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Pulmonary Function Changes During Diving: An Updated Narrative review and Implications for Fitness to Dive

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Abstract: Pulmonary function during diving deserves attention because respiratory changes underwater may affect diver safety and the pre-dive medical evaluation. This narrative review examines the physiological basis, short- and long-term pulmonary effects, respiratory complications, preventive measures, and implications for fitness to dive. Diving-related pulmonary responses result from increased ambient pressure, whole-body immersion, intrathoracic blood redistribution, and increased breathing-gas density. Acute exposure may produce transient reductions in pulmonary diffusing capacity, maximal voluntary ventilation, the FEV_1/FVC ratio, and small-airway expiratory flows, particularly after wet, deep, or saturation diving, although static lung volumes may remain relatively preserved in some acute exposures. Arterial oxygen tension increases with depth during compressed-gas diving, while carbon dioxide responses vary according to workload and ventilatory demand. Most acute changes in healthy recreational divers are mild and reversible. Long-term findings are less consistent: some studies of commercial and saturation divers suggest cumulative small-airway dysfunction or accelerated functional decline, whereas recent longitudinal observations in military SCUBA divers found no significant adverse effect on the FEV_1/FVC ratio. These findings support a risk-based respiratory evaluation that includes medical history, physical examination, spirometry, and selective additional testing in divers with respiratory symptoms or risk factors.

Keywords: pulmonary function, diving, immersion, fitness to dive

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Introduction

Diving is an activity performed in underwater environments for recreational, sporting, occupational, or specific operational purposes. Broadly, diving can be classified into breath-hold diving, in which the diver holds their breath, and diving with respiratory support, such as self-contained underwater breathing apparatus (SCUBA), which enables the inhalation of pressurised gas in accordance with the surrounding ambient pressure. Both forms of diving expose the body to immersion and hydrostatic pressure; however, their physiological consequences differ. In breath-hold diving, the primary changes are related to reduced lung volume due to compression, apnoea, progressively developing hypoxia, and oxygen-conserving mechanisms. In contrast, during SCUBA diving, in addition to the effects of immersion, the lungs are exposed to increased partial pressures of gases, increased inspired gas density, and a greater mechanical load on breathing (Bosco et al., 2018; Paganini et al., 2024; Tetzlaff & Thomas, 2017).

The lungs are particularly sensitive to environmental changes during diving because ventilation, diffusion, and perfusion are directly influenced by pressure, immersion, temperature, and inspired gas properties. Immersion promotes the redistribution of blood from peripheral circulation to the thoracic cavity, thereby increasing pulmonary vascular pressure, reducing lung compliance, and increasing the work of breathing. In SCUBA diving, increasing depth raises the partial pressures of oxygen and nitrogen in accordance with Dalton's law, while increased gas density elevates airway resistance and adds to ventilatory load. In breath-hold diving, lung volume decreases with increasing pressure, as described by Boyle's law; however, gas exchange may still occur during certain phases of the dive, resulting in changes in arterial gas partial pressure during descent and ascent (Paganini et al., 2024; Tetzlaff, 2023; Tetzlaff & Thomas, 2017).

The effects of diving on pulmonary function are not uniform and are influenced by the type of diving, depth, duration, water temperature, frequency of exposure, and individual susceptibility. In recreational SCUBA diving, pulmonary function changes after a single exposure are generally mild and are often associated with immersion, cold temperatures, and decompression stress; therefore, in many healthy divers, these findings tend to be clinically insignificant. In contrast, studies on commercial and saturation diving have suggested potential long-term effects, including small-airway dysfunction, reduced diffusing capacity, and accelerated decline in pulmonary function, although findings across studies remain inconsistent. Recent primary studies further illustrate this variability. Lian et al. (2022) reported acute reductions in FEV_1, FEV_1/FVC, small-airway expiratory flows, and pulmonary diffusing capacity following a simulated 500-m saturation dive, whereas major lung volumes remained relatively stable. Paganini et al. (2024) demonstrated a depth-related increase in arterial oxygen tension during in-water SCUBA diving, while carbon dioxide responses varied according to activity and ventilatory demand. Conversely, long-term observations in military SCUBA divers showed no significant adverse effect of diving exposure on the FEV_1/FVC ratio (Ulm et al., 2025). These findings indicate that pulmonary responses to diving vary according to the characteristics and intensity of exposure as well as the population studied.

Although some of these changes occur at a subclinical level, their clinical relevance remains important because they are closely related to diver safety. Pulmonary barotrauma is a severe complication that occurs due to gas expansion during ascent in the presence of air trapping and may progress to pneumothorax, pneumomediastinum, or arterial gas embolism. In addition, immersion pulmonary oedema is a potentially fatal condition that develops through a combination of increased pulmonary capillary pressure, central blood redistribution, and negative airway pressure during immersion. Tetzlaff (2023) emphasised that normal respiratory and cardiovascular physiological function is a fundamental requirement for minimising the risk of serious injury during diving. Therefore, pulmonary diseases associated with functional impairment or parenchymal abnormalities should be regarded as factors that may increase the risk of complications during underwater exposure (Banham et al., 2024; van Hulst & van Ooij, 2024; Tetzlaff, 2023).

Previous reviews have comprehensively described the physiological effects of diving on the respiratory system and the general respiratory considerations for fitness to dive. However, several recent primary studies, particularly those published after or not fully incorporated into earlier reviews, have provided additional evidence regarding arterial blood gas responses during in-water SCUBA diving, acute pulmonary alterations following ultra-deep simulated saturation exposure, long-term spirometric trajectories in military divers, and pulmonary vascular adaptations in elite breath-hold divers (Kjeld et al., 2024; Lian et al., 2022; Paganini et al., 2024; Ulm et al., 2025). Unlike previous broad reviews, the present review places these newer primary findings at the centre of the synthesis and relates them specifically to contemporary respiratory assessment and fitness-to-dive decision-making. Therefore, this narrative review aims to synthesise recent evidence on short- and long-term pulmonary function changes during breath-hold and compressed-gas diving and to discuss their practical implications for pre-dive respiratory evaluation and fitness-to-dive decision-making.

Method

This article was prepared using a narrative review approach. A literature search was conducted using PubMed and Scopus for publications published from January 2016 to April 2026. Google Scholar was used as a supplementary source for citation tracking and to identify potentially relevant publications that might have been missed during the primary search. Search terms included combinations of "diving," "SCUBA diving," "breath-hold diving," "pulmonary function," and "fitness to dive." Older primary studies published before 2016 were selectively included through backward citation tracking when they provided important longitudinal or foundational evidence that remained relevant to the interpretation of long-term pulmonary effects of diving.

