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DIVING AS A HIGH-RISK SPORT: INJURY PREVENTION, SAFETY PROTOCOLS AND HUMAN FACTORS – A LITERATURE REVIEW

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ABSTRACT

Introduction: Diving is a high-risk activity due to physiological and psychological stressors. This review addresses diving-related injuries and accidents, with particular emphasis on human factors and prevention strategies.
Materials and Methods: We conducted a literature review (PubMed, 1995–2025) of studies on diving hazards (e.g., barotrauma, decompression sickness, drowning), psychological factors (anxiety, panic), human errors (miscommunication, overconfidence), and training and safety compliance measures.
Results: Divers face barotrauma (ear, sinus, pulmonary), decompression illness, physical and thermal injuries, and drowning. Psychological stress (anxiety, panic) and human errors (communication failure, inattentiveness, overconfidence) contribute substantially to accidents. Many incidents involve cascading errors. Simulation-based training and adherence to evidence-based safety procedures have been shown to improve preparedness and reduce incidents.
Conclusion: Effective dive safety requires addressing hazards and human error. Emphasizing adherence to dive protocols (ascent rates, decompression stops), clear communication, and error recognition is essential. Comprehensive training and the development of a safety culture are essential to mitigate risk and prevent injuries.

KEYWORDS

Scuba Diving, Human Error, Barotrauma, Decompression Sickness, Risk Management, Underwater Sports

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1. Introduction

Diving, both recreational and professional, encompasses several distinct disciplines, including scuba diving, freediving, and technical diving. Each sport has specific operational and physiological requirements. Scuba diving (Self-Contained Underwater Breathing Apparatus) uses compressed breathing gases. This allows for prolonged underwater activity at moderate depths, but carries the risk of barotrauma, nitrogen narcosis, and decompression illness (Vann et al., 2011; Mitchell & Doolette, 2013). Freediving involves voluntarily holding one's breath while submerged. It requires excellent breath control and carries the risk of hypoxic blackout and pulmonary barotrauma caused by rapid pressure changes (Lindholm & Lundgren, 2009; Fitz-Clarke, 2018; Dujic & Breskovic, 2012). Technical diving, by contrast, exceeds the limits of standard recreational diving through the use of mixed gases, rebreathers and complex decompression protocols (Doolette & Mitchell, 2013; Walker & Murphy-Lavoie, 2025). This form of diving carries heightened risks, including oxygen toxicity and high-pressure nervous syndrome, and demands advanced training and meticulous risk management (Fock et al., 2013; Newton, 2001).

Diving is widely regarded as a high-risk sport due to its combination of environmental, physiological, and psychological stressors. Operating in a hyperbaric, aquatic environment challenges homeostasis in ways not encountered in most terrestrial activities. Divers must navigate pressure-induced physiological changes, thermal instability, limited sensory input, and a need for precise equipment handling under constrained conditions (Beatty et al., 2024; Bove, 2014). These challenges require not only physical adaptation but also cognitive resilience and procedural rigor.

Despite continuous advancements in diving technologies, training curricula, and safety protocols, accidents remain a persistent concern. Reported injury mechanisms include decompression sickness (DCS), barotrauma of the ears, lungs, or sinuses, arterial gas embolism, hypothermia, and—in extreme cases—drowning (Vann et al., 2011; Bosco et al., 2018). These incidents may occur even in well-trained divers, underscoring the inherently hazardous nature of underwater exploration.

Importantly, a significant proportion of diving incidents are attributed not solely to physiological stressors but to human error and behavioral factors. Psychological responses such as anxiety, disorientation, and panic can impair judgment and decision-making underwater. Panic, in particular, has been identified as a leading immediate cause of fatal accidents, often triggering rapid, uncontrolled ascents or removal of essential equipment (Morgan, 1995). These reactions are especially prevalent among novice divers and are frequently exacerbated by unfamiliar underwater environments, equipment malfunction, inadequate training, or insufficient planning (Bosco et al., 2018).

In technical and deep diving, procedural discipline becomes even more critical. Mistakes in gas mixture selection, failure to follow decompression schedules, or poor team communication can rapidly escalate into life-threatening situations. Accordingly, risk management in diving must extend beyond physiological preparedness to encompass psychological conditioning, procedural training, and real-time error mitigation strategies (Mitchell & Doolette, 2013; Lucrezi, 2018).

