COVID-19 pandemic, when vessels were forced to manage outbreaks without port access. TMAS also plays a role in humanitarian SAR operations, including responding to medical needs on migrant vessels in distress [1–3].

Bulgaria, as a Black Sea coastal state, EU Member State, and party to key International Maritime Organization (IMO) and International Labor Organization (ILO) conventions [International Convention for the Safety of Life at Sea (SOLAS), STCW, Maritime Labor Convention (MLC) 2006], is obligated to ensure that vessels under its flag have 24/7 access to adequate medical advice and assistance. In April 2025, amendments to the Healthcare Facilities Act (Article 6b) officially recognized telemedicine for diagnosis, treatment, rehabilitation, and prevention [14]. Related Public Health Act updates improved the legal framework for digital health records, scheduling, and sharing — all relevant for TMAS [15]. These reforms align national law with EU health and data standards, notably the General Data Protection Regulation (GDPR) [16]. Despite Bulgaria’s compliance obligations under IMO and ILO conventions, there is no targeted national policy or legislative framework explicitly integrating TMAS into the country’s regulated telemedicine system. This absence creates a policy vacuum and a compliance risk: Bulgaria may not fully meet its treaty obligations regarding service quality, availability, and accessibility.

Bulgaria still lacks an explicit statutory definition of TMAS, a designated national provider, formal SAR integration, minimum equipment and connectivity standards, or mandated quality-assurance procedures. Current TMAS-related activities are handled informally between Maritime

Regional Coordination Center (MRCC) and medical units, which leads to variability in response times, unclear accountability, and unregulated monitoring [17–19].

By contrast, Romania and Greece have implemented telemedicine laws and operate TMAS functions integrated with MRCC-coordinated SAR [20–22]. Turkey maintains a long-running radio-medical service in cooperation with the Coast Guard [23], and Germany’s Medico Cuxhaven provides a mature, hospital-based TMAS to ships worldwide [24]. These show that even without TMAS-specific laws, strong operational embedding and clear protocols deliver effective services.

Given Bulgaria’s legislative reforms of 2025 and its strategic maritime role along Black Sea routes, there is a timely opportunity to formally integrate TMAS into SAR operations, improving health outcomes, operational efficiency, and compliance with international maritime health obligations. The aim of the study is to evaluate how a unified TMAS–SAR system in Bulgaria could improve emergency medical care, enhance interagency coordination, and deliver measurable safety and economic benefits — and to identify current legislative and operational gaps.

MATERIAL AND METHODS

Bulgarian legislation — including recent amendments to the Healthcare Facilities Act and Public Health Act — was systematically reviewed, with an emphasis on regulations relevant to telemedicine and maritime health services. A comparative review of international legal frameworks and maritime conventions was undertaken to contextualize Bulgaria’s position within the global landscape. Operational data from the MRCC in Varna were examined, with emergency case records from 2018 to 2025 analyzed to identify response patterns, timelines, and interagency coordination practices. Benchmarking included detailed assessments of policies and operational models from selected countries — Romania, Greece, Turkey, and Germany — to understand their legal structures, TMAS provider designations, and integration approaches with SAR systems. Scholarly articles, industry reports, and published best-practice guidelines on TMAS and SAR integration were also analyzed, with a focus on their effects on response efficiency and safety outcomes. The synthesis of these data prioritized the identification of gaps and strengths in legal frameworks, operational coordination, and technical infrastructure, with the aim of formulating evidence-based recommendations for Bulgaria to establish an effective, integrated TMAS–SAR system.

RESULTS

LEGISLATIVE AND REGULATORY STATUS

Bulgaria formally recognized telemedicine in April 2025 through amendments to the Healthcare Facilities

Act (Article 6b), creating a legal basis for remote care delivery. Related Public Health Act amendments introduced provisions for provider licensing, platform registration, and GDPR-compliant data management. However, TMAS is neither defined nor mandated in national law; no provider is designated, and there is no legal mechanism linking TMAS to SAR operations. Current obligations are met solely via adherence to international conventions such as SOLAS, STCW, and MLC 2006, without specific national implementing rules. This reliance on external frameworks leaves both compliance and operational gaps, limiting Bulgaria's ability to deliver consistent maritime medical assistance. Table 1 summarizes the national legal provisions and TMAS-specific deficiencies.

EVIDENCE BASE AND LITERATURE REVIEW

The literature synthesis indicates that structured TMAS systems consistently improve maritime healthcare outcomes. Studies demonstrate faster decision-making, fewer unnecessary evacuations, and measurable cost savings for the shipping sector. Technological evolution has transformed TMAS from basic radio advice to multimedia digital platforms capable of transmitting images, video, and electronic health record (EHR) data in real time. During the COVID-19 pandemic, TMAS played a critical role in enabling onboard treatment without costly diversions. Emerging expert-system tools, such as “M Doc”, offer enhanced

data capture and decision support, although integration with maritime communications remains uneven. These thematic insights are summarized in Table 2.

STRATEGIC SECTORAL IMPORTANCE

Telemedical Maritime Assistance Service has cross-sectoral importance for Bulgaria's maritime domain. The integration of TMAS into Bulgaria's national maritime safety framework offers multifaceted benefits. From a safety perspective, reliable, real-time medical support can significantly reduce morbidity and mortality among seafarers. In terms of legal compliance, embedding TMAS within national legislation would ensure stronger adherence to IMO and ILO requirements. System efficiency would be enhanced by linking TMAS with SAR operations, enabling interoperability of EHRs and faster mobilization of rescue resources. The economic benefits are substantial, with reduced vessel diversion and evacuation costs improving the competitiveness of the maritime sector. Finally, from a policy leadership standpoint, implementing a robust TMAS framework could position Bulgaria as a regional leader in maritime telemedicine within the Black Sea area. Table 3 outlines these sectoral benefits.

COMPARATIVE COUNTRY MODELS

Benchmarking against Romania, Greece, Turkey, and Germany shows that all four operate functional TMAS

Table 1. Bulgaria's telemedicine law context and telemedical assistance service (TMAS)-specific gaps

Category	Situation in Bulgaria
National telemedicine law	Article 6b amendments effective from April 2025 regulate remote care broadly
Draft telemedicine bill	Proposed but not yet adopted; covers provider registration, consent, oversight
Licensing and data rules	Physicians must be licensed; platforms must register; GDPR standards apply
TMAS-specific rules	None explicitly; TMAS obligations are enforced via international treaties

GDPR — General Data Protection Regulation

Table 2. Summary of reviewed telemedical assistance service (TMAS) sources and thematic insights

Source/theme	Key insights
Economic returns of investments and efficiency	Rapid payback and significant industry cost savings
Real-time case evidence	Limited but impactful case studies show life-saving outcomes
Technological evolution	Transition from radio-based to digital, multimedia-assisted care
Structured vs. standard TMAS	Better recovery, fewer evacuations with structured systems
Pandemic telemedicine role	TMAS enabled effective onboard COVID-19 management
Expert systems development	Platforms like “M Doc” enhance data capture but face tech constraints

Table 3. Sectoral importance of telemedical assistance service (TMAS) implementation in Bulgaria

Sector	Key importance
Maritime safety and public health	Reliable medical support reduces morbidity, mortality, and unnecessary diversions
Legal compliance	TMAS in national law strengthens Bulgaria's IMO/ILO compliance
System efficiency	TMAS links national telemedicine/SAR, improves EHR interoperability
Economic impact	Cuts ship diversion/evacuation costs, boosts sector reputation
Policy innovation	Bulgaria could be Black Sea leader via TMAS framework

EHR — electronic health record; ILO — International Labour Organization; IMO — International Maritime Organization; SAR — search and rescue

Table 4. Cross-country comparison of telemedical assistance service (TMAS) legislation, operations, and integration

Country	National telemedicine law/status	TMAS-specific law/formal mandate	Designated TMAS providers/practice	Integration /with SAR and oversight	Data protection/ /EHR integration
Bulgaria	New telemedicine provisions (Article 6b) — regulated nationally (2025) [25]	No TMAS-specific law; obligations via international treaties (gap) [17]	No named national TMAS operator; ad hoc practices unclear [18, 19]	SAR managed by maritime authorities; no formal TMAS integration (gap) [17, 19]	GDPR applies; national EHR initiatives active [16]
Romania	Telemedicine framework (Gov. Emergency Ordinance No.196/2020) [20]	TMAS via maritime/SAR arrangements; centers per national arrangements [21]	Maritime authorities coordinate TMAS calls; medical contact points [21]	SAR via MRCC; TMAS coordinates with MRCC/SAR [17, 21]	Telemedicine law implies data protections; GDPR applies [20]
Greece	Public health networks; Law 5129/2024 expanding digital health [22]	TMAS via health/maritime authorities — Greek National Network (EDIT) [22]	Public-sector telemedicine; maritime functions via hospital/SAR networks [22]	Operational SAR integration (maritime prefects/MRCCs coordinate) [22]	GDPR; EHR integration and public NHIS infrastructure [22]
Turkey	Telemedicine services operate; Turkish TMAS has long operational history [23]	TMAS as established service (Radio Medical/Coast Guard collaboration) [23]	Turkish Radio Medical/Coast Guard provide TMAS; substantial volumes [23]	Coast Guard is SAR authority; TMAS coordinates with SAR [23]	National data protection; telemedicine subject to healthcare regulations [23]
Germany (EU model)	Telemedicine via health law; TMAS well-established (Medico Cuxhaven) [24]	TMAS embedded in health/maritime arrangements; clear organization [24]	Medico Cuxhaven (Helios) documented national TMAS provider worldwide [24]	Strong operational integration TMAS/MRCCs/SAR; IMO guidance adopted [24]	GDPR; established medical data processes; EHR linkage [24]

EDIT — Greek National Telemedicine Network; EHR — electronic health record; EU — European Union; GDPR — General Data Protection Regulation; IMO — International Maritime Organization; ILO — International Labour Organization; MRCC — Maritime Rescue Coordination Centre; NHIS — National Health Information System; SAR — search and rescue

systems integrated with SAR through legislation, procedural arrangements, or both. These systems have designated TMAS providers, established operational protocols with SAR authorities, and consistent data-protection measures. Bulgaria is the only comparator with telemedicine legislation but no designated TMAS provider, no formal SAR integration, and unclear operational practices. This misalignment reduces readiness and hampers interoperability with regional and EU partners. Full details are provided in Table 4.

BULGARIAN MARITIME MEDICAL INCIDENT CASES

Case reviews from MRCC Varna (2018–2025) confirm that serious maritime medical emergencies almost always require both SAR deployment and specialist medical input. Several incidents highlighted delays, multiple agency handovers, and incomplete communication chains — particularly in multi-casualty or severe trauma situations, emphasizing the operational value of a unified TMAS–SAR approach.

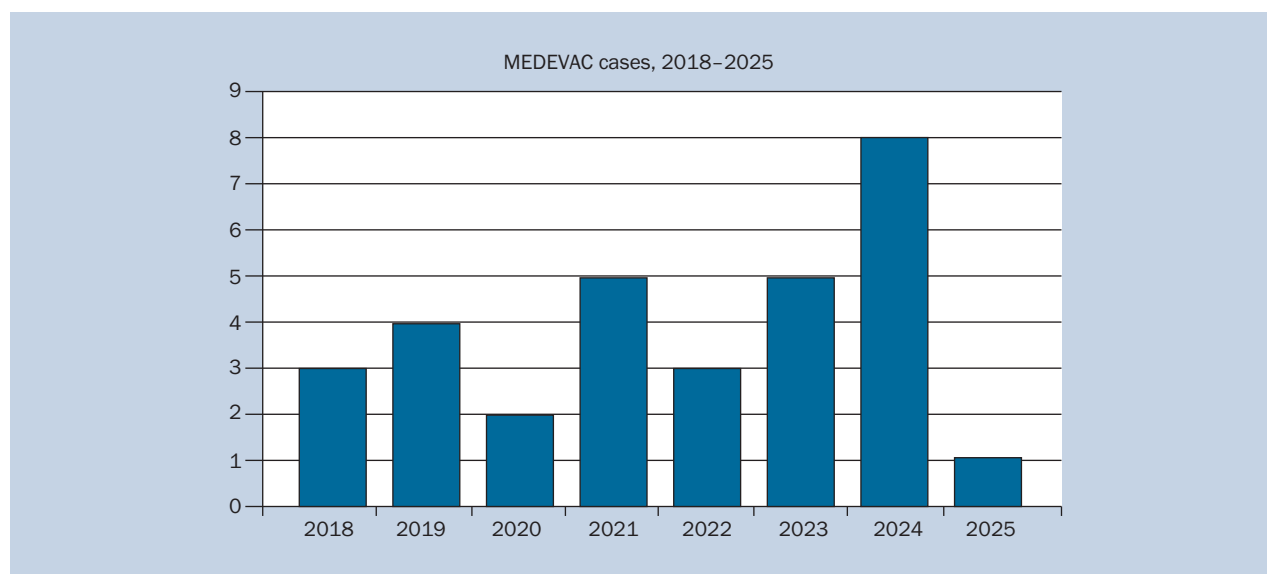


Figure 1. Cases of medical evacuation (MEDEVAC) in Bulgarian territorial waters within the period 2018–2025

Table 5. Case series of Bulgarian maritime medical emergencies, 2018–2025

Time	Vessel	Position	Case description
2018, 14 July, 1945 UTC	MV “Karadeniz 5”, c/s TCAY9, MMSI 271002106	44°09'38"N 028°38'59"E	Severe burns, helicopter evacuation requested; crew member died, evacuation cancelled
2019, 06 March, 0315 UTC	MV “Star Hyperion”	42°55'N 029°30'E	Medical assistance call; Maritime administration/ Navy rescue boat with medical team evacuated patient
2021, 03 November, 0238 UTC	MV “Simona”, c/s 9HA2127	Varna anchorage area	Man overboard at anchor; MRCC sent rescue boat “Rescue-1” with medical team and prosecutor
2023, 14 January, 1510 UTC	MV “Scout”, c/s TJM0012	Varna anchorage area	Crew member broken leg; MRCC organized medical evacuation with rescue boat “Rescue-1”
2023, 03 July, 1945 UTC	MV “Milford”	Varna anchorage area	Two crew injured in waste pipe; onboard treatment impossible, MRCC organized medical/fire teams at dock

c/s — call sign; MMSI — Maritime Mobile Service Identity; MRCC — Maritime Rescue Coordination Centre; MV — motor vessel; UTC — Coordinated Universal Time

Medical evacuation (MEDEVAC) trend analysis (Fig. 1) shows fluctuating annual activity, with a peak in 2024 of eight evacuations — the highest in the period — compared to two to five cases in earlier years. The lowest figures were recorded in 2020 (two cases) and 2025 to date (one case, partial year). The 2024 spike may reflect increased maritime traffic, more severe incident profiles, or changes in reporting and coordination. It also exposed systemic weaknesses: in several high-profile 2024 cases, coordination between agencies required multiple steps before SAR or medical resources were dispatched, lengthening response times. Without a centralized “one-door” entry point, simultaneous mobilization of medical and SAR assets was inconsistent, potentially affecting outcomes. Table 5 details selected cases, and Figure 1 presents annual MEDEVAC volumes.

INTERNATIONAL „ONE-DOOR” BEST PRACTICES

Six EU or European Economic Area (EEA) nations — the Netherlands, UK, Norway, Italy, Finland, and France — operate integrated “one-door” TMAS–SAR systems, where the same initial contact point manages both rescue coordination and medical advice. These models enable immediate triage, simultaneous mobilization of resources, and minimize communication errors. Their design is embedded in EU-compliant legal and institutional frameworks, making them directly relevant to Bulgaria’s obligations and operational context. Adopting such a model would align national practice with IMO/ILO guidance, improve speed and coordination, and enhance patient outcomes. Examples of these systems are provided in Table 6.

Table 6. Examples of unified Telemedical Maritime Assistance Service–Search and Rescue (TMAS–SAR) operational models from six maritime states

Country	Unified contact point	Function and protocols
The Netherlands	Netherlands Coastguard (JRCC Den Helder)	All emergency calls (VHF Ch. 16, phone +31 88 958 44 00) go to Coastguard; connect to Radio Medical Service and launch SAR units [5]
United Kingdom	HM Coastguard MRCC network	MGN 225 instructs vessels to call HM Coastguard on SAR channels; watch-keeper patches to designated radio-medical doctors [4, 6, 7]
Norway	Joint Rescue Coordination Centers (JRCC Stavanger/JRCC Northern Norway)	SAR Cooperation Plan: “Contact CRS/JRCC and request MEDICO. If doctor orders evacuation, JRCC provides helicopter” [8]
Italy	MRCC Rome (Guardia Costiera)	MRCC Rome coordinates SAR and is access point to national TMAS (C.I.R.M.); vessels contact CIRM via any MRCC/MRSC [9]
Finland	MRCC Turku (or national maritime emergency number 0204 1000)	NGA medical-advice list: “TMAS contacts via MRCC Turku or MRSC”; identical number for ordinary maritime distress calls [10, 11]
France	CROSS network (French MRCCs)	Ships dial 196 or call CROSS on VHF for distress; CROSS links vessel with Toulouse CCMM TMAS while coordinating SAR resources [12, 13]

CCMM — Centre de Consultation Médicale Maritime; CIRM — Centro Internazionale Radio Medico; CRS — coast radio station; CROSS — Centre Régional Opérationnel de Surveillance et de Sauvetage; JRCC — Joint Rescue Coordination Centre; MGN — Marine Guidance Note; MRCC — Maritime Rescue Coordination Centre; MRSC — Maritime Rescue Sub-Centre; NGA — National Geospatial-Intelligence Agency; VHF — very high frequency

DISCUSSION

This study identifies a persistent gap between Bulgaria’s recent telemedicine legislation and the operational requirements for delivering effective TMAS integrated with SAR. The April 2025 amendments to the Healthcare Facilities Act formally recognized telemedicine (Article 6b) [14], and related Public Health Act changes enhanced the regulatory environment for digital health systems [15]. However, no statutory definition of TMAS exists, no national provider is designated, and there is no legal framework mandating SAR integration. Consequently, TMAS functions are provided on an informal, case-by-case basis through ad hoc cooperation between MRCC and medical units, without standardized procedures or quality-assurance mechanisms [17–19].

COMPARATIVE LEGISLATIVE AND OPERATIONAL CONTEXT

The comparative analysis with Romania, Greece, Turkey, and Germany shows that legislative structures vary, but effective TMAS provision consistently relies on institutional clarity, operational protocols, and formal links to SAR [20–24]. Romania’s Government Emergency Ordinance No. 196/2020 embeds TMAS in MRCC operations [20], Greece’s Law 5129/2024 extends digital health to maritime contexts [22], Turkey’s long-standing Radio Medical Service operates directly through the Coast Guard [23], and Germany’s Medico Cuxhaven integrates TMAS with MRCC networks [24]. These cases illustrate that success does not depend solely on dedicated legislation, but on governance models that define responsibilities and ensure procedural integration.