Original human studies were prioritised for the synthesis of short- and long-term pulmonary outcomes. Relevant review articles were used primarily to provide broader physiological and clinical context and to identify additional primary studies. Clinical guidelines and consensus documents were used to support discussions on prevention and fitness-to-dive assessment, while standard respiratory physiology textbooks and a relevant book chapter were used only to support established physiological concepts and pressure-related principles. Publications addressing diving physiology, pulmonary function changes, respiratory complications, prevention, or fitness-to-dive assessment were included. Non-scientific publications, duplicate records, animal studies, and articles not directly relevant to pulmonary function or respiratory assessment in divers were excluded. A total of 24 sources were included in the final narrative synthesis, comprising 21 journal publications, two standard respiratory physiology textbooks, and one book chapter.

Lung Function

At sea level, where ambient pressure is approximately 1 atmosphere absolute (ATA), normal pulmonary function relies on the integrated activity of ventilation, diffusion, and perfusion to ensure adequate oxygen uptake and carbon dioxide elimination. Ventilation supplies fresh gas to the alveoli, whereas diffusion enables oxygen and carbon dioxide to cross the alveolar–capillary membrane along their respective partial pressure gradients. Pulmonary perfusion then carries these gases between the lungs and peripheral tissues. Under normal surface conditions, the coordinated interaction of these processes maintains sufficient arterial oxygenation and effective carbon dioxide removal without imposing a substantial respiratory workload (Broaddus et al., 2022; West & Luks, 2021).

Efficient pulmonary gas exchange also depends on an appropriate balance between alveolar ventilation and pulmonary blood flow. Lung regions receiving insufficient ventilation relative to perfusion may contribute to impaired oxygenation, while areas with ventilation exceeding perfusion may increase physiological dead space. In healthy individuals at 1 ATA, small regional variations in the ventilation–perfusion ratio are generally tolerated and have little effect on overall arterial gas exchange. Accordingly, ventilation, diffusion, perfusion, and ventilation–perfusion matching represent the fundamental physiological conditions against which respiratory changes occurring during diving can be evaluated (Broaddus et al., 2022; West & Luks, 2021).

These normal conditions are modified once the body is immersed and exposed to increasing ambient pressure. Whole-body immersion shifts blood from the peripheral circulation toward the thoracic compartment, thereby increasing pulmonary blood volume and reducing the compliance of the lungs and chest wall. Increasing depth also raises both the density and partial pressures of inspired gases. As a consequence, airway resistance may increase, airflow may become more turbulent, and the work required for breathing may become greater. These effects generally intensify with depth and may alter alveolar ventilation, pulmonary gas exchange, and haemodynamic function. During compressed-gas diving, arterial oxygen tension rises as depth increases, whereas carbon dioxide responses are more variable and are influenced by physical workload and ventilatory requirements. Therefore, pulmonary function during diving differs from normal respiratory physiology at 1 ATA because of the combined influence of ambient pressure, immersion, gas density, and intrathoracic haemodynamic changes (Bosco et al., 2018; Paganini et al., 2024; Tetzlaff, 2023; Tetzlaff & Thomas, 2017).

Diving Physiology

During diving, the body is exposed to a physical environment that differs fundamentally from normal surface conditions, primarily because of the increase in ambient pressure with increasing depth. This change directly affects gas volume, the partial pressure of oxygen, and the dynamics of pulmonary gas exchange. At sea level, an atmospheric pressure of 1 atm produces an inspired oxygen partial pressure of approximately 0.21 atm, which increases progressively at greater depths. As a result, descent is associated with lung compression, changes in alveolar gas distribution, and an increase in oxygen partial pressure that may temporarily maintain oxygenation. However, these changes also increase the physiological burden on the respiratory system and raise the risk of hyperbaric disturbances at extreme depths. Thus, the pulmonary response during diving is determined not only by immersion but also by the interaction among depth, pressure, and gas dynamics, which may limit the

The significance of increased pressure during diving lies not only in its magnitude, but also in its effects on the inspired gas and pulmonary mechanics. Tetzlaff (2023) explained that at depth, higher pressure alters gas volume within the lungs, increases the partial pressure of inspired gases, and raises the density of the ... nphasised ... ing many ... l pressure ... capacity, ... y, while ... s of

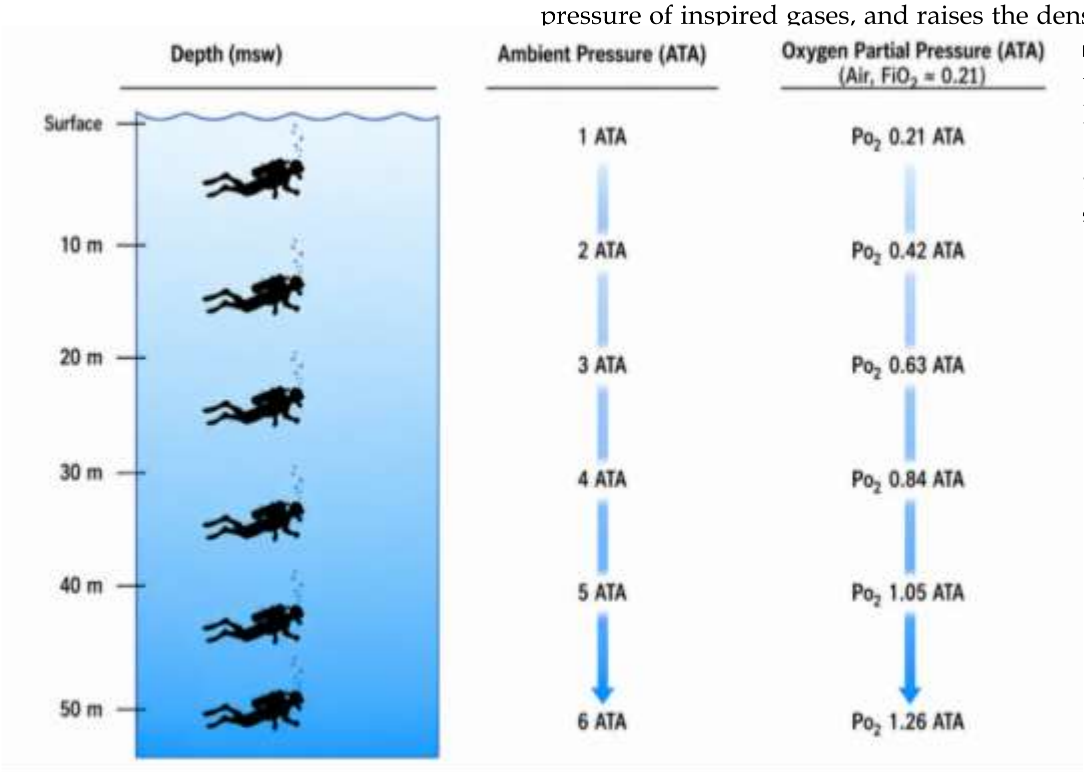

Figure 1. Relationship between diving depth, ambient pressure, and oxygen partial pressure during air diving. Source: Authors' illustration based on Broaddus et al. (2022).