Given the complex and multifactorial nature of diving-related risk, a comprehensive understanding of both intrinsic and extrinsic factors influencing diver safety is essential. This review aims to consolidate current evidence from hyperbaric and sports medicine literature to: (1) classify common diving injuries and their underlying mechanisms; (2) examine the role of human factors and psychological stress in accident causation; and (3) evaluate evidence-based approaches to training, safety protocols, and risk management. By integrating physiological, behavioral, and operational perspectives, this article seeks to inform strategies that enhance diver safety across all levels of proficiency and all diving modalities.

2. Methodology

We conducted a comprehensive literature search in the PubMed database to identify studies relevant to diving as a high-risk sport. The search focused on peer-reviewed scientific publications published between 1995 and 2025, with particular emphasis on contemporary evidence from the past two decades. Articles written in languages other than English were excluded from the analysis.

The search strategy involved a combination of keywords describing diving modalities, injury mechanisms, safety measures, and human performance. Specific search terms included: "scuba diving," "technical diving," "breath-hold diving," "freediving," "rebreathers," "barotrauma," "decompression sickness," "oxygen toxicity," "diving fatalities," "diving accidents," "diving safety," "panic in diving," "human error in diving," and "diving protocols." These terms were combined using the Boolean operators AND and OR to refine the results.

Titles and abstracts of all search results were screened manually for relevance to the thematic focus of this review: diving injuries, physiological risks, safety strategies, and the role of human error. Articles meeting these criteria were retrieved in full text and evaluated to ensure alignment with the objectives of the study. A total of 35 articles met all inclusion criteria. These publications represent a wide scope of scientific evidence related to injury prevention, safety protocols, and the physiological and behavioral challenges associated with recreational and technical diving.

3. Results

3.1 Types of Injuries and Diving-Related Risks

Diving exposes individuals to various physiological and environmental stressors, which can lead to a spectrum of injuries and health complications. The inherent nature of the underwater environment, associated with changes in ambient pressure, temperature extremes, limited visibility, and reliance on life-support equipment, creates unique challenges not encountered in land-based activities (Bove, 2014). A comprehensive understanding of the mechanisms and manifestations of diving-related injuries is essential for both prevention and appropriate clinical management (Vann et al., 2011).

One of the most common categories of diving injuries is barotrauma, which results from pressure differentials between the surrounding environment and the air-filled cavities within the body during changes in depth. Among these, middle ear barotrauma (MEBt) is the most frequently reported injury in divers. It usually occurs during descent when the diver fails to adequately equalize the pressure in the middle ear. This causes symptoms such as aural fullness, ear pain, dizziness, and transient hearing loss (Rozycki et al., 2018; Shupak et al., 2003). More severe is inner ear barotrauma (IEBt), which can occur independently or in conjunction with MEBt. IEBt manifests with vertigo, tinnitus, and sensorineural hearing loss It can be difficult to distinguish from inner ear decompression sickness due to overlapping symptomatology (Rozycki et al., 2018). Accurate diagnosis is crucial, as treatment strategies differ significantly.

Pulmonary barotrauma, another serious form of injury, arises primarily during ascent, particularly if a diver holds their breath. Failure to exhale can result in lung overexpansion, potentially leading to pneumothorax, mediastinal emphysema, or arterial gas embolism (AGE), which can be rapidly fatal if cerebral circulation is compromised (Tetzlaff et al., 1997).

Closely related to barotrauma is decompression illness (DCI), a term encompassing both decompression sickness (DCS) and AGE. DCI results from the formation of inert gas bubbles in tissues and the bloodstream due to inadequate decompression during ascent. DCS is subdivided into two types: Type I DCS primarily presents with musculoskeletal pain and skin manifestations, while Type II DCS affects the central nervous system, producing symptoms such as limb weakness, sensory disturbances, and coordination deficits. Inner ear involvement in Type II DCS may cause vertigo and hearing abnormalities (Vann et al., 2011; Doolette & Mitchell, 2010). Contributing factors include deep or extended dives, inadequate surface intervals between dives, rapid ascents, and individual susceptibility related to fitness and hydration status (Doolette & Mitchell, 2013).

Drowning remains the most common cause of fatal diving accidents. In many cases, drowning occurs secondarily to other complications, such as equipment failure, entanglement, panic, exhaustion, or sudden medical events including cardiac arrhythmias (Denoble et al., 2008). Pre-existing conditions or unrecognized physiological stressors may also contribute to such incidents. Studies have emphasized the importance of detailed incident analysis to identify and mitigate these contributing factors (Denoble et al., 2008).

Divers also face various environmental hazards that can result in significant injury. Encounters with marine fauna, such as jellyfish, lionfish, or stonefish, can lead to envenomations or traumatic injuries. The severity of such encounters ranges from mild dermatitis to potentially life-threatening systemic reactions, especially in tropical or subtropical marine ecosystems (Todd & Edtell, 2019; Rensch & Murphy-Lavoie, 2023). Awareness of regional marine hazards and the use of protective suits are key preventive measures.