BENEFITS OF THE „ONE-DOOR” MODEL

Evidence from leading maritime nations — the Netherlands, United Kingdom, Norway, Italy, Finland, and France — demonstrates that the “one-door” model, where distress and medical calls are received by a single operational hub, yields measurable improvements in emergency response [4, 13–15]. Such systems reduce communication delays, eliminate handovers, and enable simultaneous deployment of SAR and medical resources. Time-motion studies report 15–30-minute reductions in initial response times and 20–40% decreases in adverse outcomes linked to delayed interventions [5–13]. This model also improves situational awareness, optimizes asset allocation, and ensures that medical and operational decision-making are coordinated from the first point of contact.

BULGARIAN OPERATIONAL GAPS AND REFORM NEEDS

Analysis of MRCC incident data from 2018–2025 confirms that Bulgaria’s current arrangement often involves sequential agency involvement and unclear lines of responsibility, creating avoidable delays [1–3]. These inefficiencies underscore the need for a unified system that connects TMAS and SAR from the outset of an emergency call. The absence of technical interoperability, standardized communication protocols, and formalized triage procedures hinders timely medical assessment and coordinated evacuations [17–19].

PROPOSED INTEGRATED OPERATIONAL WORKFLOW FOR TMAS–SAR RESPONSE

To address these deficiencies, this study proposes an integrated operational workflow for TMAS–SAR response in Bulgaria (Fig. 2). Under this model, the vessel's master or officer conducts an initial assessment and contacts a legally designated national TMAS provider via a dedicated 24/7 communication channel. The TMAS provider — licensed under Article 6b [14] and staffed by maritime-trained physicians — delivers immediate teleconsultation, accesses EHR data where available [16], and determines the need for

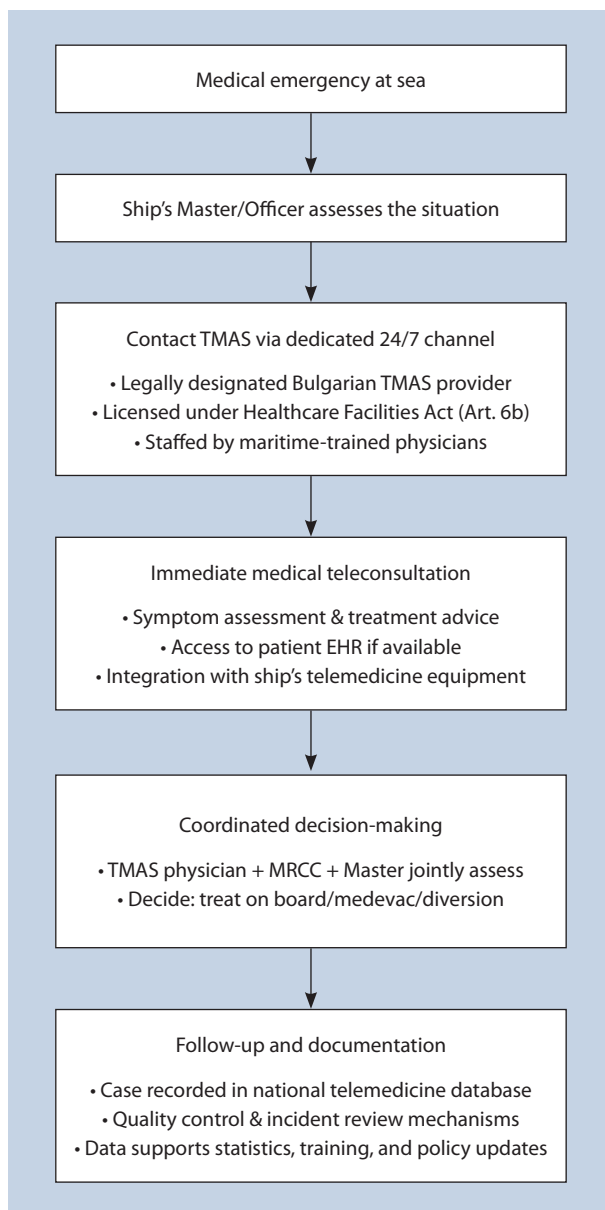


Figure 2. Proposed integrated operational workflow for Telemedical Maritime Assistance Service–Search and Rescue (TMAS–SAR) response in Bulgaria
EHR — electronic health record; MEDEVAC — medical evacuation; MRCC — Maritime Rescue Coordination Centre

onboard treatment, MEDEVAC, or diversion in direct coordination with the MRCC. All incidents are logged in the national telemedicine database, enabling systematic quality review, statistical monitoring, and feedback into training and policy development. This structure mirrors international “one-door” best practices [4–13], ensuring that SAR and TMAS operate as a single, coordinated system.

LEGAL, TECHNICAL, AND QUALITY CONSIDERATIONS

Implementation requires secondary legislation to define TMAS as a distinct service within maritime law [17], designate a national provider [18, 19], and mandate technical and procedural integration with MRCC/SAR operations. Critical enablers include redundant communication channels (satellite, VHF digital, broadband) for resilience in all maritime zones [15, 16], interoperable systems linking TMAS logs to national EHRs, and mandatory training for MRCC operators, ship Masters, and medical personnel, aligned with IMO and Centro Internazionale Radio Medico (CIRM) guidelines [4, 17]. Quality assurance should be embedded from inception, with key performance indicators for time to first medical contact, evacuation decision-making, and patient outcomes, alongside regular benchmarking against international standards [5–13].

STRATEGIC AND ECONOMIC RATIONALE

Beyond the safety and compliance benefits, integrating TMAS with SAR offers substantial economic gains. Comparator nation data suggest potential annual savings of several million euros through reduced unnecessary diversions, fewer helicopter evacuations, and optimized use of maritime safety assets [20–24]. Strategically, such a system would strengthen Bulgaria's compliance with IMO, ILO, and CIRM conventions, improve its maritime safety profile, and reinforce its leadership potential within the Black Sea region.

In sum, the evidence supports the implementation of a unified TMAS–SAR framework in Bulgaria as both an operational necessity and a strategic opportunity. By adopting proven international models and tailoring them to national legislative and technical contexts, Bulgaria can modernize its maritime emergency response, safeguard seafarer welfare, and enhance its standing as a responsible maritime nation in line with EU and international standards.

Limitations and future research directions

The present study has several limitations that should be addressed in future work. First, the MRCC case series is derived from publicly available summaries, which may omit operational details and medical data relevant to system performance [1, 3, 26]. Access to full incident reports could provide a more comprehensive evidence base. Second,

quantitative analysis is required to measure the economic and health impacts of a unified TMAS–SAR framework in Bulgaria, ideally through pilot implementation and simulation modeling. Third, systematic assessment of emerging TMAS technologies — including connectivity solutions, AI-assisted diagnostics, and integration with maritime communication systems — would inform technical design choices. Fourth, qualitative research exploring the perspectives of seafarers, ship operators, medical practitioners, and SAR personnel could ensure that system architecture meets operational needs. Finally, the potential for Black Sea regional cooperation in TMAS provision warrants investigation, as shared infrastructure and coordinated protocols may enhance cost efficiency, interoperability, and compliance with international standards.

CONCLUSIONS

Bulgaria's April 2025 telemedicine reforms established a legal foundation for remote healthcare but left critical operational, institutional, and technical gaps preventing effective integration of TMAS with SAR operations. The present framework lacks a statutory TMAS definition, designated provider, formal SAR integration, unified communication protocols, minimum connectivity standards, and embedded quality assurance. Evidence from operational case analysis confirms that fragmented, sequential agency responses delay decision-making and risk adverse outcomes, while international best-practice models demonstrate the benefits of unified “one-door” TMAS–SAR systems in reducing response times, improving coordination, and enhancing patient safety. Implementing such a system in Bulgaria would enable parallel mobilization of medical and rescue resources, optimize asset use, improve survival rates, and deliver measurable cost savings through reduced diversions and evacuations. Achieving this requires secondary legislation to operationalize TMAS–SAR integration, inter-agency governance mechanisms, investment in redundant communication infrastructure, integration with national EHR systems, and continuous performance monitoring aligned with international standards. With recent legislative momentum, advancing digital health capabilities, and its strategic position in the Black Sea, Bulgaria is well-placed to implement a modern, compliant, and regionally leading TMAS–SAR system — strengthening maritime safety, safeguarding seafarer welfare, and reinforcing its standing as an innovative and responsible maritime nation.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement: All data supporting the findings of this study are derived from publicly available legislative texts, international maritime guidelines, and scientific

publications cited in the References section. No new datasets were generated or analyzed during the course of this research.

Ethics statement: Ethical approval was not required as this study analyzed publicly available, anonymized data.

Author contributions:

Conceptualization: TY, NR; methodology: NR; legislative analysis: TY; data curation: TY; visualization: TY; writing — original draft: TY; writing — review & editing: TY, NR; final approval of the manuscript: NR. Both authors have agreed to their respective contributions and accept accountability for the integrity and accuracy of the work.

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REFERENCES

1. Maritime Fairtrade. Mental health at sea: tackling the seafarers' invisible crisis. Singapore: Maritime Fairtrade. <https://maritime-fairtrade.org/mental-health-at-sea-tackling-seafarers-invisible-crisis/> (1.07.2025).
2. Chawla P. Seafarers' physical and mental health must come first [Internet]. Athens: Safety4Sea. <https://safety4sea.com/seafarers-physical-and-mental-health-must-come-first/> (1.07.2025).
3. The importance of focusing on seafarers' mental health during long voyages. Mumbai: Nautilus Shipping. <https://www.nautilusshipping.com/news-and-insights/the-importance-of-focusing-on-seafarers-mental-health-during-long-voyages> (1.07.2025).
4. Telemedicine: how laws and regulation are shaping the future of telemedicine in the UK. London: Eversheds Sutherland. <https://www.eversheds-sutherland.com/en/netherlands/insights/telemedicine-how-laws-and-regulation-are-shaping-the-future-of-telemedicine-in-the-uk> (3.07.2025).
5. Assistance and service provision: radio medical advice. Den Helder: Netherlands Coastguard. <https://kustwacht.nl/en/assistance-and-service-provision/radio-medical-advice/> (3.07.2025).
6. Maritime and Coastguard Agency: Radio Medical Advice For Ships At Sea. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/282262/mgn225.pdf (3.07.2025).
7. Maritime and Coastguard Agency: Radio Medical Advice For Ships At Sea. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/282262/mgn225.pdf (3.07.2025).
8. Joint Rescue Coordination Centre Norway. SAR Cooperation Plan 2024. Bodø: JRCC Norway; 2024. https://www.hovedrednings-sentralen.no/wp-content/uploads/2024/08/SAR-Cooperation-Plan-2024_v1.pdf (3.07.2025).
9. Comando Generale del Corpo delle Capitanerie di Porto - Guardia Costiera. Rome: SAR Contacts. <https://sarcontacts.info/contacts/comando-generale-del-corpo-delle-capitanerie-di-porto-guardia-costiera-5972/> (7.07.2025).

10. National Geospatial-Intelligence Agency. NGA medical advice list [Internet]. Bethesda (MD): NGA. <https://msi.nga.mil/api/publications/download?key=16694477%2FSFH00000%2F117chapter5.pdf> (7.07.2025).
11. Finnish Border Guard. Alarm instructions of the maritime rescue. Helsinki: Finnish Border Guard; 2019. https://web.archive.org/web/20190616130603/https://www.raja.fi/guidelines/advice_to_boaters/alarm_instructions_of_the_maritime_rescue (7.07.2025).
12. Ministère de la Mer. Maritime telemedical assistance service (TMAS). Paris: RIF. <https://www.rif.mer.gouv.fr/maritime-telemedical-assistance-service-tmas-a556.html?lang=en> (7.07.2025).
13. Centre de Consultations Médicales Maritimes. How to call French TMAS. Toulouse: CHU Toulouse; 2021. https://www.chu-toulouse.fr/IMG/pdf/2021_12_modalite_s_d_appel_ccmm_how_to_call_french_tmas.pdf (7.07.2025).
14. Voutcheva M. First regulation of telemedicine in Bulgaria was introduced by changes of Healthcare Facilities Act. Sofia: LinkedIn; 2025. <https://www.linkedin.com/pulse/first-regulation-telemedicine-bulgaria-introduced-act-voutcheva-m9xsf> (10.07.2025).
15. LinkedIn. Healthcare EHR medical software. Sunnyvale (CA): LinkedIn. https://www.linkedin.com/posts/dhcluster_healthcare-ehr-medicalsoftware-activity-7245040627262906368-QY-CP (10.07.2025).
16. CEE Legal Matters. Regulating telemedicine and personalising healthcare: an overview of the latest revision to the Bulgarian Public Health Act. Sofia: CEE Legal Matters. <https://ceelegalmatters.com/bulgaria/27710-regulating-telemedicine-and-personalising-healthcare-an-overview-of-the-latest-revision-to-the-bulgarian-public-health-act> (14.07.2025).
17. International Maritime Organization. Medical assistance at sea: MSC.1/Circ.960. London: IMO. <https://wwwcdn.imo.org/localresources/en/OurWork/Safety/Documents/MS-C.1-Circ.960%20-%20Medical%20Assistance%20At%20Sea.PDF> (14.07.2025).
18. CMS Law. Digital health apps and telemedicine in Bulgaria. London: CMS. 2025 Jul 14 (<https://cms.law/en/int/expert-guides/cms-expert-guide-to-digital-health-apps-and-telemedicine/bulgaria>).
19. National Centre for Public Health and Analyses. Health Act. Sofia: NCPHA. https://www.ncpr.bg/images/EU_zakonodatelstvo/2018/14.03.2018/2019/17.04.2019/HEALTH_ACT.pdf (14.07.2025).
20. CMS Law. Romania permanently regulates telemedicine. London: CMS Law-Now; 2020. from: <https://cms-lawnow.com/en/ealerts/2020/11/romania-permanently-regulates-telemedicine> (14.07.2025).
21. European Maritime Safety Agency. Contact details Romania – DONA. Lisbon: EMSA. <https://portal.emsa.europa.eu/web/dona/contact-details-romania> (14.07.2025).
22. International Bar Association. Healthcare telemedicine survey – Greece. London: IBA. <https://www.ibanet.org/document?id=Healthcare-Telemedicine-Survey-Greece> (14.07.2025).
23. Çakır E, Arslan Ö. Turkish Telemedical Assistance Service: last four years of activity. International Maritime Health. 2018; 69(3): 184–191, doi: 10.5603/imh.2018.0030, indexed in Pubmed: 30270420.
24. Deutsche Flagge. Telemedical Maritime Assistance Service (TMAS). Hamburg: Deutsche Flagge. <https://www.deutsche-flagge.de/en/maritime-medicine/tmas> (14.07.2025).
25. IVLawFirm. First regulation of telemedicine in Bulgaria was introduced by changes of Healthcare Facilities Act. Sofia: IVLawFirm; 2025. <https://ivlawfirm.com/en/first-regulation-of-telemedicine-in-bulgaria-was-introduced-by-changes-of-healthcare-facilities-act/> (17.07.2025).
26. European Maritime Safety Agency. DONA - Contact details Bulgaria [Internet]. Lisbon: EMSA. <https://portal.emsa.europa.eu/web/dona/contact-details-bulgaria> (22.07.2025).

Understanding fatigue in the fishing industry: a case study of biodata collected at-home and at sea

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ABSTRACT

Measurement of fatigue in the marine industry is a critical aspect of safe operations on water. Countless incidents have been linked to fatigue, particularly those involving navigation. This paper focuses on a case study to explore the impact of fatigue on bridge operations onboard a fishing trawler. The data was selected from a larger project used to develop an interactive fatigue risk identification application involving several other crew positions. The specific focus on this case includes 56 days of data collection occurring over a period that spanned time both at sea and at home. The collected data includes objective (heart rate and reaction time) and subjective (fatigue rating, sleep quality, and activity logs) data as well as vessel environmental and movement data. Results indicated that there was a noticeable difference between at-sea versus at-home heart rate, and ratings of mental fatigue. Visual analyses of the data reveals that there was minimal change in nearly all of the variables collected during the at sea time blocks. Collecting data in a dynamic environment poses a number of challenges; however, it also provides the opportunity to contextualize the data from a macroenvironmental perspective and allows for an identification of factors which contribute to a change in fatigue. Future studies should strive to include vessel/workspace environmental data whenever possible.

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Keywords: fatigue, heart rate, sleep quality

INTRODUCTION

Fatigue in healthy populations has been described as a feeling of weariness, exhaustion, tiredness, weakness, and lack of energy related to both physical and mental capacity [1–3]. However, given its connection to physiological, psychological, and behavioral manifestations, a universal definition of fatigue has proven difficult [1]. Fatigue is considered a multifactorial construct that affects a person's ability to perform even some of the simplest tasks and impacts health-related quality of life [3]. To incorporate the many facets of fatigue, Aaronson et al. [1] propose the following definition: “The awareness of a decreased

capacity for physical and/or mental activity due to an imbalance in the availability, utilization, and/or restoration of resources needed to perform activity” (p. 46). Unfortunately, it has been shown that individuals are not always aware that fatigue has begun to impair performance until it is too late [4].

A more recent definition proposed by The International Civil Aviation Organization [5] defines fatigue as “a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness

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and ability to safely operate an aircraft or perform safety related duties” (p. 32). More broadly, Chong and Baldwin [2] define fatigue as “an adaptive state of stress that occurs due to the interaction between an individual and their environment” (p. 1). Finally, and more relevant to the current review, the International Maritime Organization [6] defines fatigue as “a reduction in physical and/or mental capability as the result of physical, mental or emotional exertion, which may impair nearly all physical abilities including: strength; speed; reaction time; decision making; or balance” (p. 4).

As with the definition proposed by Aaronson et al. [1], these additional conceptualizations do not necessarily provide direction on how to detect the onset of fatigue. Understanding deficits in performance is important; however, early detection of degradation in performance is critical (both from the individual's and from an industrial safety point of view) to identifying strategies that address and/or mitigate fatigue risk. Detection is particularly important, as fatigue has been shown to reduce vigilance, attention, situation awareness, decision making ability, and increase reaction time [7]. Based on similar findings across multiple domains, Jepsen, Zhao, and van Leeuwen [8] recommend that fatigue research should focus on the development of predictive tools and mitigation management systems for seafarers.

Therefore, this case study is specifically focused on fatigue in the marine industry. Specifically, commercial fishers are known to work extremely long hours and engage in highly demanding physical activities for extended periods of time. As evidence of this, Sánchez-Beaskoetxea et al. [9] note that of 33 fishing vessel related accidents reported by US National Transportation Safety Board (NTSB) between 1975 and 2017, 15 (45%) were directly related to fatigue due to lack of sleep and/or excessive workload. It was also reported that of all the NTSB marine accidents examined during that time frame (127 ships), fishing vessel events were more likely to be related to fatigue than to any other cause [9].

Interestingly, citing fatigue as a contributing factor following an accident investigation is based on subjective interpretations of work schedules, physical and mental requirements, and the duration of the voyage. It is purported that longer exposure to detrimental factors increases fatigue [10]. Physiological measures specifically related to fatigue are not normally taken during a voyage, thus, the accident investigators rely on factors and environmental conditions which are known to increase the likelihood of being fatigued. In the absence of these measures, it is not currently possible to definitively identify the level of fatigue or how much it contributed to the accident.

