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PERSONAL SAFETY OF CHILDREN IN THE CONTEXT OF FULL-FACE SNORKEL MASK USE: RISK ANALYSIS OF HYPERCAPNIA AND HYPOXAEMIA

Abstract

The article presents the risks associated with the use of full-face snorkeling masks. In children. Based on scientific research findings, the risk of hypercapnia and hypoxemia It is discussed, this may result from rebreathing air with a high concentration of CO_2. Particular attention is given to the increased risk in children due to their smaller tidal volume and a higher ratio of dead space to lung volume. The lack of safety standards for this type of equipment and difficulties in its use during emergencies are also highlighted.

Keywords

snorkeling, full-face mask, hypercapnia, hypoxemia, children, safety

Introduction

Snorkeling is the younger cousin of freediving and the stepbrother of scuba diving, which has gained enormous popularity worldwide as a separate form of water recreation accessible to a broad range of people. While freediving is a sport of holding one's breath for as long as possible, snorkeling involves observing the underwater world from the water's surface with only the face submerged, protected by a specialized mask, and breathing atmospheric air through a tube that is an integral part of the mask. Unlike scuba diving, snorkeling does not require complicated and expensive equipment or specialized training[1]. Overall, diving is often described as an activity for everyone. It is not reserved for heroes of the deep sea. Physical fitness is limited to packing your equipment into a car trunk or into a boat. Once submerged, physical conditions cease to play a significant role[2]. Consequently, snorkeling may seem like an even easier sport to start exploring the underwater world and, often mistakenly, safer for beginners. The basic equipment for snorkeling includes a mask, a snorkel, and fins, making the gear much cheaper and more accessible than scuba diving with tanks. The lack of need for long courses or certification further increases the popularity of this form of underwater exploration[3].

In recent years, innovative full-face snorkeling masks have emerged on the market, enabling simultaneous breathing through both the nose and mouth while providing a wide underwater field of view. Their design quickly gained popularity, especially among amateurs and families with children[4]. However, along with the widespread use of this equipment, serious safety concerns have also arisen, particularly regarding its use by children. These issues mainly relate to the risk of carbon dioxide poisoning (hypercapnia) and hypoxia (oxygen deficiency), which can result from faulty airflow and the re-breathing of exhaled CO_2 inside the mask.

This article aims to present a catalog of hazards associated with the use of full-face snorkeling masks in children, based on scientific research findings. It will discuss specific risk factors resulting from the particular physiological characteristics of children, which make them more vulnerable to the effects of hypercapnia and hypoxia during the use of this type of equipment.

Methodology

The research problem of this study arises from the lack of sufficient scientific data and technical standards concerning the safety of full-face snorkeling masks for children. There is a justified concern that the design of these masks, characterized by

1 D. Rebikoff, *Free Diving*, wyd. Sidgwick & Jackson, Londyn 1955, p. 6

2 P. Tailliez, F. Dumas, C. Jacques-Yves, *The Complete Manual of Free Diving*, wyd. G. P. Putnam's Sons, Nowy Jork 1957, p. 11

3 S. Hong, H. Rahn, „The Diving Women of Korea and Japan", *Scientific American,* 1967;216(5):34–43. [PubMed], [access: 19.07.2025].

4 H. B. Newton, „Neurologic complications of scuba diving", *American Family Physician,* 2001 Jun 1;63(11):2211-8. PMID: 11417773 [access: 08.08.2025].

a significant dead space volume, may lead to an increased risk of hypercapnia (carbon dioxide buildup) and hypoxemia (oxygen deficiency), especially under physical exertion conditions. This issue is further compounded by the fact that most available studies pertain to adults, and conclusions regarding children are mainly based on extrapolation, without extensive empirical research.

In this context, the main research question has been formulated: how does the use of full-face snorkeling masks by children affect the safety of their health and life, with particular emphasis on the risk of hypercapnia and hypoxemia?

Specific questions include the following issues:

1. What are the potential mechanisms leading to CO_2 accumulation in full-face snorkeling masks for children?
2. To what extent does the dead space volume in a full-face mask exceed the tidal volume of a child in different age groups?
3. What conclusions can be drawn from studies on adults regarding their application to the pediatric population?
4. What prophylactic measures and recommendations can be formulated to reduce the risks for children using this type of equipment?

The main objective of this study is to assess the hazards resulting from the use of full-face snorkeling masks by children in the context of their health and safety. Specific goals include:

– Analyzing the construction of full-face snorkeling masks in terms of dead space volume and its impact on gas exchange in children,
– Reviewing scientific research related to hypercapnia and hypoxemia associated with the use of full-face masks,
– Identifying gaps in current knowledge and the absence of safety standards for full-face masks designed for children,
– Developing recommendations for parents, guardians, and manufacturers regarding the safe use of snorkeling equipment by the youngest users.

This study is of a review nature. Particular emphasis was placed on assessing the risk of hypercapnia (carbon dioxide poisoning) and hypoxemia (oxygen deprivation), resulting from rebreathing air with elevated CO_2 content. The analysis was conducted based on available scientific publications, experimental research, and technical documentation provided by snorkeling equipment manufacturers in user manuals.