adaptive capacity of the lungs underwater (Bosco et al., 2018; Paganini et al., 2024; Patrician et al., 2021; Tetzlaff, 2023). The relationships among increasing depth, changes in ambient pressure, and the increase in oxygen partial pressure during diving are illustrated in Figure 1.

1. Pressure

At sea level, the human body is exposed to an absolute pressure of approximately 1 atmosphere absolute (1 ATA), which is numerically equivalent to 1 standard atmosphere (atm). When a person enters water and descends to greater depths, the ambient pressure increases linearly because of the additional hydrostatic pressure exerted by the water. Thus, at a depth of 10 m of seawater, the pressure reaches 2 ATA; at 20 m, it reaches 3 ATA, and it continues to increase with increasing depth. This increase in pressure far exceeds the pressure normally experienced by the body during daily life on land, so that the underwater environment imposes immediate changes on respiratory physiology (Tetzlaff, 2023; Tetzlaff & Thomas, 2017).

oxygen and nitrogen (Beatty et al., 2024; Tetzlaff, 2023).

Pressure has important clinical implications during diving because it changes throughout descent and ascent, influencing gas compression, the partial pressures of inspired gases, and the subsequent expansion of gas within the lungs and other air-containing spaces. These physiological effects are explained by gas laws that describe the relationships among pressure, volume, partial pressure, and gas solubility (Bosco et al., 2018; Tetzlaff, 2023). In diving medicine, pressure is generally reported in atmospheres absolute (ATA). At sea level, 1 ATA is numerically equivalent to 1 standard atmosphere (atm), or approximately 1.013 bar and 760 mmHg. The technical atmosphere (at), however, represents a different unit, defined as 1 kgf/cm^2 and equivalent to approximately 0.968 atm. The commonly used conversions among these pressure units are summarised in Table 1 (Bennett & Cibis, 2022).

Table 1. Common conversion of pressure units. Adapted and corrected from Bennett & Cibis (2022).

	ATM/ ATA	at	Bar	mmHg	mmH_2O
ATM/ ATA	1	1.033	1.013	760	10332.56
at	0.968	1	0.981	735.56	10000.3
Bar	0.987	1.02	1	750	10197.44
mmHg	1.316×10^{-3}	1.36×10^{-3}	1.33×10^{-3}	1	13.6
mmH_2O	9.67×10^{-5}	9.89×10^{-5}	9.81×10^{-5}	0.0736	1

2. The Gas Laws

Physiological changes that occur during diving are fundamentally related to gas laws, as increased environmental pressure underwater alters the physical characteristics of both the inspired gas and the gas contained within the body cavities. Boyle's law states that, at a constant temperature, pressure is inversely proportional to gas volume. An increase in ambient pressure decreases the volume of gas within a closed space. In breath-hold diving, the intrathoracic gas volume progressively decreases with increasing depth due to compression. Conversely, in SCUBA diving, the same principle explains the re-expansion of gas within the lungs during ascent (Bosco et al., 2018; Patrician et al., 2021; Tetzlaff, 2023).

Dalton's law states that the total pressure of a gas mixture is the sum of the partial pressures of its individual component gases. In diving, this law explains that although the fractions of oxygen and nitrogen in air remain constant, their partial pressures increase with increasing depth. This increase has direct effects on respiratory physiology, as the partial pressure of oxygen in the alveoli and arterial blood also increases, while the higher partial pressure of nitrogen increases nitrogen uptake into tissues and contributes to the development of inert gas narcosis. Thus, Dalton's law clarifies that the physiological effects of diving are determined not only by the type of gas inhaled but also by changes in the partial pressure of that gas at a given depth (Paganini et al., 2024; Tetzlaff, 2023).

Henry's law states that the amount of gas that dissolves in a liquid is proportional to the partial pressure of that gas. This principle indicates that the higher the partial pressure of a gas at depth, the greater the amount of gas that dissolves in the blood and tissues. During diving, nitrogen, an inert gas, gradually dissolves while the diver remains at depth. However, during ascent, as the pressure decreases, previously dissolved gas may come out of solution and form bubbles if decompression occurs too rapidly. This mechanism provides an important basis for understanding decompression stress and various diving-related disorders associated with gas bubble formation (Beatty et al., 2024; Bosco et al., 2018).

Overall, Boyle's, Dalton's, and Henry's laws complement one another in explaining gas behaviour during diving. Boyle's law explains changes in gas volume, Dalton's law explains changes in partial pressure, and Henry's law explains increased gas solubility in body fluids. Together, these laws provide a strong foundation for understanding how the lungs undergo mechanical and gas exchange changes during diving and explain the emergence of certain clinical risks in divers (Beatty et al., 2024; Bosco et al., 2018; Tetzlaff, 2023).

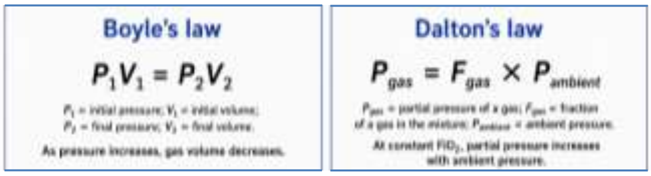

Figure 2. Application of Boyle's and Dalton's laws during diving. Illustration created by the authors.