Past research suggests that fatigue plays a critical role in decision making and physical performance while at

sea [7, 9]. Unfortunately, little is reported on the periods of time just prior to or following an accident. It is unclear whether marine personnel are more, or less fatigued when they are at sea when compared to onshore periods. For example, when arriving home after a prolonged period at sea, it is possible that crew members feel obligated to make up for their absence by taking on a large portion of familial tasks (e.g., food preparation, cooking, cleaning, childcare, fixing items around the house). This may also be the case just prior to their departure, which may reduce the amount of sleep obtained before arriving onboard. It should be noted that while at sea, many of these tasks are completed by other crew members.

Given past findings related to fatigue in the marine industry [7–9], and the fact that no objective measures are typically gathered during actual marine operations so that it can be compared to those data with “normal” everyday life experiences (i.e., pre-, or post-voyage), it is important to collect and report on differences to ensure a more holistic understanding of fatigue. To better explore the differences between at sea and at-home measures, this paper focuses on a case study to identify the impact (if any) of fatigue on bridge operations onboard a commercial fishing trawler. Data was purposefully selected from a larger project focused on fatigue risk identification involving several other crew positions; however, the specific focus on this case includes 56 days of data collection occurring over a period spanning both time at sea and at-home. Collected data includes objective (heart rate and reaction time), and subjective (fatigue rating, sleep quality, and activity logs) measures. Combination of these data provides the opportunity to contextualize the findings from a macroenvironmental perspective.

MATERIAL AND METHODS

The data was collected from one senior crewmember with over a decade of experience working a 6 hour on/6 hour off schedule onboard a fishing trawler. Ethical approval for the study was granted from Veritas REB (Protocol #2022-3062-1191-1), and the crewmember provided informed written consent prior to participating.

Data included heart rate captured at ~0.5 Hz (i.e., ~40 recordings per minute) from an armband positioned below the bicep (Scosche Rhythm 24, Oxnard, CA) and averaged every 60 seconds, ratings of fatigue [3], sleep quality (0 = awful, excellent = 5) and duration (in hours of consecutive sleep), and a digitized ultra-short psychomotor vigilance test [11] completed at least twice each day (once in the morning and once in the evening). The at-sea schedule consisted of 6-hours of work from 00:00 to 06:00, 6-hours of off-shift time from 06:00 to 12:00, 6-hours of work from 12:00 to 18:00, and another 6-hour off-shift period from 18:00 to 23:59. During off-shift periods, the crewmember

also completed tasks such as eating, showering, laundry, and personal correspondence which needed to be completed before going to sleep. Thus, the chance of obtaining six consecutive hours of sleep was minimal. The crewmember was also expected to arrive for a shift 15 minutes prior to the its start to ensure a handover briefing could be carried out for the outgoing crewmember.

Data was to be captured for the first 10 days of the fishing trip (Block 1), 10 days in the middle part of a trip (Block 2), the last 10 days of the fishing trip (Block 3), and the first 10 days at home immediately following arrival back in homeport (Block 4). Based on past research [12], the schedule of 6 hours on shift and 6 hours off shift was believed to represent (*a priori*) periods of time that would best show a gradual increase in reported/measured levels of fatigue and a re-set back to baseline values once at-home. The crewmember was asked to capture as much heart rate data (by wearing the armband) as possible throughout each block. Given the dynamic nature of offshore fishing [13], the crewmember was unable to collect data on all of the days but was successful in providing information for a total of 56 days across all of the time blocks (9 days in Block 1, 27 days in Block 2, 6 days in Block 3, and 14 days in Block 4). The additional data provided in the middle part of the trip as well as that while the crewmember was at home was used in the analyses.

DATA COLLECTION

To capture the data from the various inputs, a purpose-built application (Skilltinuous, Training Works, St. John's, NL) was developed and loaded onto a ruggedized iPad (Apple, Cupertino, CA) connected to the vessel's Internet. Environmental data (vessel movement) was captured with two independent sensors (2JCIE-BU01, Omron) located at various sites onboard the vessel (e.g., bridge, galley, fish processing plant, accommodation area). The sensor hub recorded 3-axis acceleration for 6 degrees of freedom (pitch/gyrox [dps], yaw/gyroz [dps], roll/gyroy [dps], heave/accelz [g], sway/accelx [g], and surge/accely [g]), temperature [°C], relative humidity [%], light [lux], noise [dB], barometric pressure [hPa], estimated total concentration of volatile organic compounds in parts per billion (eTVOCppb), estimated carbon dioxide in parts per million (eCO_{2ppm}), and vibration through three sensors [number of earth quakes, number of vibrations, and spectral intensity (SI)].

The crewmember received instructions on how to use the iPad application (Skilltinuous) and the armband. A baseline measure of five minutes was collected as an initial benchmark for the remainder of the data collection process. After logging into the iPad, the crewmember was

asked to provide daily ratings, activities, and complete the psychomotor vigilance test (PVT). Use of the ultra-short version of the PVT was based on its reported ability to detect fatigue, the ease of use, and minimal time requirements for the crewmember [11]. The fatigue log scales were based on mental, physical, perceived, and overall ratings of fatigue as outlined in previous research [3]. These ratings were captured with a visual analog scale with three anchor points. The use of a slider was designed to record a value (in the background) from 1 to 10 in increments of 0.5 that corresponds to the position where the crewmember slid the toggle (Fig. 1). The position selected on the slider corresponds to the distance along a 150 mm line and represents qualitative text-based anchors. Daily activity logs consisted of text-based inputs and dropdown menu options that were recoded into numerical values. The option to add text-based information was used to explore activities that might not be available in the dropdown menu.

The use of the visual analog scale accomplished two goals [14]. First, it did not limit the use of the scale by providing an anchored number to a written term. For example, had the user selected a 2 on a Likert scale and then worked for 12 hours, it would likely introduce a bias when selecting a value following the shift, because, from a cognitive perspective, it would be unlikely for a person to report being less fatigued than before completing the work. In this example, the scale would be reduced to a possible selection of 3 to 10, rather than 1 to 10, leading to a situation in which the crew member would select a higher value after performing some amount of work, even if they do not feel more tired. Second, the use of a slider limited the likelihood of a central tendency bias [15].

The presentation of the scale also provided a free range of values and was not biased toward reporting more fatigue as the time at sea progresses. For example, if a crew member recalled that a value of 1 or 2 was selected on the first day of the voyage after a 4-hour sleep, it would be unlikely that they would select the same or a lesser value after 50 days of working 6 hours on/6 hours off, even if they did not feel more tired.

Heart rate data

Heart rate (HR) data was separated into several variables thought to reflect important markers during the analysis. For example, maximum HR (HR_{max}) was a reflection of how much physical and/or cognitive effort had been exerted in the previous 24-hours. As it was possible that this value could be influenced by environmental conditions (e.g., rough seas, high levels of carbon dioxide, ambient temperature) HR_{max} data was examined for correlations to other variables. Similarly, as it has been anecdotally



Figure 1. Skilltinuous iPad application panels for data collection of daily activities log, psychomotor vigilance test (PVT), and fatigue rating

reported that vessel motion interrupted sleep, sleeping HR was also explored for factors that may have caused a change from day to day. Given the work environment and schedule of the crewmember, it was not possible to collect a traditional resting HR value (i.e., supine for 5 minutes in a quiet space); therefore, baseline HR (HR_{BL}) values were identified from the raw data immediately after waking and filtered for clear indications of movement (e.g., increase of more than 10 beats per minute from the previous 60 seconds).

Psychomotor vigilance test data

To capture a psychomotor response time, the crewmember was presented with 16 randomly generated prompts. The maximum period between the end of one prompt and the next was set at 1 second with a minimum period of 500 ms. The maximum allowable time lapse between a prompt and a response was set at 3500 ms. The total time to complete the test was set at 60 seconds. As this PVT version was considered ultra-short in comparison to the 10-minute version [16], the data needed to be interpreted within several thresholds [11]. For example, in an ultra-short version, a response time of over 350 ms was classified as a lapse. A false start was identified if the crew member response was less than 50 ms.

RESULTS

All data were visually analyzed, and descriptive statistics have been provided. The data were divided into quantitative and qualitative categories and then combined in mixed analyses. It should be noted that *a priori* it was hypothesized that at-home data would be different from the other three time blocks which occurred at sea [17, 18]. This assumption was based on previous research purporting that fatigue is increased while at sea [19–21], particularly for extended periods and while working a 6-hour on/6-hour off schedule [8].

QUANTITATIVE DATA

Heart rate data

After filtration of the error code (noted as 255 in the data), all HR data (collected at ~0.5 Hz) were averaged into 60-second epochs. These 60 second blocks were then used to determine several specific attributes related to possible changes that were influenced by variables noted during discussions with the crewmember. Data were tested for independent variables of time block (0 = at-home, 1 = at-sea). Data collection occurred as often as possible, however, there were periods where the armband battery needed to be charged, or the device onboard memory needed to be transferred to an external database. During these random periods, data collection was not possible.

To identify potential changes associated with independent variables, the HR data was subdivided into seven distinct categories: 1) HR_{BL} , 2) daily average HR (HR_{daily}), 3) HR_{max} , 4) work HR (HR_{work}), 5) off-shift HR ($HR_{off-shift}$), 6) sleep HR (HR_{sleep}), and 7), and sleep dip HR (HR_{dip}). HR_{work} and $HR_{off-shift}$ during the at-home period were calculated when specific times allocated for chores around the house were noted in a daily log. The HR categories were used to determine whether there were any noticeable changes in the biodata related to the four time blocks. The daily activity logs were also used to identify any specific instances of increased activity (none were noted in the data). Table 1 includes the descriptive information for the seven categories.

A visual examination of HR_{BL} , HR_{daily} , HR_{max} , $HR_{off-shift}$, and HR_{dip} data did not appear to reveal any major differences across the different time blocks. However, HR_{work} appeared to be considerably different, particularly between the first 10 days, the mid-trip block at sea, and the at-home data (Fig. 2A). Similarly, HR_{sleep} also appeared to be different between the first 10 days, the mid-trip block at sea, and the at-home period (Fig. 2B). It was further noticed that the variability in HR data appeared to be higher while at-home.

Table 1. Heart rate (HR) descriptive information

Time block	Heart rate variable (SD)						
	HR_{BL}	HR_{daily}	HR_{max}	HR_{work}	$HR_{off-shift}$	HR_{sleep}	HR_{dip}
First 10 days	86.83 (4.39)	87.98 (1.97)	132.33 (5.39)	94.90 (5.91)	91.57 (5.09)	80.69 (3.60)	-6.74 (8.21)
Mid-trip	85.81 (3.74)	90.27 (4.43)	142.93 (18.63)	96.37 (6.73)	93.14 (3.69)	80.61 (3.72)	-5.53 (6.24)
Last 10 days	86.34 (2.59)	88.20 (1.31)	140.00 (15.47)	97.01 (4.60)	92.63 (4.23)	80.12 (4.52)	-7.21 (4.39)
At-home	89.75 (24.21)	96.54 (16.54)	148.93 (16.50)	107.67 (12.20)	93.57 (13.71)	73.66 (6.27)	-3.65 (10.44)

HR_{BL} — baseline heart rate; HR_{daily} — daily average heart rate; HR_{dip} — sleep dip heart rate; HR_{max} — maximal heart rate; $HR_{off-shift}$ — off-shift heart rate; HR_{sleep} — sleep heart rate; HR_{work} — work heart rate

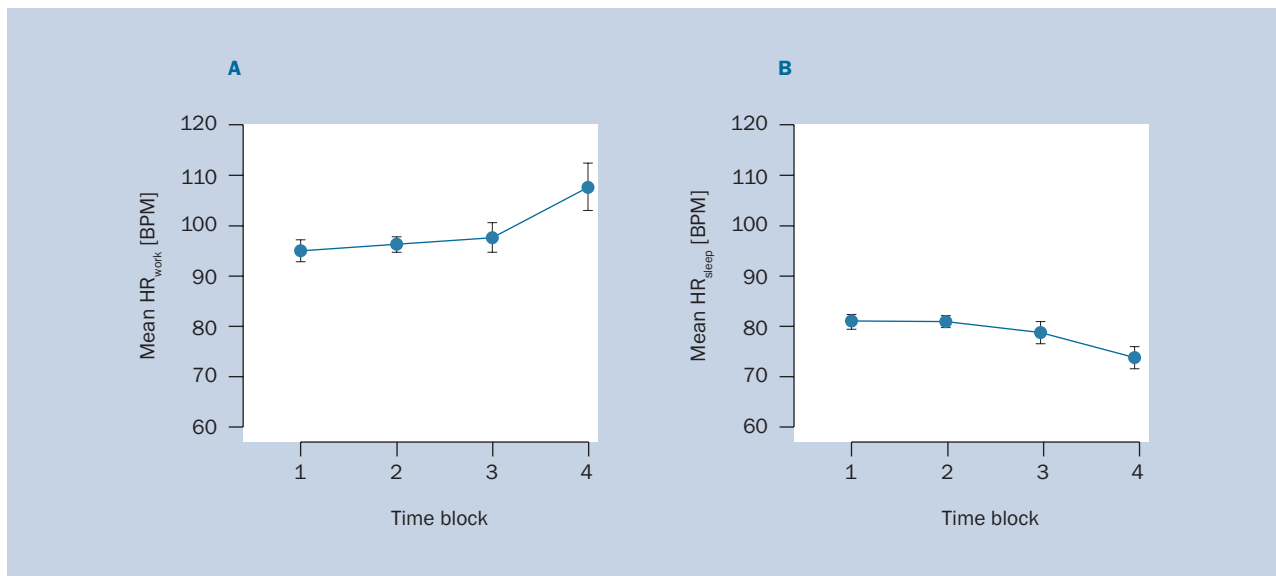


Figure 2. Mean work heart rate (HR_{work}) (A) and sleep heart rate (HR_{sleep}) (B) based on time block. Error bars represent standard error

Table 2. Psychomotor vigilance test (PVT) descriptive information

Time block	Mean (SD)	False starts (SD)	Lapses (SD)
First 10 days	275.39 (16.54)	0.44 (0.73)	0.67 (0.87)
Mid-trip days	280.05 (11.52)	0.31 (0.47)	1.03 (1.15)
Last 10 days	286.33 (15.12)	0.00 (0.00)	1.50 (1.29)
At-home	303.22 (19.49)	1.33 (1.12)	1.78 (1.20)

A comparison between at-home and at-sea data revealed that there were no noticeable differences for the HR_{BL}, HR_{daily}, HR_{max}, HR_{off-shift}, and HR_{dip} data. HR_{work} and HR_{sleep} appeared to be considerably different between the at-sea and at-home data. The mean HR_{work} while at-home was 107.67 and 96.15 while at sea. The mean at-home HR_{sleep} was 73.66 bpm while the at-sea mean was 80.65 bpm.

Psychomotor vigilance test data

Psychomotor vigilance test data contains three distinct components: overall average time to response, number of lapses, and number of false starts. PVT data was also visually analyzed for possible differences between at-home and at-sea periods. As with the other data and due to operational tempo and other requirements, the crew member did not provide information every day throughout the collection period. Table 2 provides the mean response times (ms), false starts, and lapses for the PVT based on time blocks.

Based on a visual examination of the PVT average data, there appears to be a steady increase in the time required to respond to the test. The largest differences appear to occur

between the first 10 days, the mid-trip period, and the at-home block (Fig. 3A). There also appears to be a considerable difference in the number of false starts when comparing the four time blocks (Fig. 3B).

Sleep

Table 3 provides descriptive information for the self-reported duration and quality of sleep. Based on a visual examination of the sleep duration reports, there appears to be a considerable difference between the number of consecutive hours of sleep while at-home compared to those during the period while at sea (Fig. 4). The data also suggests that sleep duration progressively decreased throughout the time at sea. There did not appear to be any noticeable difference in the rating of sleep quality across the different time blocks.

Fatigue rating

A rating of fatigue was given for four different components: mental, physical, perceived, and overall. Table 4 provides descriptive data for each time blocks. Again, the crew member did not provide a rating of fatigue during each

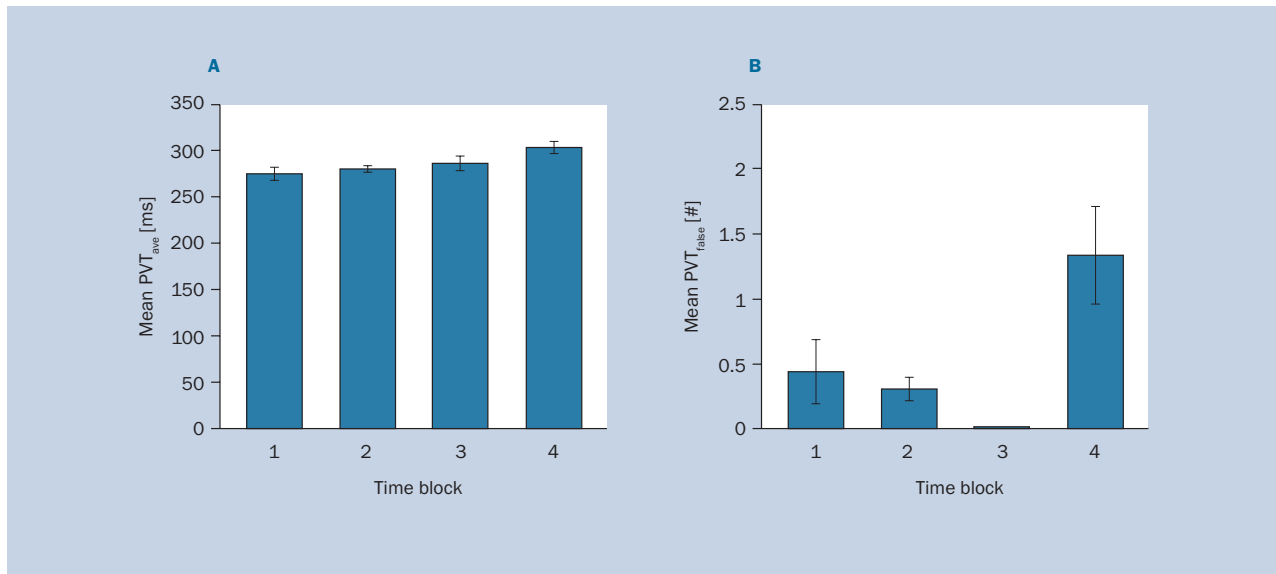


Figure 3. Mean psychomotor vigilance test (PVT) average (A) and mean PVT false starts (B) based on time blocks

Table 3. Sleep rating descriptive information.

Time block	Hours of sleep (SD)	Quality of sleep (SD)
First 10 days	4.11 (0.38)	3.94 (0.64)
Mid-trip days	3.63 (0.45)	4.03 (0.52)
Last 10 days	3.13 (0.88)	3.38 (1.03)
At-home	7.78 (0.25)	3.77 (0.56)

of the data collection time blocks. Perceived fatigue was a rating based on the previous day (better than the previous day).

No noticeable differences were identified for physical, perceived, or overall fatigue ratings across time blocks or when comparing at-home versus at-sea data. Based on the available data, there appeared to be a considerable difference in mental fatigue rating across the different time blocks. A visual examination suggests that the last 10 days at sea were rated as having been less mentally fatiguing than all other time blocks (Fig. 5). When combining the data from at-sea and comparing that to the at-home ratings, there appeared to be a noticeable difference. The mean at-sea mental fatigue rating was 1.71 while the at-home rating was 2.11.