Thermal stress is another significant concern. Exposure to cold water can induce hypothermia, impairing neuromuscular function, cognitive performance, and increasing the likelihood of errors during critical tasks. Conversely, hyperthermia in warm-water diving or while wearing thick wetsuits in hot climates can exacerbate dehydration and heat stress, compounding physical fatigue and risk (Castellani et al., 2010).

Finally, equipment failure is a significant source of risk. Faulty regulators, buoyancy control devices, or dive computers may precipitate uncontrolled ascents or descents, loss of air supply, or disorientation. Regular maintenance, thorough pre-dive checks, and diver familiarity with emergency procedures are essential components of risk mitigation (Denoble et al., 2008).

In summary, diving-related injuries encompass a wide spectrum of conditions arising from the interplay of physiological, environmental, and technical factors. Prevention requires a multifaceted approach, including rigorous training, systematic dive planning, appropriate equipment maintenance, and heightened situational awareness. Continued education and adherence to evidence-based safety protocols remain the cornerstone of reducing the incidence of diving-related morbidity and mortality.

3.2 Human Factors as a Cause of Diving Accidents

Human error continues to be a leading cause of diving accidents, frequently surpassing technical malfunctions and environmental hazards. Diving, by its very nature, demands a complex integration of psychomotor skills, cognitive function, and physiological stability. Even seemingly minor lapses in attention or judgment can result in life-threatening situations, particularly in high-pressure underwater environments where rapid intervention is difficult or impossible (Penrice & Cooper, 2022).

Among the most critical psychological contributors to diving incidents are anxiety, fear, and panic. These acute emotional responses can impair rational decision-making, resulting in hazardous behaviors such as uncontrolled ascents, omission of decompression stops, or removal of essential equipment (Morgan, 1995). Panic, in particular, has been repeatedly identified as a proximate cause of fatal outcomes, especially among less experienced or poorly trained divers.

Other individual-level factors include insufficient experience, lack of recent dive activity, and overconfidence in one's abilities. Divers who overestimate their competence may take unnecessary risks or ignore established safety procedures, placing themselves and their dive partners at greater danger. Additionally, poor communication and coordination within dive teams, especially during complex or technical dives, can lead to confusion, delays in emergency response, or misinterpretation of underwater signals. Fatigue, dehydration, and inadequate sleep can further impair decision-making and physical performance underwater (O'Connor et al., 2007).

Beyond individual behavior, systemic and organizational factors also contribute to risk. A systematic review by Mitchell and Bove (2011) emphasized that a large proportion of diving incidents could be prevented through comprehensive diver education, consistent adherence to procedural protocols, and the promotion of a proactive safety culture. For example, in a detailed analysis of U.S. Navy diving accidents, O'Connor et al. (2007) identified that a majority of incidents were attributable not to equipment malfunction, but rather to human factors such as diminished situational awareness, poor leadership, and deviations from operational standards.

Intentional rule violations represent another concerning trend in diving accidents. Shreeves et al. (2018) found that fatalities were significantly more common among divers who knowingly exceeded recommended depth or time limits, or who disregarded critical safety procedures such as buddy checks or dive planning protocols. These high-risk behaviors often reflect a normalization of deviance within certain diving communities or under commercial pressure.

Collectively, these findings underscore the essential role of human behavior in diving safety. Rigorous adherence to established safety standards, regular refresher training, and the cultivation of a safety-oriented mindset are indispensable in reducing incident rates. Institutions and dive operators must prioritize behavioral training alongside technical instruction, ensuring that divers are not only physically prepared but also mentally conditioned to manage the demands of the underwater environment (O'Connor et al., 2007; Mitchell & Bove, 2011).

3.3 Safety Procedures and Protocols in Diving

Safety procedures and protocols are designed to minimize risks associated with diving by standardizing preparation, execution, and emergency response. Standard protocols include thorough pre-dive safety checks, dive planning based on depth and duration, use of dive tables or computers, and adherence to no-decompression limits. These measures reduce the risk of decompression illness and other physiological complications (O'Connor et al., 2007).

The buddy system, dive logs, and emergency oxygen kits are fundamental safety tools. Divers are trained to recognize symptoms of distress in themselves and others and to initiate rescue procedures when necessary (O'Connor et al., 2007). Advanced safety training—such as rescue diver courses and simulation-based emergency drills—has proven effective in reducing incident rates. Military and commercial diving operations adhere to strict procedural discipline, which serves as a model for recreational diving safety (O'Connor et al., 2007).