3. Physiological change during diving

During diving, physiological changes are primarily determined by an increase in hydrostatic pressure, which increases linearly with depth. However, the effects of pressure cannot be separated from the influence of whole-body immersion in water. In the early phase of diving, immersion shifts blood volume from the peripheral circulation to the thoracic cavity, thereby increasing central blood pooling, cardiac filling, and pulmonary blood volume. These changes reduce both lung and chest wall compliance while increasing the work of breathing. Thus, divers are not only exposed to an environment with higher ambient pressure but also experience intrathoracic haemodynamic changes that directly affect ventilatory mechanics (Bosco et al., 2018; Tetzlaff & Thomas, 2017; Beatty et al., 2024).

Increasing pressure during diving also alters the physical characteristics of the inspired gas. Increasing depth raises the density of the breathing gas, thereby increasing airway resistance and making airflow in the large airways more turbulent. At certain depths, this ventilatory resistance may reduce effective alveolar ventilation and increase the tendency toward carbon dioxide retention. This condition may be further aggravated by the use of regulators, wetsuits, and tight diving equipment, which restrict chest wall and abdominal expansion (Tetzlaff & Thomas, 2017; Lian et al., 2022).

Increased ambient pressure increases the partial pressures of oxygen and nitrogen in the alveoli, blood, and tissues. In SCUBA diving, this results in a proportional increase in PaO_2 with depth. This condition increases oxygen availability at depth; however, it also increases exposure to hyperoxia and the dissolved inert gas burden in the body. The longer the exposure, the greater the amount of gas entering the blood and tissues, requiring the body to eliminate this gas load safely during ascent. Under certain conditions, these changes may be associated with a transient reduction in diffusing capacity, the formation of venous gas microbubbles, or decompression stress with subclinical effects on pulmonary function (Beatty et al., 2024; Paganini et al., 2024; Tetzlaff & Thomas, 2017).

In breath-hold diving, the effects of pressure on pulmonary physiology are more pronounced because there is no external gas supply during descent or ascent. As pressure increases, lung volume progressively decreases, and at greater depths, the lungs may be compressed to near the predicted residual volume. Nevertheless, the human body can tolerate this condition through the diving response and a shift of blood into the thorax, which helps preserve intrathoracic integrity during descent. At maximum depth, the increase in gas partial pressure may temporarily increase PaO_2; however, severe lung compression may also lead to airway closure, atelectasis, and V/Q mismatch. Under certain conditions, these mechanisms may explain why some divers exhibit a hyperoxemic response at depth, whereas others experience impaired gas exchange due to intrapulmonary shunt or V/Q mismatch. As illustrated in Figure 3, physiological changes during deep breath-hold diving differ between descent and ascent, with phase-specific risks related to lung compression, thoracic blood redistribution, hypoxaemia, pulmonary barotrauma, and other pressure-related disturbances (Patrician et al., 2021; Tetzlaff et al., 2021; Tetzlaff, 2023).

Effects of Diving on Pulmonary Function

Diving imposes complex physiological stress on the lungs because the respiratory system must adapt to increased ambient pressure, immersion, changes in gas density, and alterations in intrathoracic ...se factors may affect pulmonary function through changes in ventilation, diffusing capacity, expiratory flow, and small airway function, although the magnitude of these changes depends greatly on the type of diving, depth, duration, water temperature, frequency of exposure, and individual characteristics of the diver.

Tetzlaff and Thomas (2017) emphasised that the pulmonary effects of diving are not uniform, as the responses may differ between dry hyperbaric exposure, wet diving, recreational diving, and deep or saturation

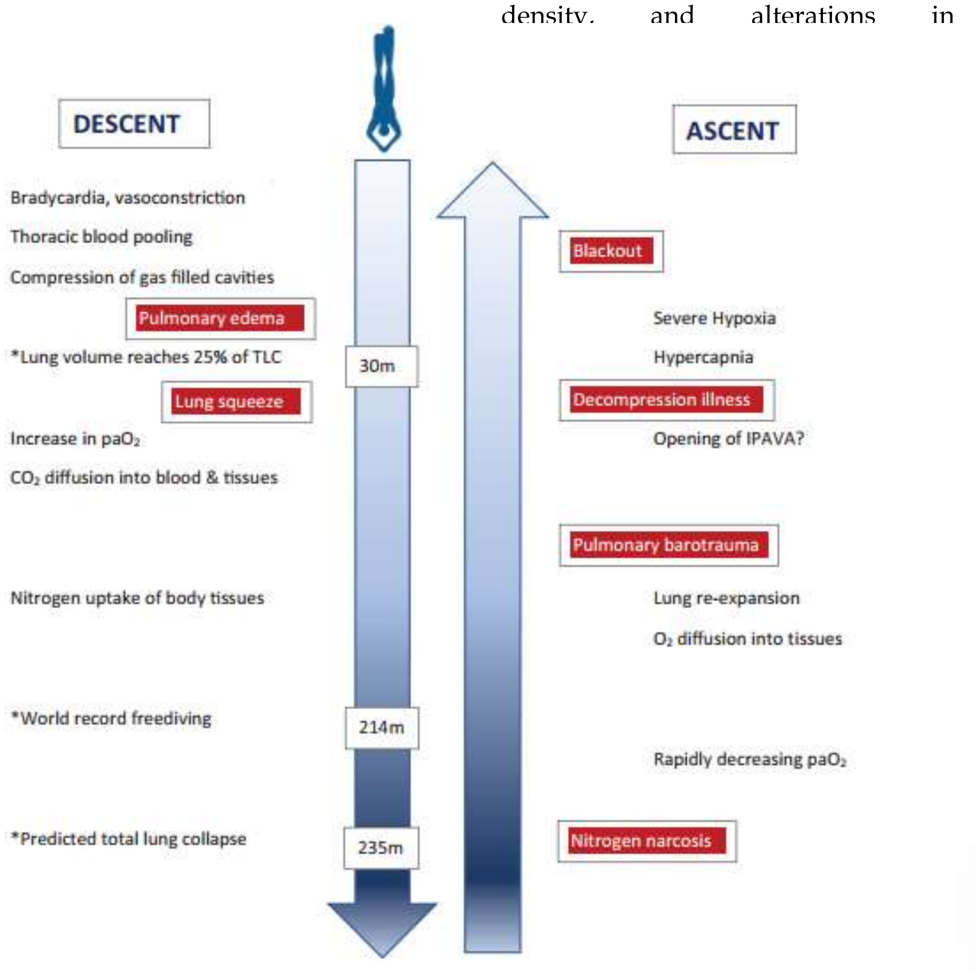

Figure 3. Physiological changes and clinical risks during deep breath-hold diving. Reproduced from Tetzlaff et al. (2021)

diving. Consistent with this, several studies have shown that changes in pulmonary function after diving may be transient and reversible, particularly after certain acute exposures. In contrast, findings from long-term repeated exposures remain variable, ranging from mild impairment to the absence of clinically significant decline. Therefore, the effects of diving on pulmonary function are more appropriately understood as a spectrum of physiological and clinical responses influenced by the intensity and type of exposure. Accordingly, the discussion should distinguish between short-term and long-term effects (Bosco et al., 2018; Lian et al., 2022; Tetzlaff & Thomas, 2017; Ulm et al., 2025).