VESSEL DATA

Environmental data

A visual examination of the environmental conditions (Tab. 5) data recorded from the bridge of the vessel was

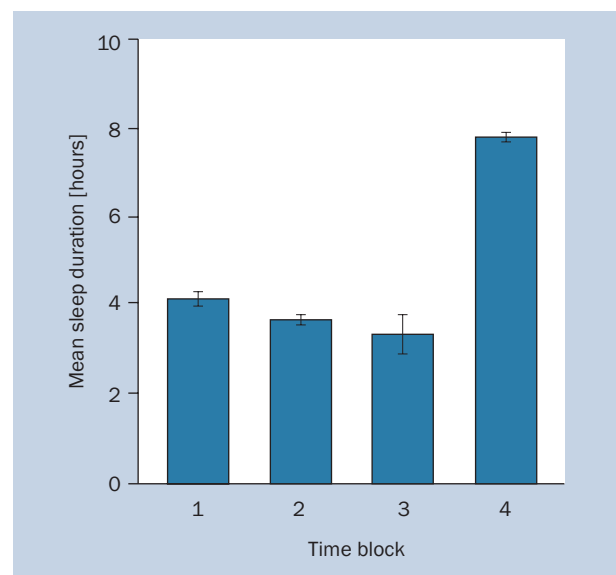


Figure 4. Mean sleep duration based on time blocks

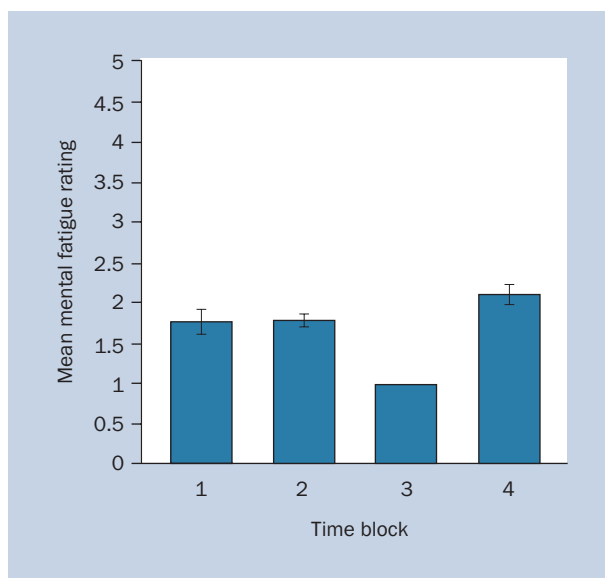
carried out for the three time blocks while at sea. The data of the last 10 days were not always available due to connectivity issues with the Internet. It was noted that noise levels were noticeably lower in the first 10 days at sea when compared to the other two time blocks. Despite differences in the environmental data across the individual time blocks, these changes did not appear to noticeably influence any of the other variable.

Vessel movement

The bridge sensor hub data appeared to indicate that no noticeable differences occurred in vessel pitch across

Table 4. Fatigue rating (from 1 to 10) descriptive information

Time block	Fatigue ratings (SD)			
	Mental	Physical	Perceived	Overall
First 10 days	1.78 (0.44)	2.22 (0.67)	4.67 (1.23)	2.22 (0.67)
Mid-trip	1.79 (0.41)	1.97 (0.42)	4.76 (0.51)	1.90 (0.42)
Last 10 days	1.00 (0.00)	2.00 (0.00)	5.00 (0.00)	2.00 (0.00)
At-home	2.11 (0.33)	2.33 (0.50)	5.11 (0.33)	2.11 (0.60)

**Figure 5.** Mental fatigue rating based on time block

the three time blocks. Table 6 provides mean values across the three time blocks. Based on an examination of the data, there did not appear to be a noticeable difference in the amount of roll, yaw, heave, or sway for the vessel based on the different time blocks. Vessel movement data suggest that there was considerably more pitch during the first 10 days at sea. Vessel surge data suggests that there were considerably more fore and aft movement between the first 10 days and the last 10 days at sea. Day-to-day variability was not analyzed in this case study; however, in cases where the crewmember noted a particular environmental event (rough seas) in the daily log, biodata and reaction time did not appear to be negatively influenced. It was noted, based on the available data, that vessel roll impacted both sleep quality ratings and sleep duration.

DISCUSSION

This case study is the first known project to contextualize both qualitative and quantitative data from a fishing crew

member with environmental data and vessel movements across at-sea and at-home periods. It was expected (based on past research and personal communications with other marine crew) that the at-sea data would show a distinctly different picture of biodata and self-reporting of fatigue [8, 11, 22, 23]. This assumption was based on past research related to the nature of shift work onboard a working fishing vessel [10, 21, 24, 25], and particularly for those working a 6 on/6 off schedule [12]. Specifically, it was expected that as the crewmember spent more time at sea, performance on the PVT would have decreased, HR values would have increased, ratings of sleep quality would have decreased, and that ratings of fatigue would have increase after completing over 30 days of a 6 on/6 off work schedule [3, 12, 26, 27].

It could be argued that because this crewmember spent the majority of time on the bridge, fatigue levels may have not been influenced by more physically demanding tasks experienced by crew working on the deck or during fish processing. For example, the differences in crew position would likely have influenced all derived HR values, while environmental conditions may have increased ratings of fatigue and decreased sleep quality. To better contextualize the data, future marine related fatigue risk research should consider the crewmember's work environment and tasks.

The data do not appear to support the assumption that fatigue rating or biodata (heart rate in this case) are higher while at sea, particularly for completing bridge duties. In fact, the data suggest that the crew member had higher HR_{work} , slower reaction times and increased errors on the PVT as well as higher mental fatigue rating while at home. These differences were noticeable despite the crew member having more sleep and a lower HR_{sleep} . The data also suggest that neither environmental conditions nor vessel movements negatively influenced the biodata or self-reported levels of fatigue while at sea. It is possible that this crewmember was chronically fatigued, thus there would be no noticeable difference across the various time blocks or while at home. As noted by Thomas and Smith [4], individuals are not always aware that they

Table 5. Environmental data from one Data Acquisition Unit located on the bridge of the vessel

Time block	Environmental measure								
	Ambient temperature [°C]	Relative humidity [%]	Pressure [hPa]	Noise [dB]	eTVOC [ppb]	eCO2 [ppm]	SI value [kine]	PGA [gal]	SI [-]
First 10 days	23.7 (3.36)	26.56 (5.12)	2.22 (0.67)	78.65 (2.24)	126.17 (128.10)	1014.51 (437.99)	0.07 (0.09)	68.40 (99.94)	1.49 (2.08)
Mid-trip	24.70 (2.19)	25.97 (3.03)	1.90 (0.42)	89.31 (8.10)	464.74 (360.64)	1708.92 (364.28)	0.06 (0.11)	53.95 (81.35)	1.92 (2.29)
Last 10 days	26.20 (0.99)	24.00 (0.85)	2.00 (0.00)	94.55 (10.11)	105.50 (26.16)	1098.50 (171.83)	N/A	N/A	N/A

Measurements of temperature in degrees Celsius (°C), atmospheric pressure in hectopascal (hPa), noise in decibels (dB), air quality estimated by the concentration of total volatile organic compounds (eTVOC) in parts per billion (ppb), estimated carbon dioxide (eCO2) in parts per million (ppm), spectral intensity (SI) value measured in kine (cm/s) for vibration (number of earth quakes, peak ground acceleration (PGA) measured in galileo (gal), and number of vibrations)

Table 6. Vessel movement data based on time blocks

Time block	Vessel movement					
	Pitch	Yaw	Roll	Heave	Sway	Surge
First 10 days	3.66 (2.68)	26.56 (5.12)	0.24 (0.06)	78.65 (2.24)	126.17 (128.10)	0.24 (0.06)
Mid-trip	0.10 (1.58)	25.97 (3.03)	0.19 (0.08)	89.31 (8.10)	464.74 (360.64)	0.19 (0.08)
Last 10 days	0.08 (1.08)	24.00 (0.85)	0.13 (0.06)	94.55 (10.11)	105.50 (26.16)	0.13 (0.06)

are fatigued, particularly if their level of performance has become the “norm” and is not compared against a period of time where they are well rested. As fatigue is not directly measured prior, during, or following a marine accident, and no other known studies have explored this possibility, it is currently unknown whether other crewmembers could also be chronically fatigued.

LIMITATIONS

The primary limitation of this case study is the inconsistency of data collection. The HR data collection device (armband) was limited to recording BPM for a maximum of 8 hours due to onboard storage and battery capacities. This limitation required the crew member to remove the device for data transfer and charging the battery. During these periods, it is possible that other work activities were occurring which may have influenced HR_{work} values. The data collection device was selected as it met certain criteria, which addressed snagging hazard avoidance, provided onboard data storage, was comfortable to wear for extended periods of time, and most importantly, the data was considered valid and reliable across the dynamic environments in which it was deployed. However, the device was limited in its ability to capture more than one variable (memory limitation) over a long period (battery limitation). This study is

also limited in its ability to generalize to the other crewmembers and other marine settings. However, this case study provides a unique perspective on data collected across multiple periods at sea as well as at home. A final limitation is related to the vessel environmental and movement data, as it was only reported for the bridge of the vessel. Sensor placed in other workspaces not frequented by this seafarer may have resulted in different results. In this case study, the crewmember spent the majority of time on the bridge (shifts and handover as well as completing paperwork); therefore, environmental conditions in other locations were not deemed to influence the biodata or fatigue ratings for this individual.

CONCLUSIONS AND RECOMMENDATIONS

Given the findings from this case study and based on past research, the following conclusion and recommendation are made:

- Data collection across all aspects of a voyage as well as at home provides an increased level of understanding fatigue risk in a marine setting.
- As no off-the-shelf operationally acceptable (e.g., intrinsically safe, non-snagging) data collection device currently captures long-term biodata and environmental conditions, there is a need to develop such a system/device.

- Although not found to be of significant influence in this case study, the inclusion of environmental data such as ambient temperature, noise levels, and vessel movement are important factors when contextualizing biodata in a marine setting.
- Further long-term data collection in real-world settings is required to ensure fatigue risk prediction and mitigation strategies provide benefit to industry workers in harsh environments.
- More sensitive biodata measures such as heart rate variability should be included in future marine related fatigue risk studies.
- Machine learning models and algorithms will need to be developed for data analytics and predictive insights related to long-term fatigue risk data.

KEY MESSAGE

Based on the findings from this case study and a review of past literature, it is important to consider not just the data collected while completing at-sea operations, but also factors influencing fatigue which occur while at-home. Combined, these sources of information aid in contextualizing subjective and objective measures of fatigue in the maritime domain. This combination will provide a better framework to develop fatigue risk identification, prediction and management strategies.

ARTICLE INFORMATION AND DECLARATIONS

Ethics statement: Ethical approval for the study was granted from Veritas REB (Protocol #2022-3062-1191-1) and the crewmember provided informed written consent prior to participating.

Author contributions: Michael Taber was involved in the conceptualization of this work, completed all ethical approval documentation, was involved in data collection, performed the data analysis and interpretation, and wrote the manuscript. Tamara Vatcher was involved in the conceptualization of this work, was involved in data collection and interpretation, and reviewed this manuscript.

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REFERENCES

1. Aaronson LS, Teel CS, Cassmeyer V, et al. Defining and measuring fatigue. *Image J Nurs Sch*. 1999; 31(1): 45–50, doi: [10.1111/j.1547-5069.1999.tb00420.x](https://doi.org/10.1111/j.1547-5069.1999.tb00420.x), indexed in Pubmed: [10081212](https://pubmed.ncbi.nlm.nih.gov/10081212/).
2. Chong SD, Baldwin CL. The origins of passive, active, and sleep-related fatigue. *Front Neuroergon*. 2021; 2: 765322, doi: [10.3389/fnrgo.2021.765322](https://doi.org/10.3389/fnrgo.2021.765322), indexed in Pubmed: [38235224](https://pubmed.ncbi.nlm.nih.gov/38235224/).
3. Luo H, Lee PA, Clay I, et al. Assessment of fatigue using wearable sensors: a pilot study. *Digit Biomark*. 2020; 4(Suppl 1): 59–72, doi: [10.1159/000512166](https://doi.org/10.1159/000512166), indexed in Pubmed: [33442581](https://pubmed.ncbi.nlm.nih.gov/33442581/).
4. Thomas M, Smith A. An investigation into the cognitive deficits associated with chronic fatigue syndrome. *Open Neurol J*. 2009; 3: 13–23, doi: [10.2174/1874205X00903010013](https://doi.org/10.2174/1874205X00903010013), indexed in Pubmed: [19452031](https://pubmed.ncbi.nlm.nih.gov/19452031/).
5. International Civil Aviation Organization (ICAO). Fatigue management guide for airline operators. 2nd Edition. 2015.
6. International Maritime Organization (IMO). Guidelines on fatigue. 2002.
7. Strauch B. Investigating fatigue in marine accident investigations. *Proc Manuf*. 2015; 3: 3115–3122, doi: [10.1016/j.promfg.2015.07.859](https://doi.org/10.1016/j.promfg.2015.07.859).
8. Jepsen JR, Zhao Z, van Leeuwen WMA. Seafarer fatigue: a review of risk factors, consequences for seafarers' health and safety and options for mitigation. *Int Marit Health*. 2015; 66(2): 106–117, doi: [10.5603/IMH.2015.0024](https://doi.org/10.5603/IMH.2015.0024), indexed in Pubmed: [26119681](https://pubmed.ncbi.nlm.nih.gov/26119681/).
9. Sánchez-Beaskoetxea J, Basterretxea-Iribar I, Sotés I, et al. Human error in marine accidents: is the crew normally to blame? *Marit Transp Res*. 2021; 2: 100016, doi: [10.1016/j.martra.2021.100016](https://doi.org/10.1016/j.martra.2021.100016).
10. Warm JS, Parasuraman R, Matthews G. Vigilance requires hard mental work and is stressful. *Hum Factors*. 2008; 50(3): 433–441, doi: [10.1518/001872008X312152](https://doi.org/10.1518/001872008X312152), indexed in Pubmed: [18689050](https://pubmed.ncbi.nlm.nih.gov/18689050/).
11. Arsintescu L, Kato K, Cravalho P, et al. Validation of a touchscreen psychomotor vigilance task. *Accid Anal Prev*. 2019; 126: 173–176, doi: [10.1016/j.aap.2017.11.041](https://doi.org/10.1016/j.aap.2017.11.041).
12. Härmä M, Partinen M, Repo R, et al. Effects of 6/6 and 4/8 watch systems on sleepiness among bridge officers. *Chronobiol Int*. 2008; 25(2): 413–423, doi: [10.1080/07420520802106769](https://doi.org/10.1080/07420520802106769), indexed in Pubmed: [18484371](https://pubmed.ncbi.nlm.nih.gov/18484371/).
13. Wertheim AH. Working in a moving environment. *Ergonomics*. 1998; 41(12): 1845–1858, doi: [10.1080/001401398186018](https://doi.org/10.1080/001401398186018), indexed in Pubmed: [9857842](https://pubmed.ncbi.nlm.nih.gov/9857842/).
14. Kuhlmann T, Dantlgraber M, Reips UD, et al. Investigating measurement equivalence of visual analogue scales and Likert-type scales in Internet-based personality questionnaires. *Behav Res Methods*. 2017; 49(6): 2173–2181, doi: [10.3758/s13428-016-0850-x](https://doi.org/10.3758/s13428-016-0850-x), indexed in Pubmed: [28130728](https://pubmed.ncbi.nlm.nih.gov/28130728/).
15. Hollingworth HL. The central tendency of judgment. *J Philos Psychol Sci Methods*. 1910; 7(17): 461, doi: [10.2307/2012819](https://doi.org/10.2307/2012819).
16. Basner M. Ultra-short objective alertness assessment: an adaptive duration version of the 3 minute PVT (PVT-BA) accurately tracks changes in psychomotor vigilance induced by sleep restriction. *Sleep Adv*. 2022; 3(1): zpac038, doi: [10.1093/sleepadvances/zpac038](https://doi.org/10.1093/sleepadvances/zpac038), indexed in Pubmed: [37193407](https://pubmed.ncbi.nlm.nih.gov/37193407/).
17. Oldenburg M, Herzog J, Barbarewicz F, et al. Online survey among maritime pilots: job-related stress and strain and the effects on their work ability. *J Occup Med Toxicol*. 2021; 16(1): 35, doi: [10.1186/s12995-021-00322-2](https://doi.org/10.1186/s12995-021-00322-2), indexed in Pubmed: [34433479](https://pubmed.ncbi.nlm.nih.gov/34433479/).
18. Pauksztat B. 'Only work and sleep': seafarers' perceptions of job demands of short sea cargo shipping lines and their effects on work and life on board. *Marit Policy Manag*. 2017; 44(7): 899–915, doi: [10.1080/03088839.2017.1371347](https://doi.org/10.1080/03088839.2017.1371347).
19. Allen P, Wellens B, Smith A. Fatigue in British fishermen. *Int Marit Health*. 2010; 62(3): 154–158, indexed in Pubmed: [21154302](https://pubmed.ncbi.nlm.nih.gov/21154302/).

20. Andrei D, Griffin M, Grech M, et al. How demands and resources impact chronic fatigue in the maritime industry. The mediating effect of acute fatigue, sleep quality and recovery. *Saf Sci.* 2020; 121: 362–372, doi: [10.1016/j.ssci.2019.09.019](https://doi.org/10.1016/j.ssci.2019.09.019).
21. Gander P, van den Berg M, Signal L. Sleep and sleepiness of fishermen on rotating schedules. *Chronobiol Int.* 2008; 25(2): 389–398, doi: [10.1080/07420520802106728](https://doi.org/10.1080/07420520802106728), indexed in Pubmed: [18533331](https://pubmed.ncbi.nlm.nih.gov/18533331/).
22. Mehta R, Peres S, Kannan P, et al. Comparison of objective and subjective operator fatigue assessment methods in offshore shiftwork. *J Loss Prev Process Ind.* 2017; 48: 376–381, doi: [10.1016/j.jlp.2017.02.009](https://doi.org/10.1016/j.jlp.2017.02.009).
23. Mostert SN, Martin J, Van Wijk C. The relationship between health literacy and health behaviours amongst a South African Navy sample. *Int Marit Health.* 2025; 76(1): 11–20, doi: [10.5603/imh.101675](https://doi.org/10.5603/imh.101675), indexed in Pubmed: [40247768](https://pubmed.ncbi.nlm.nih.gov/40247768/).
24. Grech MR, Neal A, Yeo G, et al. An examination of the relationship between workload and fatigue within and across consecutive days of work: is the relationship static or dynamic? *J Occup Health Psychol.* 2009; 14(3): 231–242, doi: [10.1037/a0014952](https://doi.org/10.1037/a0014952), indexed in Pubmed: [19586219](https://pubmed.ncbi.nlm.nih.gov/19586219/).
25. Yancheshmeh F, Mousavizadegan SH, Amini A, et al. Poor sleep quality, long working hours and fatigue in coastal areas: a dangerous combination of silent risk factors for deck officers on oil tankers. *Int Marit Health.* 2020; 71(4): 237–248, doi: [10.5603/IMH.2020.0042](https://doi.org/10.5603/IMH.2020.0042), indexed in Pubmed: [33394488](https://pubmed.ncbi.nlm.nih.gov/33394488/).
26. Sunde E, Bratveit M, Pallesen S, et al. Noise and sleep on board vessels in the Royal Norwegian Navy. *Noise Health.* 2016; 18(81): 85–92, doi: [10.4103/1463-1741.178481](https://doi.org/10.4103/1463-1741.178481), indexed in Pubmed: [26960785](https://pubmed.ncbi.nlm.nih.gov/26960785/).
27. Tamura Y, Kawada T, Sasazawa Y. Effect of ship noise on sleep. *J Sound Vib.* 1997; 205(4): 417–425, doi: [10.1006/jsvi.1997.1007](https://doi.org/10.1006/jsvi.1997.1007).