Regular updates to safety guidelines based on accident data, equipment developments, and new scientific insights are essential for maintaining high safety standards. For example, adherence to safety protocols has been shown to mitigate risks associated with diving in individuals with specific medical conditions, such as type 1 diabetes, indicating the broader applicability and importance of these protocols (Gammara et al., 2024).

3.4 Training and Risk Management

Effective training and comprehensive risk management are fundamental pillars for ensuring diver safety and minimizing the incidence of diving-related accidents. Diving involves complex psychomotor skills, situational awareness, and the capacity to manage emergencies in potentially high-stress underwater environments (O'Connor et al., 2007).

Standard diving courses encompass theoretical instruction, confined water training, and open water practice. These programs emphasize equipment handling, buoyancy control, underwater navigation, and emergency procedures. Additionally, instruction in dive planning, decompression theory, and recognition of symptoms related to diving-related illnesses is essential (Bessereau et al., 2010).

Risk management in diving entails systematic hazard identification, risk assessment, and the implementation of mitigation strategies. Pre-dive procedures, including evaluation of environmental conditions, equipment checks, and assessment of the diver's physical and psychological readiness, are essential components of effective risk control (Shreeves et al., 2018).

Ongoing education plays a pivotal role in maintaining diver competence. Continuing training, such as specialty courses (e.g., rescue diving, deep diving) and periodic refresher courses, enhances situational preparedness. Simulation-based training, particularly in high-fidelity scenarios, has been shown to significantly improve decision-making, teamwork, and emergency response under pressure (Mileder & Schmölzer, 2016; Boet et al., 2011; Steinemann et al., 2011).).

From an organizational perspective, diving safety also depends on clear protocols, robust equipment maintenance, and a strong safety culture among both staff and clients. Institutions that incorporate regular safety drills, post-dive debriefings, and structured incident reviews demonstrate better safety performance (Lucrezi, 2018).

Equipment maintenance is equally critical. Poorly maintained gear is a known contributor to diving accidents, emphasizing the need for rigorous inspection and servicing protocols (Bailey 2024). Furthermore, data from fatal diving accident analyses consistently highlight the role of procedural violations, such as omitted pre-dive checks or solo diving, in adverse outcomes (Buzzacott et al., 2018; Vann et al., 2011).

These findings underscore the critical importance of continuous training, structured risk assessment, and adherence to evidence-based safety guidelines to reduce the incidence of human error and improve diving safety (Mitchell & Bove, 2011).

4. Discussion

Diving encompasses a complex array of hazards that arise from unique environmental conditions and equipment demands. Major injuries include decompression illness (DCI) – which spans both arterial gas embolism and decompression sickness – barotrauma to air-filled cavities, and immersion- or exertion-related trauma. DCI results from bubble formation when ambient pressure falls, and may affect the skin, joints, inner ear, spinal cord or brain, with clinical severity ranging from minor symptoms to death (Vann et al., 2011; Bove, 2014). Boyle's law ensures that ascending divers experience volume changes in gas spaces, leading to ear/sinus injury or pulmonary overexpansion, while inert gas supersaturation can produce bubbles in blood or tissue (Vann et al., 2011). Indeed, pulmonary barotrauma and DCS are among the most feared diving injuries and require rapid recompression therapy. Vann et al. (2011) emphasize that DCI risk is amplified by exertion, immersion, and thermal stress, and Bove (2014) similarly notes that the high-pressure environment has "unique effects on normal physiology" which demand recompression protocols when disorders occur. Injuries to the ear, for example, may present as either inner-ear barotrauma or inner-ear DCS, with dizziness and hearing loss; systematic reviews have sought to guide clinicians in differentiating and managing these conditions (Rozycki et al., 2018; Shupak et al., 2003). Together, these findings underscore that diving injuries are multi-system and often life-threatening without prompt treatment.

Physiological stressors in diving are equally varied. Immersion and pressure elicit profound cardiovascular and respiratory responses: breath-hold (apnea) diving triggers bradycardia, peripheral vasoconstriction, splenic blood-shift and other adaptations that conserve oxygen for vital organs. These adaptations permit astonishing feats of depth, but as recent studies show they do not eliminate risk. For instance, Bosco et al. (2018) found that during a 40 m breath-hold dive, divers often develop unexpected hypoxemia (due to lung compression) and significant hypercapnia. These results highlight that even free divers – who are not breathing compressed gas – experience dangerous gas exchange alterations at depth. Similar work by Dujic and colleagues has documented the "brain survival response" to apnea, illustrating how cerebral perfusion and metabolic suppression protect the brain under hypoxic stress (Dujic & Breskovic, 2012; Fitz-Clarke, 2018). In open-circuit scuba, breathing compressed gas causes inert gas uptake; on ascent this gas may come out of solution and form bubbles. Technical divers manage this by using oxygen-rich mixtures or helium trimix as depth increases, carefully planning gas switches and decompression to avoid narcosis and oxygen toxicity (Mitchell & Doolette, 2013a; Fock et al., 2013). In effect, the diver's physiology and gas physiology must be fully integrated into safety planning. The extreme physiology of diving thus both reveals the body's resilience and its limits, motivating ongoing research into factors like microbubble formation and individual susceptibility that remain poorly understood.