1. Short-term Effects

The short-term effects of diving on pulmonary function generally appear immediately after a single exposure; however, the degree of change is not always uniform, as it is influenced by depth, duration, exposure medium, water temperature, physical activity, and decompression profile. Current evidence suggests that these acute responses are closely related to the characteristics of the exposure and may affect ventilation, small-airway function, pulmonary diffusing capacity, lung aeration, and arterial gas exchange. Among healthy individuals undertaking recreational or moderate diving, these changes are generally limited and reversible. More substantial alterations have been documented after very deep or saturation-diving exposures (Tetzlaff & Thomas, 2017; Tetzlaff, 2023).

During wet diving, changes in ventilation may occur because elevated ambient pressure is accompanied by whole-body immersion, thermal stress, increased central blood volume, and the additional mechanical burden of diving equipment. Cheng (2021) observed short-term changes in pulmonary ventilation after a 20-min underwater exposure at a depth of 12 m. These changes included reductions in minute ventilation (MV) and maximal voluntary ventilation (MVV). Differences between the underwater and dry hyperbaric conditions also suggested that immersion and equipment-related respiratory loading contributed to the observed ventilatory response. Evidence from more recent recreational diving studies indicates that such effects are usually temporary. Gouin et al. (2023), for example, assessed divers after one week of repeated recreational closed-circuit rebreather diving in cold water. The investigators identified transient post-dive changes in lung aeration, demonstrated by an increased lung ultrasonography score, together with a slight reduction in oxygen saturation that remained within non-pathological limits. Conventional spirometric measurements did not show significant changes, and all measured abnormalities returned to baseline within 24 h after the final dive. These observations indicate that temporary pulmonary stress may occur even when standard spirometry remains normal, while recovery may take place relatively quickly after recreational diving exposure (Cheng, 2021; Gouin et al., 2023).

Greater short-term alterations have been reported following extreme saturation diving. In a primary study involving nine experienced saturation divers, Lian et al. (2022) examined pulmonary function three days after a simulated 500-m saturation dive and found significant reductions in several parameters. FEV_1 declined by 2.88%, from 4.16 ± 0.51 L to 4.04 ± 0.54 L ($p = 0.039$), whereas the FEV_1/FVC ratio decreased by 3.58%, from 78.4 ± 7.0% to 75.6 ± 8.2% ($p = 0.009$). Measures reflecting small-airway expiratory flow were also affected. FEF_{50}, FEF_{75}, and FEF_{25-75} decreased by 16.3%, 10.0%, and 13.5%, respectively. A similar pattern was observed in pulmonary diffusing capacity, with reductions of 10.4% in DLCO and 9.4% in DLCO/VA. By comparison, FVC, PEF, RV, and TLC remained unchanged to a statistically significant degree. These results suggest that acute deep-saturation exposure may affect small-airway function and pulmonary diffusing capacity more readily than static lung volumes (Lian et al., 2022).

Acute diving also alters arterial blood gases while the diver is still at depth. Paganini et al. (2024) reported a substantial increase in PaO_2 during in-water SCUBA diving at depths of 15 and 42 m, followed by a return toward baseline after resurfacing. $PaCO_2$ showed a less consistent pattern and appeared to vary according to physical workload and ventilatory requirements. Although ambient pressure increased considerably and blood was redistributed toward the thoracic compartment, pulmonary gas exchange remained relatively stable under the recreational workload assessed in the study. These observations show that physiological responses recorded during a dive may not be identical to pulmonary changes measured after resurfacing. They also emphasise that the timing of physiological measurements should be considered when interpreting acute pulmonary responses to diving (Paganini et al., 2024).

Overall, findings from recent primary studies show that acute pulmonary responses to diving are not uniform and depend substantially on the type and intensity of exposure. Recreational and moderate diving generally results in mild, reversible physiological changes, and standard spirometric measurements may remain within normal limits even when other indicators suggest temporary pulmonary stress. By contrast, very deep or saturation-diving exposures may lead to measurable reductions in small-airway expiratory flow and pulmonary diffusing capacity that remain detectable for several days. Collectively, the available evidence suggests that small-airway function, pulmonary diffusion, lung aeration, and arterial gas exchange may provide more sensitive indicators of short-term diving-related pulmonary responses than static lung volumes alone (Gouin et al., 2023; Lian et al., 2022; Paganini et al., 2024).

2. Long-term Effects

The long-term effects of diving on pulmonary function remain unclear. In contrast to the short-lived changes that may occur after a single dive, chronic respiratory responses differ considerably across diving populations. This variation may be related to differences in dive depth, breathing gas composition, cumulative exposure, decompression practices, occupational workload, and individual characteristics. Earlier investigations raised concerns that repeated deep and saturation diving might gradually impair expiratory airflow and small-airway function. More recent longitudinal studies, however, have not consistently identified clinically meaningful deterioration in standard pulmonary function measures. For this reason, the long-term respiratory effects of diving should be interpreted in relation to the type, intensity, and cumulative pattern of exposure rather than assumed to occur uniformly in all divers (Skogstad & Skare, 2008; Sames et al., 2018; Ulm et al., 2025).

Earlier longitudinal studies suggested that deep saturation diving could be followed by persistent alterations in selected pulmonary function parameters. Thorsen et al. (1993) examined 24 professional divers after deep saturation exposures and found a significant reduction in FEV_1 one year after diving. This decline was accompanied by lower mid-expiratory flow and reduced expiratory flow at low lung volumes, while FVC remained relatively stable. Nevertheless, the annual decline in FEV_1 during subsequent follow-up was not significantly different from that observed in the reference group. This finding indicates that the initial reduction did not necessarily represent a continuously accelerating loss of lung function. Similar concerns were explored by Skogstad and Skare (2008) in a 12-year follow-up of professional divers. Their study identified reductions in several indices of lung function and pulmonary transfer capacity. Most of these changes were largely attributable to ageing, while cumulative diving exposure remained significantly associated only with FEF_{25-75} after adjustment for relevant factors. Taken together, these findings suggest that when long-term functional effects of repeated diving do occur, smaller-airway expiratory flow may be more vulnerable than conventional lung-volume measurements (Thorsen et al., 1993; Skogstad & Skare, 2008).