Job demands and burnout among Chinese seafarers — the chain mediating effects of work engagement and depression

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ABSTRACT

Background: This study aimed to investigate the mediating effects of work engagement and depression on the relationship between job demands and burnout among Chinese seafarers.

Material and methods: The study used Harman's single-factor test, descriptive analysis, correlation analysis, and mediation analysis. A total of 1,084 Chinese seafarers participated in this study, completing the Job Demands subscale of the Job Content Questionnaire (JCQ), the Utrecht Work Engagement Scale (UWES), the Depression subscale of the Depression Anxiety Stress Scales (DASS), and the Maslach Burnout Inventory-General Survey (MBI-GS). Data were collected from July 2025 to August 2025.

Results: The results indicated that, among Chinese seafarers: 1) job demands significantly and negatively predicted burnout; 2) work engagement mediated the relationship between job demands and burnout; 3) depression mediated the relationship between job demands and burnout; and 4) work engagement and depression exerted a chain mediating effect between job demands and burnout.

Conclusions: The findings have important practical implications for understanding the factors influencing burnout among Chinese seafarers and offer new insights for mental health interventions and maritime safety management.

(Int Marit Health 2026; 77, 3: 206–213)

Keywords: seafarers, job demands, burnout, work engagement, depression

INTRODUCTION

Burnout refers to a prolonged negative response experienced by individuals who are unable to effectively cope with persistent workplace stressors [1]. Among seafarers, the prevalence of burnout is 10.8% [2]. Burnout not only leads to physical and psychological distress among seafarers but also compromises the safe operation of the entire maritime industry [3], highlighting the critical importance of addressing this issue.

Burnout is primarily associated with work-related factors, such as job demands. Job demands refer to physical,

psychological, social, or organizational aspects of work that require sustained physical, cognitive, or emotional exertion and can lead to varying degrees of physical or psychological exhaustion [4]. According to the classic Job Demands-Resources (JD-R) theory, the work environment consists of two components, job demands and job resources, and occupational health is shaped through two processes — health impairment and motivation activation. However, individuals may perceive job demands differently. Some researchers have categorized them as either challenging or hindering [5]. Challenging job demands require effort but also facilitate

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personal development and rewards [6], for example, workload and time pressure [5]. Although such demands consume resources, when aligned with individual needs, they can stimulate motivation, buffer against negative effects such as stress, and enhance mental health by increasing engagement and self-efficacy. In contrast, hindering job demands primarily contribute to burnout through resource depletion [6]. This distinction moves beyond the traditional single-dimensional view of job demands, clarifying that not all demands are detrimental; some can serve as “positive stressors” when aligned with individual growth needs.

As noted, the relationship between job demands and burnout has been widely studied, yet findings remain inconsistent. Furthermore, relatively few studies have focused specifically on seafarers, particularly in the Chinese context. Most research has found a positive correlation between job demands and burnout, suggesting that higher job demands increase the risk of burnout [7, 8]. However, some studies report that when employees perceive job demands as highly challenging, their negative impact on burnout is attenuated [9]. Conversely, other research indicates a positive relationship between challenging job demands and burnout [10]. Based on these mixed findings, we propose Hypothesis H1: Job demands among Chinese seafarers directly predict their burnout.

In addition to examining the direct relationship between job demands and burnout, it is important to investigate the underlying mechanisms linking them. According to the JD-R theory, long-term exposure to hindering job demands depletes individual resources and reduces work engagement through the health impairment process [11, 12]. Conversely, work engagement is viewed as a product of “resource activation” [13], defined as a positive, fulfilling psychological state associated with work, characterized by vigor, dedication, and absorption [14]. Challenging job demands, in particular, stimulate achievement motivation, encouraging individuals to invest energy and maintain focus, thereby reducing burnout. Numerous studies have confirmed a positive correlation between challenging job demands and work engagement [6, 10, 15–17], while work engagement itself is negatively correlated with burnout [3, 18]. In contrast, hindering job demands limit the effective use of work resources, leading to lower work engagement and higher burnout among seafarers [8, 19]. Based on this reasoning, we propose Hypothesis H2: Work engagement mediates the relationship between job demands and burnout.

Depression, a key manifestation of the health impairment process in the JD-R theory, is characterized by core symptoms such as loss of interest or affect, persistently low energy, pronounced feelings of guilt or low self-worth, and difficulty concentrating [20]. Due to the distinctive nature of their occupation, seafarers are considered a high-risk

group for mental health issues [21]. Previous studies have demonstrated that job demands are significantly and positively correlated with depression among French merchant seafarers [22], suggesting that job demands may act as a risk factor for depression. Additionally, research on Turkish seafarers indicates that lower levels of burnout are associated with better mental health [23]. Depression, as a common emotional disorder, has also been shown to mediate the correlation between workplace stressors (e.g., workplace violence) and burnout among healthcare workers [24]. Based on these findings, we propose Hypothesis H3: Depression mediates the relationship between job demands and burnout.

The JD-R theory emphasizes that the dynamic balance between job demands and job resources decisively influences employees’ work status and mental health [11]. Within this framework, hindering job demands can deplete psychological resources, reducing work engagement [8], triggering depressive symptoms [25], and ultimately leading to burnout [8]. In contrast, challenging job demands can enhance the positive effects of job resources on work engagement [11], thereby lowering depression levels and mitigating burnout [6, 10]. Based on this reasoning, we propose Hypothesis H4: Work engagement and depression exert a chain mediating effect between job demands and burnout.

With the deepening implementation of China’s “strong maritime nation” initiative and the implementation of marine development strategies such as the “maritime community with a shared future,” the marine economy has grown rapidly, leading to a significant increase in demand for maritime transportation. As a core human resource of the maritime industry, seafarers play an irreplaceable role in global economic development. A high-quality seafarer workforce is crucial for ensuring China’s international competitiveness in the maritime sector. According to the 2024 China Seafarer Development Report, the total number of registered Chinese seafarers reached 2.0358 million by the end of 2024, making China the world’s second-largest seafarer supplier. Compared with workers in onshore occupations, seafarers face more complex risks and challenges, including long-term shift work, exposure to harsh physical environments, prolonged separation from family, and inadequate support systems [26]. Consequently, burnout among Chinese seafarers has become increasingly prominent, often leading to aggravated depressive symptoms and reduced work engagement [3, 27]. These issues may further contribute to maritime accidents, affecting the stability and international competitiveness of China’s maritime industry.

Based on the JD-R theory, this study focuses on Chinese seafarers to analyze the direct effect of job demands on burnout, as well as the mediating roles of work engagement

and depression. Understanding the causes of burnout among Chinese seafarers and the mechanisms linking relevant variables is crucial, yet research in China in this area remains limited. For the maritime industry, which relies heavily on Chinese seafarers, investigating burnout is of particular significance. This study also highlights that job demands are not uniform; by optimizing challenging job demands and strengthening job resource support, it is possible to enhance work engagement, reduce depression, alleviate burnout at its source, lower the risk of maritime accidents, and ensure the safe and efficient development of the maritime sector. The findings provide both a theoretical foundation and practical guidance for designing targeted psychological interventions and improving maritime safety management.

MATERIAL AND METHODS

PARTICIPANTS

Convenience sampling was used to recruit Chinese seafarers through an online questionnaire platform (Wenjuanxing) from July 2025 to August 2025. The inclusion criteria were as follows: 1) age 18 years or older; 2) at least 6 months of maritime work experience; 3) basic text reading and comprehension abilities; 4) no clearly diagnosed mental illness or severe organic disease; and 5) signed informed consent. After excluding questionnaires completed in less than 3 minutes and those that failed the attention-check items, a total of 1,084 valid questionnaires were obtained. Among the participants, only 5 were female seafarers, reflecting the gender imbalance in the maritime environment [28]. Participants' ages ranged from 18 to 58 years ($M \pm SD = 38.61 \pm 7.60$). Of these, 576 (53.14%) were senior seafarers and 508 (46.86%) were ordinary seafarers; 256 (23.62%) had senior high school/vocational secondary school education or below, 534 (49.26%) had a junior college-level education, and 294 (27.12%) had a bachelor's degree or above.

MEASURES

Job Content Questionnaire (JCQ)

Job demands were measured using the Job Demands subscale of the Chinese version of the JCQ [29]. This 5-item subscale is scored on a 4-point scale ranging from 1 ("Strongly Disagree") to 4 ("Strongly Agree"). In this study, the subscale demonstrated acceptable internal consistency, with a Cronbach's α coefficient of 0.80.

Utrecht Work Engagement Scale (UWES)

Work engagement was assessed using the simplified Chinese version of the UWES [30]. This 9-item scale comprises three subscales: Vigor, Dedication, and Absorption, and is scored on a 5-point response format ranging from 1 ("Strongly Disagree") to 5 ("Strongly Agree"), with higher

scores reflecting greater work engagement. In this study, the scale demonstrated excellent internal consistency, with a Cronbach's α coefficient of 0.90.

Depression Anxiety Stress Scales (DASS)

Depression was measured using the Depression subscale of the simplified Chinese version of the DASS [31]. This 7-item subscale is scored on a 4-point scale ranging from 1 ("Never") to 4 ("Always"), with higher scores indicating higher levels of depression. In this study, the subscale demonstrated high internal consistency, with a Cronbach's α coefficient of 0.85.

Maslach Burnout Inventory-General Survey (MBI-GS)

Burnout was assessed using the Chinese version of the MBI-GS [32]. This 15-item scale comprises three subscales: Emotional Exhaustion, Cynicism, and Reduced Personal Accomplishment. Items are scored on a 5-point scale ranging from 1 ("Strongly Disagree") to 5 ("Strongly Agree"). After reverse-scoring the items of the Reduced Personal Accomplishment subscale, total scores were calculated, with higher scores indicating greater levels of burnout. In this study, the scale demonstrated excellent internal consistency, with a Cronbach's α coefficient of 0.90.

DATA ANALYSIS

Data were processed and analyzed using IBM SPSS 29.0 and R 4.3.3. The statistical analyses included Harman's single-factor test, descriptive statistics, correlation analysis, and mediation analysis.

RESULTS

COMMON METHOD BIAS TEST

Harman's single-factor test was conducted to assess common method bias. The results indicated that a single unrotated factor accounted for 32.91% of the total variance, which is below the critical threshold of 40% [33], suggesting that common method bias was not a significant concern in this study.

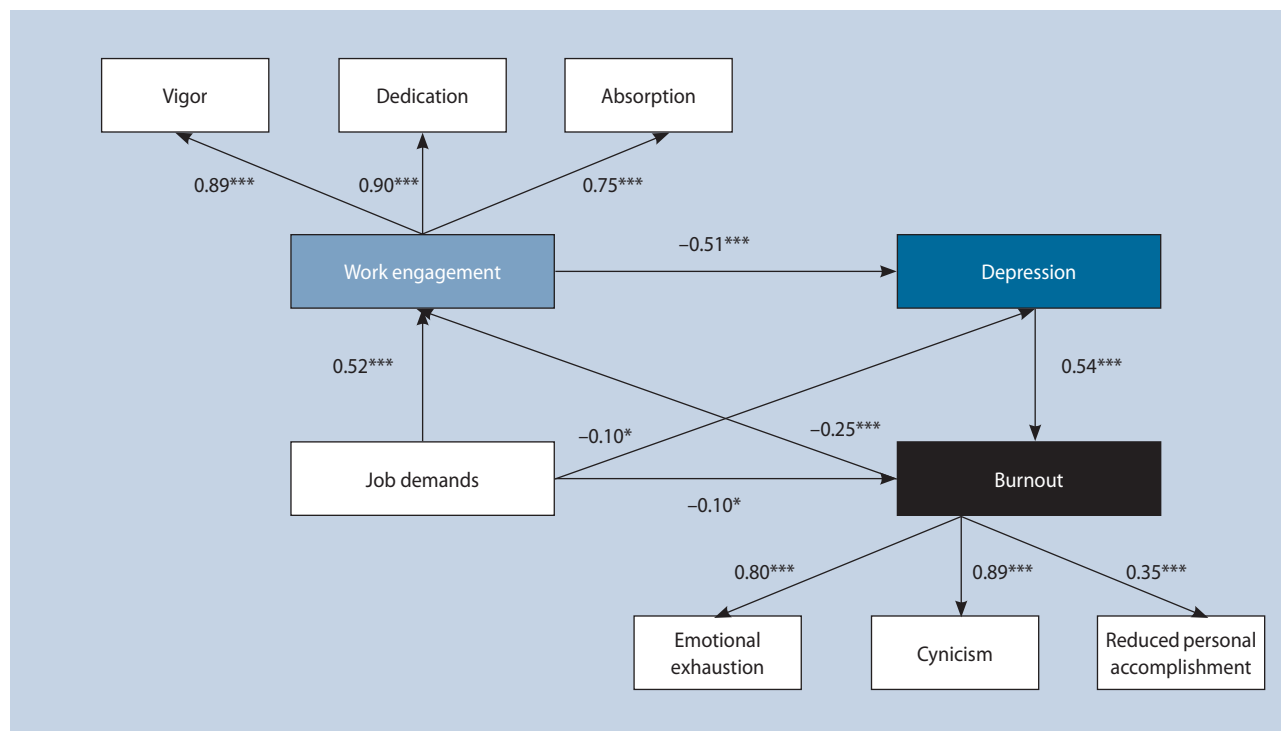
DESCRIPTIVE STATISTICS AND CORRELATION ANALYSIS

Descriptive statistics and correlation analyses for all variables are presented in Table 1. Burnout was significantly negatively correlated with job demands and work engagement, and significantly positively correlated with depression. Depression was significantly negatively correlated with job demands and work engagement, whereas work engagement was significantly positively correlated with job demands. Regarding demographic variables, educational background was negatively correlated with job demands

Table 1. Descriptive statistics and correlation analysis of variables

Variable	M ± SD	1	2	3	4	5	6
1. Gender							
2. Educational background		0.04					
3. Seafarer rank		0.05	-0.42***				
4. Job demands	14.20 ± 2.54	0.01	-0.08**	0.19***			
5. Work engagement	32.53 ± 5.98	-0.00	-0.02	0.04	0.43***		
6. Depression	9.33 ± 2.73	-0.00	0.12***	-0.09**	-0.28***	-0.48***	
7. Burnout	30.38 ± 8.87	-0.00	0.04	-0.00	-0.37***	-0.58***	0.61***

p < 0.01, *p < 0.001

**Figure 1.** Mediation model plot; *p < 0.05, ***p < 0.001

and positively correlated with depression, whereas seafarer rank was positively correlated with job demands and negatively correlated with depression. Gender showed no significant correlations with any of the variables. Based on these results, educational background and seafarer rank were included as control variables in subsequent analyses, whereas gender was excluded.

MEDIATION ANALYSIS

A latent variable structural equation model was constructed using the lavaan package in R 4.3.3 to examine the relationships among variables, as shown in Figure

1. After controlling for seafarers' educational background and seafarer rank, the model demonstrated good fit [$\chi^2/df = 5.24$, Comparative Fit Index (CFI) = 0.92, Tucker-Lewis Index (TLI) = 0.90, root mean square error of approximation (RMSEA) = 0.06, standardized root mean square residual (SRMR) = 0.06], indicating that work engagement and depression had a chain mediating effect between job demands and burnout among Chinese seafarers.

As illustrated in Figure 1, the direct path from job demands to burnout was significant [$\beta = -0.10$, SE = 0.04, 95% confidence interval (CI) = (-0.19, -0.02), $p < 0.05$]. The paths from job demands to work engagement [$\beta = 0.52$,

SE = 0.04, 95% CI = (0.44, 0.59), $p < 0.001$] and from job demands to depression [$\beta = -0.10$, SE = 0.04, 95% CI = (-0.19, -0.02), $p < 0.05$] were also significant. Additionally, the paths from work engagement to depression [$\beta = -0.51$, SE = 0.04, 95% CI = (-0.59, -0.43), $p < 0.001$] and from work engagement to burnout [$\beta = -0.25$, SE = 0.05, 95% CI = (-0.35, -0.16), $p < 0.001$] were significant. The path from depression to burnout was likewise significant [$\beta = 0.54$, SE = 0.04, 95% CI = (0.46, 0.63), $p < 0.001$].

The bias-corrected bootstrap method with 5,000 resamplings was used to calculate 95% confidence intervals. The results indicated that the individual mediating effects of work engagement and depression were significant, as was their chain mediating effect. Detailed results of the mediation analysis are presented in Table 2.

DISCUSSION

This study found that job demands not only directly predicted burnout among Chinese seafarers but also indirectly affected burnout through three pathways: work engagement, depression, and the chain mediating effect of both variables.

The results indicated that job demands had a significant negative predictive effect on burnout among Chinese seafarers, consistent with previous studies [10] and supporting Hypothesis H1. In a high-intensity, high-risk work environment, elevated job demands may enhance individuals' sense of control and self-worth, whereas low job demands may be perceived as "marginalization" or "distrust," potentially leading to burnout. Thus, among Chinese seafarers, job demands are not purely detrimental but can serve as a source of work motivation. This aligns with the JD-R theory, which posits that high workload, as a form of challenging job demand, can stimulate a sense of accomplishment and directly reduce burnout [11], further extending the application of this theory to the seafaring context.

This study confirmed Hypothesis H2, showing that higher job demands increased work engagement among Chinese

seafarers, which in turn reduced burnout. This finding differs from some previous studies [8], likely because earlier research often treated job demands too simplistically as a uniformly negative factor, assuming that they lead to fatigue and lower work engagement [6, 17]. However, not all job demands are detrimental: challenging demands (e.g., high workload) can motivate seafarers, whereas hindering demands (e.g., role conflict) may induce stress [34]. The JD-R theory posits that job demands can enhance the effects of job resources on work engagement; specifically, when seafarers encounter challenging job demands, they may leverage training, autonomy, and feedback as motivational resources to manage these demands [13, 35], thereby mitigating burnout. The results of this study provide empirical support for this theoretical perspective.

Additionally, this study found that depression mediated the relationship between job demands and burnout, highlighting the psychological mechanisms linking job-related factors to burnout and supporting Hypothesis H3. When seafarers cognitively appraise high job demands as opportunities for career development, they can alleviate negative emotions such as depression, thereby preventing the progression toward burnout [36]. This finding aligns with the revised JD-R model, which emphasizes that individuals' cognitive evaluations shape the psychological impact of work stressors [37]. Among Chinese seafarers, enhancing the sense of professional mission to redefine the meaning of work may serve as a critical strategy to manage mental health risks associated with high job demands, a consideration especially relevant within the collectivist cultural context of China.