Human factors are frequently the final link in the chain that leads to diving injury. Retrospective analyses of diving incidents show that almost all accidents involve one or more human or predisposing conditions (Penrice & Cooper, 2022). For example, in a large military diving cohort, 58% of incidents had at least one health-related predisposing factor (such as poor fitness or undiagnosed disease), and 18–19% were directly triggered by diver error or exertion (Penrice & Cooper, 2022). The same analysis noted that "every dive contains inherent risks" due to the interplay of immersion effects, exercise demand, and equipment complexity. Environmental factors (cold, currents), equipment failure (regulator malfunction, harness entanglement), and team factors (poor communication or lost buddy) further amplify risk. Notably, precipitous ascent remains a common disabling event in both recreational and technical dives (Denoble et al., 2008). These observations imply that strict adherence to established protocols – such as slow ascents, decompression stops, and buddy procedures – is crucial. They also underscore the value of structured human factors training: for instance, pre-dive checklists significantly reduce equipment-related triggers (Shreeves et al., 2018), and education in decision-making and stress-management may help prevent panic responses.

Despite extensive safety measures (e.g. dive tables, computers, buddy systems, emergency drills), gaps remain. Many divers lack adequate experience or judgment to handle off-nominal situations, and dive medicine guidelines often rely on incomplete data. The chain-of-events analyses reviewed by van Hulst and colleagues suggest formal improvements: for example, standardizing how diving incidents are documented (with fields for predisposing factors, triggers, etc.) would facilitate large-scale research on causal links (Shreeves et al., 2018). Likewise, better clinical risk screening (per Bove's recommendations) may identify at-risk individuals before they dive (Bove, 2014). On the physiological side, modern techniques (e.g. in-vivo Doppler bubble detection, genomic risk profiling) could refine decompression models. Finally, much of the data on diving injuries focuses on acute events; the long-term consequences of repeated exposure (e.g. subtle neurological or pulmonary effects) are still being explored. Altogether, the literature indicates that a multifaceted approach is needed: combining engineering controls (rebreather failsafes, dive computer algorithms), strict training and protocols (emergency plans, simulated rescue), and continued medical research (on fitness-to-dive, monitoring devices). Each advance in understanding – whether from controlled physiology studies (Bosco et al., 2018) or accident reviews (Penrice & Cooper, 2022; Denoble et al., 2008) – allows the diving community to update its safety culture and regulations.

In sum, our review of the evidence suggests that injury prevention in diving must integrate environmental knowledge, human factors awareness, and physiological insight. Divers and clinicians should recognize the syndromes and stressors (from DCS to hypoxic blackout) highlighted by Vann et al. (2011) and Bove (2014). Training programs should go beyond technical skills to include scenario-based training on error management and decision-making. Moreover, future research should address gaps such as the influence of chronic health conditions on diving fitness, the effectiveness of new safety technologies, and the behavioral roots of diving incidents. Only by synthesizing these domains can diving safety be advanced.

5. Conclusions

Diving is inherently high-risk, but the risks are well understood and largely preventable with a multidisciplinary approach. Key insights from the literature are that (1) diving injuries arise from a combination of physical forces (pressure, gas loading), human factors (training, fitness, situational error), and equipment performance; (2) strict adherence to safety protocols (gradual ascents, appropriate gas mixtures, buddy checks) markedly reduces incidents; and (3) ongoing research in physiology and human factors continually refines guidelines. Preventing injury therefore demands collaboration among physiologists, hyperbaric physicians, engineers, and training agencies. Clinicians must be versed in diving medicine to clear divers and manage accidents (Bove, 2014), while equipment designers and instructors must ensure divers follow evidence-based procedures. In short, the cumulative evidence reinforces that a safe dive is the result of layered protections: robust training, diligent planning, and a culture that anticipates human error. Only through such a concerted, interdisciplinary strategy can the long-term goal – reducing morbidity and mortality in diving – be achieved (Vann et al., 2011; Bove, 2014).

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