Later evidence from occupational divers has been more reassuring. Sames et al. (2018) analysed serial spirometric measurements from 232 occupational divers who were followed for periods ranging from 10 to 25 years. Although both FVC and FEV_1 decreased over time, the observed reductions were slightly smaller than those expected as part of normal ageing. PEF declined more than predicted among divers with longer occupational exposure, but the size of this reduction was small and considered unlikely to have clinical significance. Overall, the investigators found no clinically meaningful decline in spirometric function that could be specifically attributed to long-term occupational diving. These findings indicate that repeated occupational exposure does not necessarily lead to progressive pulmonary impairment and also underline the need to distinguish age-related physiological decline from changes that may be directly associated with diving (Sames et al., 2018).

More recent evidence has further questioned the assumption that prolonged SCUBA diving inevitably leads to progressive airflow limitation. Ulm et al. (2025) assessed 331 French military divers using 2,685 spirometric measurements obtained over a mean follow-up period of 23.9 years. Diving exposure was associated with higher FEV_1, FVC, and FEF_{75} values relative to predicted levels, while no significant adverse effect was found for the FEV_1/FVC ratio. These results provide important longitudinal evidence that long-term SCUBA exposure among carefully selected and medically monitored military divers does not appear to cause clinically significant obstructive ventilatory impairment. However, caution is required when applying these findings to other diving populations. Military divers differ from many recreational, commercial, and saturation divers in terms of physical fitness, medical screening, training standards, and ongoing health surveillance (Ulm et al., 2025).

Large lung volumes reported in experienced divers should also be interpreted carefully. Elevated FVC values may reflect pre-existing physiological characteristics, selection effects, training-related adaptation, or a combination of these factors. At the same time, increased lung volume does not rule out the presence of structural pulmonary abnormalities. Van Hulst and van Ooij (2024) identified blebs and bullae in a subgroup of military divers with unusually large lungs. Their findings indicate that apparently favourable spirometric volumes should not automatically be regarded as evidence of benign physiological adaptation. Therefore, structural lung abnormalities and functional respiratory changes need to be evaluated separately when pulmonary findings are considered in fitness-to-dive assessments (van Hulst & van Ooij, 2024).

Overall, the available literature does not demonstrate a single consistent pattern of long-term pulmonary change across all types of diving. Earlier studies involving professional and deep saturation divers raised concerns about persistent reductions in expiratory flow, particularly in indices related to small-airway function, whereas more recent longitudinal investigations in occupational and military divers have generally shown little evidence of clinically significant deterioration in conventional spirometric measures (Thorsen et al., 1993; Skogstad & Skare, 2008; Sames et al., 2018; Ulm et al., 2025). The differences among studies may be explained by variation in diving population, cumulative exposure, depth, breathing gas, decompression procedures, duration of follow-up, and participant selection. Longitudinal evidence from recreational divers remains particularly limited (Tetzlaff & Thomas, 2017; Ulm et al., 2025). Future research should therefore apply standardised pulmonary function testing, quantify cumulative diving exposure in greater detail, and include sufficiently long follow-up periods across recreational, occupational, military, and saturation-diving populations. Such studies are needed to clarify whether particular exposure patterns are associated with clinically meaningful long-term changes in pulmonary function.

Prevention of Diving-Related Pulmonary Effects

Preventing the pulmonary effects of diving requires a multidimensional approach, as respiratory disturbances during diving do not arise from a single factor but from the interaction among the dive profile, breathing gas characteristics, environmental conditions, physical activity, and individual susceptibility. In this context, controlling depth, bottom time, ascent rate, and adherence to decompression procedures are key components in reducing the risk of tissue supersaturation and gas bubble formation. Bosco et al. (2018) emphasised that decompression procedures are designed to allow inert gas elimination through the lungs with minimal risk of bubble formation, whereas Beatty et al. (2024) showed that many diving-related disorders can be reduced through adherence to diving protocols and early recognition of physiological triggers. Thus, controlling the dive profile represents the fundamental basis for preventing diving-related pulmonary effects (Beatty et al., 2024; Bosco et al., 2018).

In addition to the dive profile, environmental and behavioural factors must also be controlled. Cold water is known to increase peripheral vasoconstriction, exacerbate central blood volume redistribution, and may increase the risk of conditions such as immersion pulmonary oedema, particularly when accompanied by strenuous physical activity. Banham et al. (2024) identified cold water, heavy exertion, and equipment that generates excessive negative inspiratory pressure as important extrinsic factors in immersion pulmonary oedema. Consistent with this, Bosco et al. (2018) and Tetzlaff and Thomas (2017) showed that body cooling during the decompression phase, increased muscular work, and immersion itself may aggravate respiratory and pulmonary vascular stress. Therefore, relevant preventive strategies include adequate thermal protection, avoidance of excessive physical exertion—particularly during the bottom and ascent phases—and maintaining diving conditions that do not increase the haemodynamic or ventilatory burden on the lungs (Banham et al., 2024; Bosco et al., 2018; Tetzlaff & Thomas, 2017).

Prevention should also focus on reducing the risk of pulmonary barotrauma and arterial gas embolism. Bosco et al. (2018) explained that pulmonary barotrauma during ascent may occur as a result of breath-holding or focal gas trapping due to airway obstruction; therefore, proper breathing technique and avoiding breath-holding during ascent are essential principles. In addition, anatomical abnormalities, such as blebs or bullae, as well as a history of spontaneous pneumothorax, should be carefully considered because they may increase the risk of gas trapping and pulmonary injury during pressure changes. Thus, prevention of barotrauma cannot rely solely on technical skills but also requires appropriate medical evaluation in individuals with a history of or existing pulmonary disease (Bosco et al., 2018; van Hulst & van Ooij, 2024).

Furthermore, preventing oxygen exposure through the appropriate selection of breathing gas is another important aspect of prevention. Schipke et al. (2022) explained that oxygen-enriched air, or nitrox, offers advantages in reducing nitrogen narcosis and bubble formation; however, its use must still consider safe oxygen partial pressure limits, for example, ensuring that pO_2 does not exceed 1.4 bar, to prevent oxygen toxicity affecting the central nervous system and lungs. Therefore, prevention of diving-related pulmonary effects should be understood as a combination of depth and decompression profile control, management of temperature and physical activity, prevention of barotrauma through proper breathing technique and medical screening, and safe breathing gas selection according to the dive profile. Such a comprehensive approach is important for reducing the risk of both acute and cumulative pulmonary disorders in divers (Banham et al., 2024; Beatty et al., 2024; Schipke et al., 2022).