The results of this study also demonstrated that work engagement and depression exerted a chain mediating effect between job demands and burnout among Chinese seafarers; that is, work engagement stimulated by job demands can buffer negative emotions such as depression, thereby reducing burnout and supporting Hypothesis H4. This finding advances the understanding of the positive pathway in the JD-R theory [38], indicating that when Chinese seafarers

Table 2. Statistical results of the mediation model

Path	Effect value	95% confidence interval	Effect rate [%]
Job demands → work engagement → burnout	-0.13	[-0.18, -0.08]	30.09
Job demands → depression → burnout	-0.06	[-0.10, -0.01]	13.89
Job demands → work engagement → depression → burnout	-0.14	[-0.18, -0.11]	32.41
Indirect effect	-0.33	[-0.39, -0.27]	76.39
Direct effect	-0.10	[-0.19, -0.02]	23.61
Total effect	-0.43	[-0.51, -0.35]	100.00

face high job demands, work engagement not only generates positive outcomes but also functions as a critical psychological resource, indirectly protecting seafarers from burnout by mitigating depressive symptoms [39, 40]. This chain-mediating pathway underscores the importance of simultaneously enhancing work engagement and preventing depressive symptoms to effectively manage burnout in the high-pressure maritime environment.

The findings have important practical implications for reducing burnout among Chinese seafarers. This study revealed that job demands significantly and negatively predicted burnout, suggesting that seafarers can derive a sense of professional value from challenging demands, thereby improving work effectiveness [10, 37]. In the Chinese cultural context, which emphasizes collectivism, seafarers are more likely to link job demands with family well-being, ship performance, the growth of maritime enterprises, and even national maritime development, rather than perceiving them as isolated personal burdens. This perspective diminishes the hindering nature of job demands, highlights their challenging significance, and facilitates a positive work attitude. By constructing occupational meaning at the cultural level, seafarers can perceive high demands as opportunities for personal value realization, framing them as worthwhile challenges. Based on these insights, and considering cultural factors unique to Chinese seafarers, such as collectivism, a sense of professional mission, and family orientation, psychological interventions for this group can be designed from the following three perspectives.

First, to optimize the cognitive reframing and goal-setting of job demands, maritime companies can assign moderately challenging tasks aligned with Chinese seafarers' career development paths, address negative cognitive biases through regular pre-service cognitive training, and guide them to leverage both their own positive resources and those of their colleagues to reduce the risk of burnout.

Second, regular targeted emotion-management interventions should be implemented. Research indicates that group psychological training can prevent and alleviate negative emotions, such as depression, among Chinese seafarers [41]. Structured group counseling sessions focused on stress management should be conducted regularly, alongside a dynamic monitoring system for their mental health. For individuals exhibiting depressive tendencies, timely psychological counseling should be provided to prevent the progression from depressive symptoms to burnout [24].

Third, differentiated psychological support resources should be strengthened. Given the low proportion of female seafarers, dedicated psychological support networks should be established for female seafarers to reduce the negative impact of gender-related challenges on mental health.

This study has several limitations. First, the cross-sectional design may limit the ability to infer causal relationships. Future research could employ longitudinal designs to track seafarers across different voyage cycles (e.g., the full cycle of short-haul coastal voyages) or combine behavioral experiments to further investigate causal links, thereby enhancing the reliability and causal inference of the findings. Second, this study provides limited discussion of seafarer-specific factors such as voyage duration, ship type, and route. Future studies could incorporate these variables, develop more complex models, and analyze both the independent and interactive effects of various factors on burnout. Third, the study sample consisted solely of Chinese seafarers, limiting the generalizability of the results to other cultural contexts. Future research could extend the investigation to seafarers from other countries or conduct comparative analyses across different national contexts. Fourth, only five female seafarers were included in the valid sample, reflecting a substantial gender imbalance due to occupational characteristics such as long-term work at sea and closed work environments. This limits the generalizability of the findings to female seafarers. Relevant authorities could promote gender equality in the maritime industry by optimizing work arrangements, reducing barriers for women entering the profession, and gradually improving gender balance, thereby enabling future studies to obtain more representative samples.

CONCLUSIONS

1. Job demands significantly and negatively predict burnout among Chinese seafarers; that is, higher job demands are associated with a lower likelihood of burnout.
2. Both work engagement and depression mediate the relationship between job demands and burnout among Chinese seafarers.
3. Work engagement and depression exert a chain mediating effect between job demands and burnout among Chinese seafarers, forming the pathway: job demands → work engagement → depression → burnout.

ARTICLE INFORMATION AND DECLARATIONS

Data availability statement: Data is available upon request.

Ethics statement: Approval was obtained from the ethics committee of Tianjin Normal University (ID: 2025070301). Written informed consent was obtained from all participants. All procedures were conducted in accordance with relevant guidelines and regulations.

Author contributions: JW participated in the method implementation, data collection, manuscript elaboration and revision. HW participated in the research design, data collection and analysis, manuscript elaboration.

All authors contributed to the manuscript and agreed to the published version.

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Conflict of interest: The authors report no conflicts of interest.

Supplementary material: None.

REFERENCES

- Guseva Canu I, Marca SC, Dell'Oro F, et al. Harmonized definition of occupational burnout: A systematic review, semantic analysis, and Delphi consensus in 29 countries. *Scand J Work Environ Health*. 2021; 47(2): 95–107, doi: [10.5271/sjweh.3935](https://doi.org/10.5271/sjweh.3935), indexed in Pubmed: [33258478](https://pubmed.ncbi.nlm.nih.gov/33258478/).
- Oldenburg M, Jensen HJ, Wegner R. Burnout syndrome in seafarers in the merchant marine service. *Int Arch Occup Environ Health*. 2013; 86(4): 407–416, doi: [10.1007/s00420-012-0771-7](https://doi.org/10.1007/s00420-012-0771-7), indexed in Pubmed: [22526089](https://pubmed.ncbi.nlm.nih.gov/22526089/).
- Chung YS, Lee PW, Lee JK. Burnout in seafarers: its antecedents and effects on incidents at sea. *Maritime Policy & Management*. 2017; 44(7): 916–931, doi: [10.1080/03088839.2017.1366672](https://doi.org/10.1080/03088839.2017.1366672).
- Demerouti E, Bakker AB, Nachreiner F, et al. The job demands-resources model of burnout. *J Appl Psychol*. 2001; 86(3): 499–512, indexed in Pubmed: [11419809](https://pubmed.ncbi.nlm.nih.gov/11419809/).
- Lepine J, Podsakoff N, Lepine M. A Meta-Analytic Test of the Challenge Stressor–Hindrance Stressor Framework: An Explanation for Inconsistent Relationships Among Stressors and Performance. *Academy of Management Journal*. 2005; 48(5): 764–775, doi: [10.5465/amj.2005.18803921](https://doi.org/10.5465/amj.2005.18803921).
- Podsakoff NP, LePine JA, LePine MA. Differential challenge stressor-hindrance stressor relationships with job attitudes, turnover intentions, turnover, and withdrawal behavior: a meta-analysis. *J Appl Psychol*. 2007; 92(2): 438–454, doi: [10.1037/0021-9010.92.2.438](https://doi.org/10.1037/0021-9010.92.2.438), indexed in Pubmed: [17371090](https://pubmed.ncbi.nlm.nih.gov/17371090/).
- Buscema F, Cena L, Cricenti C, et al. Through restless waters and deep commotion: A study on burnout and health impairment of Italian seafarers from the JD-R model perspective. *F1000Res*. 2025; 14: 19, doi: [10.12688/f1000research.159198.2](https://doi.org/10.12688/f1000research.159198.2), indexed in Pubmed: [39844846](https://pubmed.ncbi.nlm.nih.gov/39844846/).
- Wan Z, Liu Y, Jiang Y, et al. Burnout and work ability: A study on mental health of Chinese seafarers from the job demand resource model perspective. *Ocean & Coastal Management*. 2023; 237: 106517, doi: [10.1016/j.ocecoaman.2023.106517](https://doi.org/10.1016/j.ocecoaman.2023.106517).
- Li P, Taris TW, Peeters MCW. Challenge and hindrance appraisals of job demands: one man's meat, another man's poison? *Anxiety Stress Coping*. 2020; 33(1): 31–46, doi: [10.1080/10615806.2019.1673133](https://doi.org/10.1080/10615806.2019.1673133), indexed in Pubmed: [31578098](https://pubmed.ncbi.nlm.nih.gov/31578098/).
- Vinod Nair A, McGregor A, Caputi P. The Impact of Challenge and Hindrance Demands on Burnout, Work Engagement, and Presenteeism. A Cross-Sectional Study Using the Job Demands-Resources Model. *J Occup Environ Med*. 2020; 62(8): e392–e397, doi: [10.1097/JOM.0000000000001908](https://doi.org/10.1097/JOM.0000000000001908), indexed in Pubmed: [32404829](https://pubmed.ncbi.nlm.nih.gov/32404829/).
- Bakker A, Demerouti E, Sanz-Vergel A. Job Demands–Resources Theory: Ten Years Later. *Annual Review of Organizational Psychology* and Organizational Behavior. 2023; 10(1): 25–53, doi: [10.1146/annurev-orgpsych-120920-053933](https://doi.org/10.1146/annurev-orgpsych-120920-053933).
- Schaufeli W, Bakker A. Job demands, job resources, and their relationship with burnout and engagement: a multi-sample study. *Journal of Organizational Behavior*. 2004; 25(3): 293–315, doi: [10.1002/job.248](https://doi.org/10.1002/job.248).
- Bakker A, Demerouti E. The Job Demands-Resources model: state of the art. *Journal of Managerial Psychology*. 2007; 22(3): 309–328, doi: [10.1108/02683940710733115](https://doi.org/10.1108/02683940710733115).
- Schaufeli W, Salanova M, González-Romá V, et al. The Measurement of Engagement and Burnout: A Two Sample Confirmatory Factor Analytic Approach. *Journal of Happiness Studies*. 2002; 3(1): 71–92, doi: [10.1023/a:1015630930326](https://doi.org/10.1023/a:1015630930326).
- Bakker A, Demerouti E, Schaufeli W. The crossover of burnout and work engagement among working couples. *Human Relations*. 2005; 58(5): 661–689, doi: [10.1177/0018726705055967](https://doi.org/10.1177/0018726705055967).
- Lesener T, Gusy B, Wolter C. The job demands-resources model: A meta-analytic review of longitudinal studies. *Work & Stress*. 2018; 33(1): 76–103, doi: [10.1080/02678373.2018.1529065](https://doi.org/10.1080/02678373.2018.1529065).
- Broeck AV, Cuyper NDe, Witte HDe, et al. Not all job demands are equal: Differentiating job hindrances and job challenges in the Job Demands–Resources model. *European Journal of Work and Organizational Psychology*. 2010; 19(6): 735–759, doi: [10.1080/13594320903223839](https://doi.org/10.1080/13594320903223839).
- Upadaya K, Vartiainen M, Salmela-Aro K. From job demands and resources to work engagement, burnout, life satisfaction, depressive symptoms, and occupational health. *Burnout Research*. 2016; 3(4): 101–108, doi: [10.1016/j.burn.2016.10.001](https://doi.org/10.1016/j.burn.2016.10.001).
- Schaufeli W, Taris T. A Critical Review of the Job Demands-Resources Model: Implications for Improving Work and Health. *Bridging Occupational, Organizational and Public Health*. 2013: 43–68, doi: [10.1007/978-94-007-5640-3_4](https://doi.org/10.1007/978-94-007-5640-3_4).
- Marcus M, Yasamy M, Ommeren Mv, et al. Depression: A Global Public Health Concern. Geneva: World Health Organization. 2012.
- Sivri F, Uğurlu Ö, Blanco-Davis E, et al. Mapping Mental Health of Seafarers Post-COVID-19: A Gaussian Graphical Model of Depression, Anxiety, and Maritime Working Conditions. *Inquiry*. 2025; 62: 469580251371386, doi: [10.1177/00469580251371386](https://doi.org/10.1177/00469580251371386), indexed in Pubmed: [40955857](https://pubmed.ncbi.nlm.nih.gov/40955857/).
- Lucas D, Coadic N, Jégaden D. Assessment of mental health and psychosocial factors in French merchant officer cadets. *Int Marit Health*. 2023; 74(1): 62–69, doi: [10.5603/IMH.2023.0007](https://doi.org/10.5603/IMH.2023.0007), indexed in Pubmed: [36974494](https://pubmed.ncbi.nlm.nih.gov/36974494/).
- Tavacıoğlu L, Taç U, Eski Ö, et al. Burnout and job satisfaction among Turkish oceangoing seafarers. *Int Marit Health*. 2019; 70(4): 232–238, doi: [10.5603/IMH.2019.0037](https://doi.org/10.5603/IMH.2019.0037), indexed in Pubmed: [31891177](https://pubmed.ncbi.nlm.nih.gov/31891177/).
- Zhao X, Zhang Z, Chen Z, et al. Mediating role of depression between workplace violence and job burnout among healthcare workers. *Zhong Nan Da Xue Xue Bao Yi Xue Ban*. 2023; 48(6): 903–908, doi: [10.11817/j.issn.1672-7347.2023.230043](https://doi.org/10.11817/j.issn.1672-7347.2023.230043), indexed in Pubmed: [37587076](https://pubmed.ncbi.nlm.nih.gov/37587076/).
- Qin W, Li L, Zhu D, et al. Prevalence and risk factors of depression symptoms among Chinese seafarers during the COVID-19 pandemic: a cross-sectional study. *BMJ Open*. 2021; 11(6): e048660, doi: [10.1136/bmjopen-2021-048660](https://doi.org/10.1136/bmjopen-2021-048660), indexed in Pubmed: [34162652](https://pubmed.ncbi.nlm.nih.gov/34162652/).
- Brooks SK, Greenberg N. Mental health and psychological well-being of maritime personnel: a systematic review. *BMC Psychol*. 2022; 10(1): 139, doi: [10.1186/s40359-022-00850-4](https://doi.org/10.1186/s40359-022-00850-4), indexed in Pubmed: [35637491](https://pubmed.ncbi.nlm.nih.gov/35637491/).

27. Kingdom SE, Smith AP. Combined effects of work-related stress in Her Majesty's Coastguard (HMCg). *Int Marit Health*. 2012; 63(1): 63–70, indexed in Pubmed: [22669815](#).
28. Baltic and International Maritime Council (BIMCO), International Chamber of Shipping (ICS). Seafarer workforce report: The global supply and demand for seafarers in 2021. Witherby Publishing Group Limited, Edinburgh 2021.
29. Ruan YM, Zhang JW, Huang GH, et al. Application of Chinese version job content questionnaire (JCQ22) in occupationally noise-exposed workers. *Occup Health Emerg Rescue*. 2019; 37(6): 542–546, doi: [10.16369/j.oher.issn.1007-1326.2019.06.010](#).
30. Schaufeli WB, Bakker AB, Salanova M. The measurement of work engagement with a short questionnaire: a cross-national study. *Educ Psychol Meas*. 2006; 66(4): 701–716, doi: [10.1177/0013164405282471](#).
31. Lovibond PF, Lovibond SH. The structure of negative emotional states: comparison of the Depression Anxiety Stress Scales (DASS) with the Beck Depression and Anxiety Inventories. *Behav Res Ther*. 1995; 33(3): 335–343, doi: [10.1016/0005-7967\(94\)00075-u](#), indexed in Pubmed: [7726811](#).
32. Li CP, Shi K. The influence of distributive justice and procedural justice on job burnout. *Acta Psychol Sin*. 2003; 35(5): 677–684.
33. Aguirre-Urreta M, Hu J. Detecting Common Method Bias: Performance of the Harman's Single-Factor Test. *ACM Sigmis Database*. 2019; 50(2): 45–70, doi: [10.1145/3330472.3330477](#).
34. Cavanaugh MA, Boswell WR, Roehling MV, et al. An empirical examination of self-reported work stress among U.S. managers. *J Appl Psychol*. 2000; 85(1): 65–74, doi: [10.1037/0021-9010.85.1.65](#), indexed in Pubmed: [10740957](#).
35. Breevaart K, Bakker AB. Daily job demands and employee work engagement: The role of daily transformational leadership behavior. *J Occup Health Psychol*. 2018; 23(3): 338–349, doi: [10.1037/ocp0000082](#), indexed in Pubmed: [28358569](#).
36. Demerouti E, Hewett R, Haun V, et al. From job crafting to home crafting: A daily diary study among six European countries. *Human Relations*. 2019; 73(7): 1010–1035, doi: [10.1177/0018726719848809](#).
37. Bakker AB, de Vries JD. Job Demands-Resources theory and self-regulation: new explanations and remedies for job burnout. *Anxiety Stress Coping*. 2021; 34(1): 1–21, doi: [10.1080/10615806.2020.1797695](#), indexed in Pubmed: [32856957](#).
38. Bakker AB, Demerouti E. Job demands-resources theory: Taking stock and looking forward. *J Occup Health Psychol*. 2017; 22(3): 273–285, doi: [10.1037/ocp0000056](#), indexed in Pubmed: [27732008](#).
39. Schaufeli W. Engaging leadership in the job demands-resources model. *Career Development International*. 2015; 20(5): 446–463, doi: [10.1108/cdi-02-2015-0025](#).
40. Xanthopoulou D, Bakker A, Demerouti E, et al. Reciprocal relationships between job resources, personal resources, and work engagement. *Journal of Vocational Behavior*. 2009; 74(3): 235–244, doi: [10.1016/j.jvb.2008.11.003](#).
41. Hu NJ, Tian JQ. Effects of group psychological training on mental health and interpersonal communication in naval shipboard personnel. *J Navy Med*. 2022; 43(5): 490–493, doi: [10.3969/j.issn.1009-0754.2022.05.011](#).

Commentary on “Retrospective 10-year study on Filipino seafarer medical repatriations: comparing two time periods”

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Dear Editor,

I would like to commend the authors of the study “Retrospective 10-year study on Filipino seafarer medical repatriations: comparing two time periods” [1] for providing a comprehensive and policy-relevant analysis of medical repatriations among Filipino seafarers. This retrospective study highlights critical developments in maritime health, particularly the measurable impact of international conventions and national policies on the welfare of one of the world’s largest seafaring populations.

The most notable contribution of this study is its finding that repatriation rates significantly declined following the implementation of the Maritime Labor Convention (MLC) 2006 in the Philippines. This result underscores the effectiveness of regulatory reforms in improving occupational health standards, particularly through better safety enforcement and work-hour regulations. The decrease in injury- and trauma-related repatriations may suggest more effective preventive measures onboard and greater awareness of safety protocols.

However, the documented rise in repatriations due to musculoskeletal and psychiatric conditions introduces a new dimension of concern. These trends likely reflect the increasing burden of chronic overuse injuries and the long-term mental strain of working at sea. The inclusion of national frameworks such as the Philippine Mental Health Act of 2017 and the Maritime Industry Development Plan (MIDP 2028) enhances the study’s contextual relevance and offers a valuable interdisciplinary perspective linking public health, maritime governance, and workforce sustainability.

The study’s use of deployment-based repatriation rates as a benchmarking tool is particularly noteworthy. While it offers a practical method of assessing seafarer health outcomes over time, the authors are correct in cautioning against its use as a standalone performance indicator.

There is a risk that stakeholders might interpret lower repatriation rates as inherently positive, without acknowledging that such metrics must always be balanced against ethical and clinical considerations that prioritize the seafarer’s well-being.

Although the methodology and statistical analysis are robust, future studies may benefit from exploring post-pandemic patterns of repatriation and health concerns, especially as the industry continues to adapt to new global pressures. Longitudinal research will be instrumental in identifying sustained trends and evaluating the effectiveness of recent and forthcoming health initiatives.

Despite these considerations, this study presents a significant step forward in understanding the evolving health landscape of Filipino seafarers. The authors’ call for enhanced pre-employment screening, improved onboard medical care, and greater alignment between health systems and maritime operations is both timely and essential. Their contribution provides a solid foundation for future research, policy development, and international collaboration aimed at safeguarding seafarer welfare.

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REFERENCES

1. Abaya AR, Abola RB, Vidal MS, et al. Retrospective 10-year study on Filipino seafarer medical repatriations: comparing two time periods. Int Marit Health. 2025; 76(1): 33–41, doi: [10.5603/imh.100438](https://doi.org/10.5603/imh.100438), indexed in Pubmed: [40247771](https://pubmed.ncbi.nlm.nih.gov/40247771/).

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Diving and Hyperbaric Medicine

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Editorial

by James A. Denham

Dear Readers,

Welcome to this year's third issue of the *International Maritime Health Magazine*.

Every medical specialty has a history, but not every history is preserved. Hyperbaric medicine in Latin America did not emerge from a single institution or a single pioneering individual. Rather, it evolved through diverse national experiences that were shaped by geography, maritime traditions, military and civilian medicine, engineering, scientific curiosity, and the dedication of countless, often silent, professionals. The articles in this issue offer more than historical accounts of individual countries; together, they reveal the collective story of a specialty that developed along many different paths while pursuing a common goal: the care and well-being of patients exposed to exceptional conditions of pressure and oxygen. This month's issue of our Journal brings a strong contemporary focus on diving and hyperbaric medicine. Complementing these historical perspectives, our scientific section presents recent contributions addressing decompression strategies in technical diving, risk factors for decompression sickness among commercial divers, and the physiological and behavioral challenges of extreme cold-water diving.

A LEGACY UNDER PRESSURE: THE PANAMA CANAL'S PLACE IN THE HISTORY OF HYPERBARIC MEDICINE

by James A. Denham



The SS Ancon crossing the Panama Canal.

Photo credit: United States National Archives and Record Administration Catalog

The Panama Canal is normally remembered for its locks and ships and as one of the greatest engineering projects in history, serving the international maritime industry for more than 110 years. Less remembered is the story of pressure and the people who worked, dived and treated illness in its shadow.

When we think about the medical history of the Panama Canal, the treatment of yellow fever and malaria is often the first aspect that comes to mind. However, there is another significant medical narrative that emerged during this time: the history of pressure medicine.

This story begins quite early. A hyperbaric chamber built in 1903 by the Berkeley Steel Company became part of an operation in which the construction, maintenance, and

operation of the Canal required workers to perform tasks underwater or in environments where pressure could pose a medical hazard.

Although the construction of the Canal did not rely on large groups of workers inside pressurized caissons, as is sometimes believed, underwater work to maintain the Canal's infrastructure created its own challenges, making divers a crucial part of the project.

The need for quick access to recompression therapy became especially evident in 1923. The sinking of the USS O-5 submarine in the Panama Canal with two sailors trapped inside provided a dramatic reminder that pressure-related illness and underwater emergencies could quickly turn into life-and-death situations. At Coco Solo, military and medical personnel would soon be required to prove their expertise in handling such cases.

Among those who carried this forward was Sheppard "Shep" James Shreaves, a Panama Canal salvage supervisor and qualified diver whose name became inseparable from one of the Canal's most remarkable underwater rescues. When the USS O-5 submarine sank, Shreaves personally entered the water rather than risk sending his men into the dangerous operation. He spent almost 24 hours in his diving suit, tunneling beneath the submarine in 12.8 meters of water and helping rig the cables that would lift it from the mud. When the bow finally broke the surface, the two sailors, Breault and Brown, emerged alive and were quickly sent to the hyperbaric chamber along with Shreaves.

At the Panama Canal, chambers appeared, while others were transferred between institutions and took on new purposes. Some of these chambers survived. Others did not. One chamber, linked to Panama's early history and recognized as one of the world's oldest working chambers, was eventually relocated far from the Canal Zone. In contrast, other Navy chambers that had served in Panama were ultimately dismantled or, remarkably, were left to rest beneath the waters of Gatun Lake.

This article offers a reflection on how history becomes more than just a collection of dates and machines. The people who understood these chambers, the divers who used them, the physicians who treated pressure-related illness, and the institutions that maintained this knowledge formed a chain of experience. But as often happens, chains break easily when institutional memory cannot be preserved.

There is an almost perfect line waiting at the end of this story. At the entrance to the Panama Canal's Industrial Division, where generations of workers have built their professional identity, a motto captures the confidence of the institution:

"It's hard to be humble when you belong to the best!"

The history of hyperbaric medicine in Panama deserves to be remembered not as a footnote to the Canal, but as an integral part of the remarkable medical legacy that surrounds it.

READ THE FULL ARTICLE ONLINE

Scan the QR code to discover the story behind Panama's forgotten history under pressure.

The full PDF version of this article is available under "Supplementary material" on the journal's website, listed as "A Legacy Under Pressure: The Panama Canal's Place in the History of Hyperbaric Medicine".



News

contributed by Nebojša Nikolić

FROM WHO

EMERGENCY GUIDANCE ON USE OF LICENSED EBOLA VACCINE DURING CURRENT OUTBREAK

This updated World Health Organization (WHO) emergency guidance provides recommendations on the potential use of Ervebo®, the only licensed Ebola vaccine, during outbreaks caused by Bundibugyo virus (BDBV). The document reviews additional animal, immunological and observational evidence assessed by the Strategic Advisory Group of Experts on Immunization (SAGE) and concludes that, although some findings suggest possible cross-protection against BDBV, the available evidence remains insufficient to determine whether Ervebo® provides clinically meaningful protection in humans.

The guidance outlines the benefits, risks and unknowns associated with off-label use of Ervebo® during the ongoing BDBV outbreak and recommends that the vaccine be used only within research protocols. It emphasizes the importance of rapidly generating robust efficacy data through a ring randomized controlled trial, maintaining proven outbreak-control measures, clearly communicating the unknown efficacy against BDBV, and accelerating development of BDBV-specific vaccines and other countermeasures.

Guidelines available at: <https://iris.who.int/server/api/core/bitstreams/fe386701-6ee1-4854-92ce-6c7defd26b77/content>.

FROM ILO

ILO/IMO JOINT DATABASE ON ABANDONMENT OF SEAFARERS

The International Labour Organization (ILO)/International Maritime Organization (IMO) Joint Database on Abandonment of Seafarers is a collaborative effort to tackle the urgent problem of seafarers being abandoned in ports around the world. Whether as a result of unpaid wages, repatriation costs, or being left without food and medical care, these abandoned seafarers and fishers face real challenges. This regularly updated database helps authorities and the maritime community monitor abandonment cases and take swift action to support and protect those affected.

Learn more at: <https://wwwex.ilo.org/dyn/r/abandonment/seafarers/search?clear=6>.

FROM IMO

IMO SECRETARY-GENERAL URGES PRACTICAL SOLUTIONS AND RENEWED COOPERATION TO RESTORE FREEDOM OF NAVIGATION

Thousands of seafarers have been stuck in the Persian Gulf since the current conflict in the Middle East began on February 28 this year. To date, at least 70 attacks on international shipping have been verified by the International Maritime Organization (IMO), with 19 seafarers killed. With maritime security threats on the rise globally, IMO Secretary-General Arsenio Dominguez issued the following statement:

"Six months since the conflict in the Middle East began, the situation in the Strait of Hormuz is unresolved. Thousands of seafarers in the region continue to live and work under conditions of heightened risk and uncertainty. While some ships and their

crews have been able to leave the Persian Gulf, up to 400 ships carrying around 6,000 seafarers have been unable to depart safely since the conflict began. The impacts of this crisis are grave — both in the short and long term. The disruption of vital supply chains for fuels, fertilizers and other commodities has consequences for communities and economies around the world. In July, the IMO Council adopted a resolution on the protection of vital shipping lanes, reaffirming that the right of transit passage through straits used for international navigation must not be threatened, impeded, denied, hampered, impaired or suspended. It called for a coordinated and sustainable return to unhindered navigation through the Strait of Hormuz. Renewed political will and cooperation is needed to deliver on this commitment.”

In his statement, the Secretary-General called on all Member States and the shipping industry to work together with IMO and the wider United Nations system to advance practical solutions to restore the freedom of navigation through the Strait. He said: “The deterioration of maritime security around the globe — from the Black Sea to the Red Sea and Gulf of Aden – is detrimental to us all. But it is particularly distressing for the thousands of innocent seafarers affected.”

For more information on the impact of the Middle East conflict on shipping, visit: <https://www.imo.org/en/mediacentre/hot-topics/pages/middle-east-strait-of-hormuz.aspx>.

FROM THE SEAFARERS' CHARITY

TCS LONDON MARATHON 2027

The Seafarers' Charity has a limited number of charity places available for the Tata Consultancy Services (TCS) London Marathon 2027 and is inviting you to join #TeamSeafarersKGFS to raise vital funds to support seafarers and their families in need. The TCS London Marathon 2027 will take place on Sunday, April 25, 2027, in London, covering the iconic 26.2-mile marathon distance. The registration fee is £150, and the fundraising target is £2,500.

As a marathon runner, you will receive full support from The Seafarers' Charity fundraising team — from registration and preparation right through to your celebratory post-marathon reception.

As part of #TeamSeafarersKGFS, you will receive:

- The Seafarers' Charity running vest.
- A welcome pack.
- Personalized fundraising advice and information.
- Ongoing support from the fundraising team.
- And, of course, a fantastic crowd of supporters to cheer you on throughout race day.

If you are interested in taking on one of the world's most iconic marathons and helping make a difference to seafarers and their families, join #TeamSeafarersKGFS. To register, you can go to: <https://www.run2events.com/london-marathon-application>.

FROM ITF

RED-LISTED RECRUITMENT AGENCIES

The International Transport Workers' Federation (ITF) ShipBeSure website provides valuable guidance for seafarers on how to find a reputable manning agent, avoid recruitment scams, and ensure they have the appropriate employment contract in place. The website also publishes a list of recruitment and manning agencies that should be avoided.

As many clinics operate based on contracts or agreements with manning and recruitment agencies, it is in their interest to be aware of the agencies they are working with. Checking this information can help clinics protect their reputation, maintain trustworthy business relationships, and safeguard the interests of their clients.

The list of agencies to be avoided is available on the ITF ShipBeSure website. Find the list at: <https://www.itfshipbesure.org/>.

Communication

SEAFARERS' TRUST TMAS COLLABORATIVE REPORT 2025

by Luca Tommasi



In the field of maritime healthcare, telemedical maritime assistance services (TMAS) play a special role by offering medical guidance to ships that are located far from traditional medical facilities. Through their day-to-day operations, TMAS centers gather important data on the health issues that affect seafarers, fishermen, passengers, offshore workers, and other marine workers globally. Together, these statistics provide valuable insights into disease and injury trends, operational difficulties, and changing healthcare requirements in the international maritime industry.

The International Transport Workers' Federation (ITF) Seafarers' Trust TMAS Collaborative Report was established to facilitate the systematic sharing and analysis of activity data among participating TMAS centers. The project's objective is to create a more comprehensive picture of maritime medical practice than can be gained from individual national reports alone by merging data from nine European TMAS services. Additionally, the project offers a chance to evaluate the operational features of various providers, spot recurring patterns, and encourage dialogue on marine telemedicine best practices.

This 2025 report represents the third publication in the TMAS Collaborative Report series. Similar to earlier iterations, the report presents the combined activity of all participating services, giving a summary of the overall workload and case profile handled throughout the reporting period. The individual analyses from each participating TMAS that follow enable readers to recognize the similarities and differences among services functioning in various operational, regulatory, and geographic contexts.

The report emphasizes the ongoing value of international cooperation among TMAS providers in addition to recording activity levels. Since ships routinely operate across numerous states and carry foreign crews, the maritime industry is still fundamentally global. Thus, collaborative analysis of TMAS data provides a useful way to support evidence-based advancements in maritime medical practice and enhance understanding of maritime health concerns.

The editors gratefully acknowledge all participating TMAS centers and their staff for their contributions. The collective body of knowledge in maritime medicine is strengthened by their willingness to share data and experiences, which also helps to enhance healthcare for people who live and work at sea.

The complete report is available at: <https://www.seafarerstrust.org/publications/tmas-2025-collaborative-report>.

BEHIND EVERY NUMBER: WHAT THE FIRST GLOBAL REGISTER OF SEAFARER FATALITIES TELLS US



How many seafarers die each year, and what causes those deaths? The first official International Labour Organization (ILO) **Global Register of Fatalities at Sea, covering 2024**, offers an important first step toward answering these questions.

As highlighted in this article by the North American Maritime Ministry Association (NAMMA), 66 countries reported a total of 449 seafarer fatalities. More than half — 245 deaths — were attributed to illness and disease, while occupational accidents accounted for 86 deaths; 36 involved person-overboard incidents. Although the figures are not yet a complete global picture, they underline the important point that protecting seafarers' lives involves far more than just preventing accidents; it also requires attention to health, access to medical care, working conditions and mental well-being.

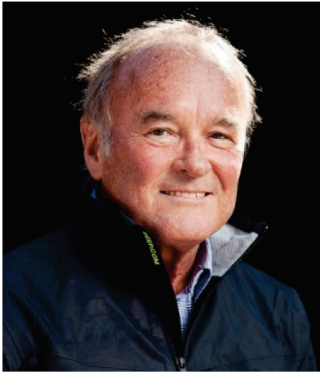
The first register is therefore less a definitive answer than the beginning of a much-needed process of consistent international reporting. Better data can help the maritime community identify risks, understand patterns and ultimately prevent future deaths.

Read the full article: <https://namma.org/behind-every-number-what-the-first-global-register-of-seafarer-fatalities-tells-us/>.

Particulars

DOCKSIDE DIALOGUES: BEYOND THE SURFACE

An interview with Michael A. Lang, PhD



Reflections on 75 Years of Scientific Diving and the Future of Hyperbaric and Marine Science

For many decades, Michael A. Lang has been at the crossroads of scientific diving, underwater research, and hyperbaric medicine. His work with the Smithsonian Institution, the National Oceanic and Atmospheric Administration (NOAA), the American Academy of Underwater Sciences (AAUS), and scientific organizations influenced generations of divers, researchers, and doctors worldwide. In this edition of Dockside Dialogues, it is a privilege to present a conversation reflecting on the evolution of these fields, the challenges that shaped them, and the opportunities that lie ahead.

1. Many divers remember not only their first dive, but their first true encounter with the sea. Looking back, when did you first realize that the sea had become a lifelong source of curiosity and inspiration? What experience convinced you this was a world you wanted to keep exploring?

I grew up in Gent, so my first contact with saltwater was the North Sea Channel. Although Belgium is internationally renowned for its fabulous variety of beers and the finest chocolates, it is not necessarily known for its beaches and balmy summers. I spent many family weekends at Knokke on the Belgian coast, walking the flat sand beaches and crawling out onto algae-covered rock jetties. At that early age, I did not know that marine biology and scientific diving would be my calling, but when my family purchased a vacation home in Torrazza, near Imperia on the Italian Riviera in 1972, the blue Mediterranean's pull was intense. Three months of summer vacation in this seaside town were stimulating to a teenager, and with the Musée Oceanographique in Monaco just a 45-minute drive away, frequent trips to Monte Carlo and its aquarium provided countless hours of viewing marine creatures through glass panes. The Octopus vulgaris on display was a magnet of fascination. Then I thought, octopodes were interesting, but would be more so if I could get in the water with them.

2. In an earlier conversation, you mentioned Bill Hamner's remarkable pioneering work on blue-water diving and his fascination with planktonic life during an Antarctic expedition. Looking back on the many expeditions you've participated in, was there a particular moment, or perhaps something you learned from Bill that fundamentally changed the way you viewed the underwater world and your role as a scientific diver?

Probably one of the most significant events of my career was the two-month scientific diving trip to the Antarctic Peninsula back in 1986 with Dr. Bill Hamner's University of California, Los Angeles (UCLA), research team. It sparked my curiosity about the physiology of cold-water diving and the amazing undersea adaptations of whales, seals, and penguins. Bill was an extraordinary scientist. He pioneered the Blue-Water Diving Project that allowed scientists to safely study planktonic organisms in the open ocean. He developed a tethered system that is still recognized today, with a big ball on the surface, a 10-meter line, a safety diver at 10 meters, and then another 10 meters of line, so you could go to a maximum depth of 20 meters. Watching him work fundamentally changed my appreciation of scientific observation and also reinforced the idea that you are a scientist first, and scuba diving is just a research tool, along with all other research tools you have to get to the worksite.

3. Over the past decade, divers have documented and shared their underwater experiences with their followers using high-resolution digital imaging, remotely operated vehicles, artificial intelligence, and instant global sharing, dramatically changing the way we see this magnificent underwater world. In your view, has this technological revolution strengthened scientific diving and ocean conservation, or are there any new challenges that have come with it?

The A/V technology is so good these days that any diver can take publication-quality photos. I remember that in 1998 we filmed a 3D IMAX Smithsonian production underwater in the Galapagos using a camera system weighing 1700 pounds with a dome port that looked the size of a refrigerator. Now similar or even better-quality footage is taken with equipment one-tenth that size. But the key is still to have a trained scientific eye underwater to recognize species or behavioral characteristics or events that are unusual.

4. You made a fascinating observation that today's cameras can produce publication-quality images, but technology alone cannot replace what you call a "trained scientific eye." How does a young scientific diver develop that eye? What distinguishes an observation that an experienced scientist's eye immediately catches and recognizes as important from one that a novice might simply swim past?

Today's imaging technology has opened remarkable opportunities for "citizen science." Volunteer divers participating in programs such as Reef Check routinely return with thousands of high-quality photographs documenting sharks, fishes, nudibranchs, corals, and countless other organisms. These images become valuable scientific records when reviewed by specialists, sometimes revealing unusual behaviors, range extensions, or even species that merit further investigation. Technology has made it possible for far more people to contribute meaningfully to marine science than ever before.

Editor's Note: "Citizen science" is the participation of volunteers in scientific research. In marine science, divers often contribute valuable photographs and field observations that help researchers monitor marine ecosystems, document biodiversity, and expand scientific knowledge.

5. We are witnessing the revival of permanent and semi-permanent subsea habitats, which allows scientists and divers to live and work underwater for extended periods. Do you see these initiatives as the beginning of a new era in scientific diving, or are they better viewed as complementary tools alongside more traditional diving technologies?

Subsea habitats and saturation diving have a proven track record of efficiency, i.e., a single decompression after unlimited exposure dive time at depth, and DEEP is a prime example when it comes to producing and maintaining undersea habitats for economic, military, scientific, and recreational purposes. The DEEP mission of "making humans aquatic" is analogous to the International Space Station hosting astronauts continuously since 2000. Compared to standard scuba, subsea habitats have a major advantage and are an extremely useful research tool for certain kinds of marine and engineering research. Scaling up with numerous modular interconnected habitats will get us closer to mainstream versus niche use.