Pulmonary Assessment for Fitness to Dive

Pulmonary assessment in fitness-to-dive evaluations aims to ensure that prospective divers have adequate respiratory functional reserve and do not have abnormalities that may increase the risk of barotrauma, gas trapping, ventilatory impairment, or reduced ability to cope with the increased work of breathing underwater. Tetzlaff (2023) emphasised that normal respiratory physiological function is a fundamental prerequisite for safe adaptation to the challenges of the underwater environment. Pulmonary function testing has long been an important component of medical evaluations for divers, particularly for identifying obstructive and restrictive disorders that may increase the risk of pulmonary injury during diving. Krzyżak and Korzeniewski (2021a) also emphasised that fitness-to-dive assessments should begin with a careful medical history, physical examination, and evaluation of relevant pulmonary conditions, such as asthma, pneumothorax, chronic lung disease, or a previous history of barotrauma (Krzyżak & Korzeniewski, 2021a; Tetzlaff, 2023; Tetzlaff & Thomas, 2017).

Spirometry is the most essential baseline examination in the pre-dive respiratory evaluation. Parameters such as FEV_1, FVC, the FEV_1/FVC ratio, and expiratory flows can be used to assess the presence of ventilatory impairment that may predispose divers to air trapping, carbon dioxide retention, or ventilatory limitation when breathing high-density gas at depth. Krzyżak and Korzeniewski (2021a) explained that pulmonary function assessment should be part of routine evaluation, whereas Tetzlaff and Thomas (2017) emphasised that obstructive and restrictive ventilatory abnormalities are important considerations in determining diving eligibility. Spirometry serves not only as a screening tool but also as an objective basis for assessing the lungs' ability to tolerate the characteristic changes in respiratory mechanics during diving (Krzyżak & Korzeniewski, 2021a; Tetzlaff & Thomas, 2017).

Assessment becomes more specific in individuals with a history of asthma or symptoms of airway hyperresponsiveness. Ustrup et al. (2020) showed that fitness-to-dive evaluation in candidates with suspected asthma can be performed through a combination of medical history, spirometry, and bronchial provocation testing. In that study, some candidates who were initially considered unfit were able to undergo reassessment after optimisation of asthma therapy. This finding indicates that decisions regarding fitness or unfitness to dive should not rely solely on a diagnostic label but should also consider the degree of symptom control and pulmonary function test results. This approach is consistent with the view of Krzyżak and Korzeniewski (2021b), who emphasised that medical decisions in divers with respiratory disease should be based on clinical stability, objective findings, and the potential risks associated with underwater exposure (Krzyżak & Korzeniewski, 2021b; Ustrup et al., 2020).

Thoracic imaging and additional examinations play a role in selected situations, particularly when structural lung abnormalities are suspected and cannot be adequately explained by spirometry alone. van Hulst and van Ooij (2024) showed that, in some divers with large lungs, CT scans may identify blebs, bullae, cysts, or air trapping that are not always visible on standard chest radiographs, and these findings may directly influence fitness-to-dive assessment. Krzyżak and Korzeniewski (2021b) also emphasised that further investigations should be performed selectively based on clinical indications, rather than as routine procedures for all divers. Therefore, pulmonary evaluation for fitness to dive should ideally be conducted in a stepwise manner, beginning with medical history, physical examination, and spirometry, followed by additional investigations when risk factors, symptoms, or initial findings suggest possible structural or functional pulmonary abnormalities (Krzyżak & Korzeniewski, 2021b; Tetzlaff, 2023; van Hulst & van Ooij, 2024). The main pulmonary conditions relevant to fitness-to-dive assessment, including their associated risks, suggested evaluations, and clinical considerations, are summarised in Table 2.

Table 2. Pulmonary conditions relevant to fitness-to-dive assessment. References: Krzyżak and Korzeniewski (2021a, 2021b); Tetzlaff and Thomas (2017); Tetzlaff (2023); Ustrup et al. (2020); van Hulst and van Ooij (2024)

Pulmonary condition	Main diving risk	Key assessment	Fitness-to-dive consideration
Asthma / airway hyperresponsiveness	Air trapping, ventilatory limitation	History, spirometry, ± bronchial provocation	Reassessment may be considered when symptoms are well controlled and pulmonary function is acceptable
Obstructive / restrictive impairment	Reduced ventilatory reserve	Spirometry and clinical evaluation	Further evaluation is required when functional impairment is present
Previous spontaneous pneumothorax	Recurrence, pulmonary barotrauma	History and thoracic imaging when indicated	Requires careful further evaluation before diving clearance
Blebs, bullae, cysts, or air trapping	Gas expansion and barotrauma	Thoracic CT when indicated	Structural abnormalities should be carefully evaluated before clearance
Previous pulmonary barotrauma	Risk of recurrence	Pulmonary function and imaging as indicated	Underlying causes and recurrence risk should be assessed before return to diving

Conclusion

Changes in pulmonary function during diving result from a complex interaction among increased ambient pressure, gas law principles, immersion, alterations in intrathoracic haemodynamics, and increased gas density, which collectively affect ventilation, diffusion, perfusion, and respiratory mechanics. Acute pulmonary changes are generally mild and reversible, whereas the evidence for long-term effects remains inconsistent. This variability may reflect heterogeneous study designs, differences in diving type, depth, cumulative diving exposure, study populations, and the timing of pulmonary function assessment, as well as the small sample sizes of many deep and saturation-diving studies. Longitudinal evidence in recreational divers also remains limited. Future research should therefore prioritise prospective multicentre studies using standardised pulmonary function testing, detailed assessment of cumulative diving exposure, and further evaluation of small-airway function. A clearer understanding of these effects is essential to strengthen respiratory screening and support evidence-based fitness-to-dive decision-making.