6. Over the past four decades, scientific diving has become remarkably safe despite the increasing complexity of underwater operations. Looking back, which changes in the dive profile do you believe have had the greatest impact on reducing risk in scientific diving?

Medical, training, equipment, and operational procedures have been effectively promulgated by the AAUS as the consensus scientific diving standard since 1980. Major elements of the University of California San Diego (UCSD)–Scripps Institution of Oceanography program (est. 1951) served as a template. Dive computer ascent rates, safety stops and widespread enriched air nitrox use have had a significant impact on decompression sickness (DCS) risk reduction. Better thermal protection equipment and strategies have reduced physiological stress and enabled comfort and focus for polar scientific diving. A 35% reduction in scuba system weight, as provided by innovations from Avelo diving, reduces the risk of arterial gas embolism (AGE) by eliminating runaway ascents and reduces the risk of orthopedic injuries for younger/smaller and especially older scientific divers. The cardiovascular (CV) health of divers remains a concern because of age and the effects of pressure on the CV system. In the general diving population analyzed by Divers Alert Network (DAN), the proportion of deaths in the CV category remains high.

7. As the diving community continues to evolve, what medical challenges do you believe will define the next decade of diving medicine?

The diving population has changed considerably over the past four decades. Today, children are entering diving at younger ages, while many experienced divers continue diving well into later life despite the CV and musculoskeletal changes that naturally accompany aging. Yet, according to DAN data, the incidence of DCS has remained remarkably stable since the 1980s, at approximately 3.2 to 3.4 cases per 10000 dives.

I think we've arrived at what I would describe as an envelope for recreational and scientific diving: a window of dive profiles within which modern dive computers perform very well. Although I don't have experimental data to prove it, after more than 45 years in the field, my impression is that we have mitigated many potential problems through several fundamental practices rather than through increasingly sophisticated algorithms. Conservative no-decompression limits, the reduced bottom times imposed by a single scuba cylinder, controlled ascent rates, and the routine use of safety stops have all contributed to reducing decompression stress.

Looking ahead, my greater concern is not DCS itself, but the changing health profile of the diving population. Cardiovascular disease, in particular, continues to account for a substantial proportion of diving fatalities, making CV fitness and healthy aging increasingly important priorities in diving medicine.

Editor's Note: An "operational envelope" refers to the range of conditions within which a system is known to operate safely and predictably. Here, Dr. Lang uses the term to suggest that modern recreational and scientific dive profiles generally remain within a range where current dive computers, ascent practices, and no-decompression limits provide consistent safety.

8. For physicians who are not diving medicine specialists, but who may occasionally be asked to evaluate a scientific diver, what are the most important principles they should understand before making a fitness-to-dive decision?

There are many resources a physician not board-certified or trained in diving medicine can consult: DAN, the Undersea and Hyperbaric Medical Society (UHMS), the European Underwater and Baromedical Society (EUBS), and the South Pacific Underwater Medicine Society (SPUMS), for contraindications (temporary or absolute) on fitness to dive. The area with a lesser degree of confidence and scientifically derived guidance is "return to diving after a pressure-related injury" that required hyperbaric chamber treatment. This varies widely among programs and country-specific scientific diving regulations. The physician should also understand that the ultimate responsibility for safety rests with the individual scientific diver as to whether they feel a dive should be initiated or aborted. In the commercial or military diving space, economics or orders may interfere with the individual diver's decision-making process.

9. In 2011, I had the privilege of serving with you on the AAUS Blue Ribbon Medical Review Panel, which revisited the medical standards for scientific divers and gave examining physicians greater discretion in requesting additional investigations based on their clinical judgment. Looking back today, do you believe that this review achieved its goal of encouraging physicians to think critically rather than simply follow a checklist? How do you view the balance today between standardized protocols and physician judgment?

Oh, absolutely. I'm convinced we did. If you look at the incident and fatality data, very few cases can be attributed to deficiencies in the medical standards themselves. That tells me the current approach is working. Physicians should absolutely retain the discretion to request additional investigations whenever the clinical situation warrants it. Many of those tests are not diving-specific at all; they relate to general CV or overall health.

The purpose of the Blue-Ribbon Panel was never to make medical evaluations less rigorous. Rather, it was to move away from unnecessary routine testing that offered little return on investment while preserving the physician's responsibility to investigate when indicated. At the Smithsonian, for example, we performed annual medical examinations on approximately 150 divers at a cost of about US\$500 per diver, yet very few divers were temporarily or permanently disqualified. That experience prompted us to ask whether the same level of safety could be maintained with a more evidence-based examination schedule.

The subsequent experience has been reassuring. Extending examination intervals according to age has proven effective, while still allowing physicians to order any additional tests they consider appropriate. At the same time, I would caution against creating unnecessary barriers to diving by requesting investigations that are not supported by evidence or by the individual's risk profile.

10. The AAUS will be celebrating 75 years of scientific diving soon. If the pioneers who established scientific diving could see the field today, what do you think would make them most proud? And, conversely, where do you think they would say there is still room for improvement?

I believe they would be immensely pleased that scientific diving has proven itself to be a useful research tool. That success is reflected in the overall advancement of science it has enabled—the research grants received, the discoveries made, the publications in high-impact journals, and the contributions scientific divers have made to our understanding of the oceans. As scientific diving has matured, the regulatory environment and the shrinking of depth certifications have inevitably become more complex. Maintaining the right balance between safety, accountability, and scientific freedom will remain an important challenge for the future.

11. You have influenced generations of scientific and recreational divers throughout your career. What would you consider to be the most rewarding?

The dozen or so interdisciplinary, international diving safety workshops I have conceived and chaired resulted in guidelines or recommendations that AAUS and the major scuba training organizations have adopted and incorporated into their training and operational programs. I think specifically of dive computers, ascent rates and safety stops, repetitive diving, nitrox, reverse dive profiles, polar diving, and freediving physiology, among other topics investigated.

12. After more than four decades of exploring the underwater world, what still excites you enough to make you want to put on a mask and enter the water?

I admit that freediving physiology is most exciting! I also love diving and did so because of work, but even then, I wouldn't think about donning my diving gear on the weekend after diving for a whole week. Today, I'm making an effort to spend more time with my grandchildren and to travel on my motorcycle.

Editor's Reflection

Some people leave you with answers. Others leave you with better questions. Dr. Lang has spent a lifetime doing both. Having known him for almost thirty years, I felt that this interview was less like an interview and more like picking up on a conversation that was put on hold for a while. From Mediterranean octopuses to Antarctica, from citizen science to the future of scientific diving, we moved on as though we were updating each other. Yet beneath them all was the same guiding principle: curiosity strengthened by evidence.

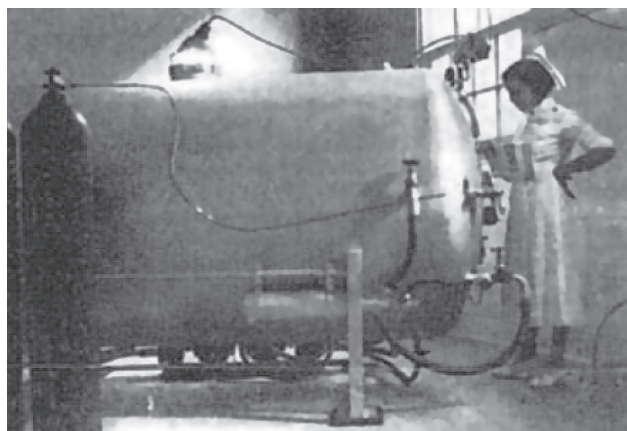
What impresses me about Michael is not only his remarkable knowledge but the way he thinks. Throughout our discussion, he continuously made the distinction between what vast experience says and what decades of data show. Technology never replaced careful observation, and his opinion was never presented as fact. Whether we were discussing dive computer algorithms or underwater photography, he frequently returned to the importance of making well-informed decisions, reminding us that technology is only a tool, and that science begins when we pause and learn to observe.

Maybe this is why Michael has become a mentor to so many. He not only shares his knowledge generously, but more importantly, he teaches a way of thinking. By the end of our conversation, I understood that his greatest contribution was not a particular publication, workshop, or piece of safety advice, but rather the generations of scientists and divers he has encouraged to ask better questions.

If this section of Dockside Dialogues aimed to reveal the person behind the professional, then this conversation achieved exactly that. I hope our readers will feel the same way I did: that a great scientist is not just known for what he knows, but also for how he thinks and how he voluntarily encourages others to think with him.

Dr. James A. Denham
Editor, IMH Magazine

Presentations



Hyperbaric Chamber at Gaffrée and Guinle Hospital (1937).

Source: Fundação Oswaldo Cruz, Casa de Oswaldo Cruz

DIVING AND HYPERBARIC MEDICINE IN BRAZIL

by Marcus Vinicius de Moraes

Brazil's journey into hyperbaric medicine began not with a network of chambers, but with a physician exploring an unfamiliar frontier. At a time when the therapeutic potential of oxygen under pressure for infectious diseases was still largely experimental, the chamber became not only a medical device but also a testing lab. The developments that took place in Rio de Janeiro in the 1930s would place Brazil unexpectedly early on the international map of hyperbaric medicine.

Long before hyperbaric medicine was linked to modern treatment centers and advanced offshore operations, a physician-scientist in Rio de Janeiro had already begun experimenting with the effects of oxygen under pressure.

In 1932, Álvaro Ozório de Almeida conducted experimental research using a hyperbaric chamber at Hospital Gaffrée e Guinle. His work established him as one of Latin America's pioneers in hyperbaric medicine. His investigations included conditions such as Hansen disease and gas gangrene. However, after he died in 1952, this early chapter did not transition into a sustained national clinical tradition.

The story would have to begin again.

During the 1960s and 1970s, hyperbaric medicine resurfaced in several different worlds. Physicians explored hyperbaric oxygen in neonatal care. The Brazilian Navy developed expertise connected with submarine and diving medicine. Professional diving expanded. And major engineering projects, including the construction of the Rio–Niterói Bridge and the São Paulo Metro, brought the practical problems of working under pressure into sharper focus.

These developments were not isolated; rather, they were different streams gradually converging with one another.

In 1983, the establishment of the Brazilian Society of Hyperbaric Medicine (SBMH) provided an institutional framework for a field that had been evolving across hospitals, universities, the Navy, and the diving industry. Just a few years later, in 1986, Paulo Iazzetti and his colleagues established a hyperbaric service at the State University of Campinas (UNICAMP), which helped connect clinical practice with academic medicine and research. Regulation followed, giving hyperbaric medicine an increasingly defined place within Brazilian healthcare.

But perhaps the most important transformation was still ahead.

Brazil's offshore industry pushed diving and medical support into deeper and increasingly remote environments. The medical challenges faced were no longer limited to decompression illness or other pressure-related disorders. Offshore medicine demanded occupational health, emergency care, remote medical assistance, evacuation planning and, increasingly, telemedicine.

As a result, diving medicine, hyperbaric medicine, occupational medicine and maritime medicine began to overlap.

That convergence is one of the most interesting features of the Brazilian story.

Brazil's history, therefore, cannot easily be reduced to a single inventor, hospital or breakthrough. It is a story of **reinvention**, of knowledge that appeared early, lost momentum, and later returned through different professional communities before becoming part of a broader medical system.

From the experimental chamber of Ozório de Almeida to modern offshore and maritime operations, Dr. Marcus Vinicius de Moraes introduces us to Brazil's fascinating hyperbaric history, showing how medicine adapted when the workplace itself moved beyond the surface.

[READ THE FULL ARTICLE ONLINE](#)

Scan the QR code to explore the full history of Diving, Hyperbaric and Maritime Medicine in Brazil.

The full PDF version of this article is available under "Supplementary material" on the journal's website, listed as "Diving and Hyperbaric Medicine in Brazil".



FROM CHAMBERS TO CLINICAL PRACTICE: THE MEXICAN JOURNEY IN HYPERBARIC MEDICINE by Ernesto Cuauhtémoc Sánchez Rodríguez and James A. Denham

Hyperbaric medicine did not emerge everywhere at the same time, nor did it follow a single path. In some countries, it grew from experimental physiology; in others, from military diving, occupational medicine, or the needs of industry. Mexico's hyperbaric journey is a story of persistence, of people and institutions rebuilding something that could have been lost.

Mexico developed its own particular trajectory, one that began early, encountered an unexpected interruption, and was then gradually rebuilt through physicians, hospitals, universities and professional organizations.

Mexico's journey began in 1962, when a monoplace hyperbaric chamber was installed at Hospital 20 de Noviembre of the Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado (ISSSTE) under the direction of Michel-Claude Christ-Olivier Chris. At the time, the arrival of such a chamber represented more than new technology. It opened the possibility of establishing a new medical field within the Mexican healthcare system.

But an accident at Hospital Xoco interrupted the development of hyperbaric medicine for approximately fifteen years. The episode became an important reminder that a chamber alone cannot create a medical discipline. Continuity must depend on people, training, and institutions capable of preserving knowledge.

When the story resumed, it did so through a new generation of physicians and professional organizations.

In 1987, a professional association gave the field a new institutional home, while clinical experience and education gradually began to grow again. Universities also played an important role in this revival by introducing a course in hyperbaric medicine at the Universidad Autónoma de México, giving a formal educational structure to a discipline that had already survived a long interruption.

Later, in 2025, the establishment of the Colegio de Medicina Hiperbárica de México marked another step in the continuing development of the field.

What happened between the first chamber of 1962 and this recent institutional milestone? Who kept the knowledge alive during the fifteen-year interruption? And how did technology introduced more than six decades ago develop into a medical discipline? Those answers are part of a history that is much richer than a chronology of chambers and dates.

In this article, Dr. Ernesto Cuauhtémoc Sánchez Rodríguez narrates the history of how a medical discipline can rise, disappear, and find the strength to start anew.

[READ THE FULL ARTICLE ONLINE](#)

Scan the QR code to discover the people, institutions and events behind the development of hyperbaric medicine in Mexico.

The full PDF version of this article is available under “Supplementary material” on the journal’s website, listed as “From Chambers to Clinical Practice: The Mexican Journey in Hyperbaric Medicine”.



HISTORICAL PERSPECTIVE: REFLECTIONS ON THE EVOLUTION AND FUTURE OF HYPERBARIC MEDICINE IN MEXICO

An interview with Dr. Ernesto Cuauhtémoc Sánchez Rodríguez



Although the historical turning points discussed in the previous article show how hyperbaric medicine has developed in Mexico, they fall short of capturing the viewpoints and experiences of those who have contributed to the field’s development.

To complement this historical review, we invited Dr. Ernesto Cuauhtémoc Sánchez Rodríguez, one of Mexico’s leading authorities in hyperbaric and diving medicine, to share his reflections on the milestones, achievements, and future challenges of this discipline. His reflections provide us with a contemporary perspective from a clinician, educator, and researcher whose career has been closely intertwined with the development of hyperbaric medicine in Mexico.

1. Which events most changed the course of hyperbaric medicine in Mexico?

The first was the accident at Xoco Hospital: it paused the growth of hyperbaric medicine in Mexico for 15 years. The second was the creation of the Association of Hyperbaric and Underwater Medicine in 1987, which was the first attempt to bring together the various regions of the country. The third was the creation of the National Autonomous University of Mexico (UNAM) Postgraduate Course in Hyperbaric Medicine and Critical Care in 2001, as this provided formal training in hyperbaric medicine within the country.

2. Which achievement deserves greater recognition?

There have been many achievements by the various leaders, but the greatest of these was the establishment of the Mexican College of Hyperbaric Medicine in 2025, which will regulate the sector at the national level in coordination with the various government and civil society organizations.

3. What is the greatest misconception about hyperbaric medicine?

That it is an alternative type of therapy that is not based on scientific and ethical research.

4. What are the principal challenges for the coming decade?

The Mexican College of Hyperbaric Medicine will face significant challenges in standardizing underwater medical care for both civilians and military personnel over the course of the next ten years. Unauthorized use of therapies for unapproved conditions, non-standardized treatment protocols, and systemic training deficiencies are the main causes of today’s problems. Additionally, a widespread failure to adhere to international safety rules puts patient care at risk, and the market expansion of substandard low-pressure chambers threatens patient care. Addressing these hurdles requires a joint effort to mandate advanced medical degrees, enforce safety codes, and invest heavily in baseline scientific research.

5. If you could pass on a lesson to future generations of hyperbaric physicians, what would it be?

A hyperbaric doctor’s worst enemy is another poorly trained hyperbaric doctor! As long as the hyperbaric community in Latin America does not have postgraduate training equivalent to or similar to medical specialty training, we will never be recognized as a medical specialty, and progress will not keep pace with evidence-based medicine. Because of this, national progress

in Latin America has been driven by local leaders who, unfortunately, leave a leadership vacuum upon retirement, plunging the field into a period of readjustment that takes years to recover from. What I mean by this is that, once a national body is established to standardize and regulate the field, it will be possible to achieve significant progress in conventional medicine in Latin America.

Editor's Closing Reflection

Dr. Sánchez emphasizes that one of the prevalent misconceptions about hyperbaric medicine is that it is often viewed as an alternative therapy, rather than a discipline grounded in scientific evidence and ethical clinical practice.

Reflecting on the future of hyperbaric medicine in Mexico, Dr. Ernesto Cuauhtémoc Sánchez Rodríguez advocates the need to strengthen education, standardize clinical practices, and enhance scientific research. Although he acknowledges the significant achievements made over recent decades, he stresses the importance of formal postgraduate training, evidence-based protocols, and nationally coordinated professional organizations to ensure consistent, high-quality patient care across the country.

One of his most striking observations is that “the greatest enemy of a hyperbaric physician is another poorly trained hyperbaric physician,” referring not to professional rivalry but to the fragmentation that occurs when education, clinical standards, and leadership are inconsistent. This is why the establishment of the Colegio de Medicina Hiperbárica de México will represent an important step toward unifying the specialty and supporting its continued development for future generations.

INFORMATION FOR AUTHORS

The International Maritime Health will publish original papers on medical and health problems of seafarers, fishermen, divers, dockers, shipyard workers and other maritime workers, as well as papers on tropical medicine, travel medicine, epidemiology, and other related topics.

Typical length of such a paper would be 2000–4000 words, not including tables, figures and references. Its construction should follow the usual pattern: abstract (structured abstract of no more than 300 words); key words; introduction; participants; materials; methods; results; discussion; and conclusions/key messages.

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All papers will be peer-reviewed. The comments made by the reviewers will be sent to authors, and their criticism and proposed amendments should be taken into consideration by authors submitting revised texts.

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All articles should be submitted to IMH electronically online at www.intmarhealth.pl where detailed instruction regarding submission process will be provided.

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Only manuscripts that have not been published previously, and are not under consideration by another publisher, will be accepted.

Full texts of oral presentations at meetings (with abstracts printed in the conference materials) can be considered.

All authors must give written consent to publication of the text.

Manuscripts should present original material, the writing should be clear, study methods appropriate, the conclusions should be reasonable and supported by the data. Abbreviations, if used, should be explained.

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Authors should give their names, addresses, and affiliations for the time they did the work. A current address of one author should be indicated for correspondence, including telephone and fax numbers, and e-mail address.

All financial and material support for the reported research and work should be identified in the manuscript.

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