References

Banham, N., Smart, D., Wilmshurst, P., Mitchell, S. J., Turner, M. S., & Bryson, P. (2024). Joint position statement on immersion pulmonary oedema and diving from the South Pacific Underwater Medicine Society (SPUMS) and the United Kingdom Diving Medical Committee (UKDMC) 2024. *Diving and Hyperbaric Medicine, 54*(4), 344–349. https://doi.org/10.28920/dhm54.4.344-349

Beatty, P., Evans, W., Gravelyn, S., Tumperi, M., Daubon, D., & Veith, A. (2024). Physiological monitoring to prevent diving disorders. *Frontiers in Physiology, 15*, 1517361. https://doi.org/10.3389/fphys.2024.1517361

Bennett, M., & Cibis, T. (2022). The underwater world and diving physiology. In T. Cibis & C. McGregor (Eds.), *Engineering and medicine in extreme environments* (pp. 57–87). Springer. https://doi.org/10.1007/978-3-030-96921-9_4

Bosco, G., Rizzato, A., Moon, R. E., & Camporesi, E. M. (2018). Environmental physiology and diving medicine. *Frontiers in Psychology, 9*, 72. https://doi.org/10.3389/fpsyg.2018.00072

Broaddus, V. C., Ernst, J. D., King, T. E., Jr., Lazarus, S. C., Sarmiento, K. F., Schnapp, L. M., Stapleton, R. D., & Gotway, M. B. (Eds.). (2022). *Murray & Nadel's textbook of respiratory medicine* (7th ed.). Elsevier.

Cheng, H. (2021). Control study of short-term aftereffect in diving exposure related pulmonary ventilation function. *Medical & Clinical Research, 6*(4), 507–517. https://doi.org/10.33140/MCR.06.04.11

Gouin, E., Balestra, C., Orsat, J., Dugrenot, E., & L'Her, E. (2023). Pulmonary effects of one week of repeated recreational closed-circuit rebreather dives in cold water. *Medicina, 59*(1), 81. https://doi.org/10.3390/medicina59010081

Kjeld, T., Isbrand, A. B., Arendrup, H. C., Højberg, J., Bejder, J., Krag, T. O., Vissing, J., Tolbod, L. P., Harms, J. H., Fuglø, D., & Hansen, E. G. (2024). Pulmonary vascular adaptations to hypoxia in elite breath-hold divers. *Frontiers in Physiology, 15*, 1296537. https://doi.org/10.3389/fphys.2024.1296537

Krzyżak, J., & Korzeniewski, K. (2021a). Medical assessment of fitness to dive. Part I. *International Maritime Health, 72*(1), 36–45. https://doi.org/10.5603/MH.2021.0005

Krzyżak, J., & Korzeniewski, K. (2021b). Medical assessment of fitness to dive. Part II. *International Maritime Health, 72*(2), 115–120. https://doi.org/10.5603/IMH.2021.0020

Lian, N., Wang, S., Hu, L., Xue, L., Gong, Y., Li, L., Yang, Y., & Zhu, L. (2022). Effect of a single simulated 500 m saturation dive on lung function. *Frontiers in Physiology, 13*, 911167. https://doi.org/10.3389/fphys.2022.911167

Paganini, M., Zucchi, L., Giacon, T. A., Martani, L., Mrakic-Sposta, S., Garetto, G., McKnight, J. C., Camporesi, E. M., Moon, R. E., & Bosco, G. (2024). Arterial blood gases in SCUBA divers at depth. *Frontiers in Marine Science, 11*, 1445692. https://doi.org/10.3389/fmars.2024.1445692

Patrician, A., Dujić, Ž., Spajić, B., Drviš, I., & Ainslie, P. N. (2021). Breath-hold diving: The physiology of diving deep and returning. *Frontiers in Physiology, 12*, 639377. https://doi.org/10.3389/fphys.2021.639377

Sames, C., Gorman, D. F., Mitchell, S. J., & Zhou, L. (2018). Long-term changes in spirometry in occupational divers: A 10–25 year audit. *Diving and Hyperbaric Medicine, 48*(1), 10–16. https://doi.org/10.28920/dhm48.1.10-16

Schipke, J. D., Deussen, A., Moeller, F., Hoffmann, U., Muth, T., Zenske, A., & Koch, A. (2022). Oxygen-enriched air reduces breathing gas consumption over air. *Current Research in Physiology, 5*, 79–82. https://doi.org/10.1016/j.crphys.2022.01.007

Skogstad, M., & Skare, Ø. (2008). Pulmonary function among professional divers over 12 years and the effect of total number of dives. *Aviation, Space, and Environmental Medicine, 79*(9), 883–887. https://doi.org/10.3357/ASEM.2333.2008

Tetzlaff, K. (2023). Pulmonary physiology and medicine of diving. *Seminars in Respiratory and Critical Care Medicine, 44*(5), 705–718. https://doi.org/10.1055/s-0043-1770065

Tetzlaff, K., Lemaitre, F., Burgstahler, C., Luetkens, J. A., & Eichhorn, L. (2021). Going to extremes of lung physiology: Deep breath-hold diving. *Frontiers in Physiology, 12*, 710429. https://doi.org/10.3389/fphys.2021.710429

Tetzlaff, K., & Thomas, P. S. (2017). Short- and long-term effects of diving on pulmonary function. *European Respiratory Review, 26*(143), 160097. https://doi.org/10.1183/16000617.0097-2016

Thorsen, E., Segadal, K., Kambestad, B. K., & Gulsvik, A. (1993). Pulmonary function one and four years after a deep saturation dive. *Scandinavian Journal of Work,* *Environment & Health, 19*(2), 115–120. https://doi.org/10.5271/sjweh.1498

Ulm, J., Blatteau, J.-E., Aigle, L., Glogowski, R., Castagna, O., & Druelle, A. (2025). Impact of self-contained underwater breathing apparatus diving on French military divers' lung function: A retrospective cohort. *CHEST Pulmonary, 3*(4), 100158. https://doi.org/10.1016/j.chpulm.2025.100158

Ustrup, A., Pedersen, S. K., & Suppli Ulrik, C. (2020). Assessment of fitness for recreational scuba diving in candidates with asthma: A pilot study. *BMJ Open Sport & Exercise Medicine, 6*(1), e000624. https://doi.org/10.1136/bmjsem-2019-000624

van Hulst, R. A., & van Ooij, P.-J. A. M. (2024). Large lungs in divers: A risk for pulmonary barotrauma? *Diving and Hyperbaric Medicine, 54*(3), 225–229. https://doi.org/10.28920/dhm54.3.225-229

West, J. B., & Luks, A. M. (2021). *West's respiratory physiology: The essentials* (11th ed.). Wolters Kluwer.