The review included studies available in the PubMed, Scopus, and Google Scholar databases, published between 2010 and 2024, with particular attention to peer-reviewed articles. The selection of publications was based on the presence of keywords such as: full-face snorkel mask, CO_2 retention, hypoxemia, hypercapnia, snorkeling safety, children, dead space, tidal volume.

Physiological data regarding the tidal volume of children aged 3 to 10 years were also incorporated, referencing the dead space volume of typical full-face masks presented in available studies. To assess the risk, a comparison was made between the ratio of mask volume to the tidal volume (TV), with exceeding 100% being considered potentially dangerous.

This review does not include original research or laboratory measurements; its character is conceptual. Due to the limited availability of studies on children, some conclusions are based on theoretical modeling and extrapolation of results from research on adults. The only actual study conducted in this area was the determination of the volume of full-face snorkeling masks through water immersion measurements to assess dead space volume.

Analysis of hazards resulting from the use of full-face masks by children

When considering the hazards that may cause changes in the normal values of vital parameters in children, one must start by defining the normal ranges of these parameters. According to the Guidelines of the European Resuscitation Council, the tidal volume is a constant value and does not change throughout a person's life. It is assumed that the normal tidal volume is in the range of 6-8 ml/kg of body weight[5]. Knowing the child's weight at various ages makes it easy to precisely determine the volumes at which a young person should breathe. Estimative, medicine uses the following formula to determine the body weight of a child up to 10 years old:

$$\text{body weight (kg)} = 2 \times (\text{age of the child} + 4)$$

Table 1. Recommended Body Weight Based on Child's Age

Age of the child (years)	Recommended Body Weight (kg)
3	14
4	16
5	18
6	20
7	22
8	24
9	26
10	28

Source: Own calculation based on the formula: body weight (kg) = 2 x (child's age + 4). Based on Pediatric Formulas[6].

5 P. Van de Voorde, N. M. Turner, J. Djakow, „10 Resuscitation Procedures in Children" [in:] *Resuscitation Guidelines 2021 of the European Resuscitation Council*, Perkins G. D., Polish Resuscitation Council Publishing, Kraków 2021, p. 385

6 T. Janus, J. Nelle, *Wzory pediatryczne – wersja podręczna*, https://intensywna.pl/wzory-pediatryczne-wersja-podreczna/, [access: 18.08.2025].

Considering the above, it is worth pondering whether the use of full-face masks by children does not pose a safety risk, especially since we know that tidal volume is closely related to body mass.

In 2003, research by Janneke Grundemann, Xavier C.E. Vrijdag, Nicole Y.E. Wong, Nicholas Gant, Simon J. Mitchell, and Hanna van Waart was published in the diving magazine Diving and Hyperbaric Medicine[7].

The authors assumed that airflow as a breathing mixture in a full-face snorkel mask (FFSM) used for snorkeling should be unidirectional to prevent re-breathing the same air.

Their study evaluated the impact of re-breathing air from a full-face mask compared to a traditional mask and snorkel setup. The research involved comparing full-face snorkeling masks (Subea Easybreath and QingSong 180°) with a conventional mask plus snorkel (Beuchat Spy) in 20 adult participants under resting conditions and during light to moderate physical activity. They measured oxygen saturation levels (SpO_2) and end-tidal carbon dioxide pressure ($etCO_2$). The results indicated that users of full-face masks more frequently experienced hypercapnia (elevated CO_2 levels) and hypoxemia (reduced oxygen levels) compared to those using traditional masks. In some cases, testing was halted due to exceeding safe CO_2 thresholds (>7.0 kPa) or oxygen saturation dropping below 85%.

Eleven years later, in 2022, a study by Harald Walach, Rainer Weikl, Jan Prentice, and others was published in Environmental Research[8]. The authors assessed the ventilation and oxygenation capacity of children, assuming that children have significantly lower adaptive abilities due to the anatomy of their respiratory system. The experiment measured inhaled carbon dioxide levels in healthy children wearing surgical masks and FFP2 masks while seated for approximately 18 minutes. a significant increase in CO_2 levels in inhaled air was observed, exceeding accepted safety standards. This study highlights that children are more susceptible to CO_2 accumulation due to their smaller tidal volumes and a higher ratio of dead space to lung volume.

What, then, is the implication of the study on children using FFP2 protective masks for their safety when using full-face snorkeling masks?

Research conducted on children using protective masks showed that, due to their respiratory anatomy, children have considerably lower adaptive capacity to tolerate elevated CO_2 levels and decreased blood oxygen. It is important to note that a protective mask that is not fully airtight, by not fitting completely to the child's face, delivered significantly higher amounts of oxygen during the study than a fully fitting

7 J. Grundemann, X. C. Vrijdag, N. Y. Wong, N. Gant, S. J. Mitchell & H. van Waart, (2023). „Full-face snorkel masks increase the incidence of hypoxaemia and hypercapnia during simulated snorkelling compared to conventional snorkels", *Diving and hyperbaric medicine*, 53(4), 313–320. https://doi.org/10.28920/dhm53.4.313-320 [access: 19.07.2025].

8 H. Walach, H. Traindl, J. Prentice, R. Weikl, A. Diemer, A. Kappes & S. Hockertz, (2022). „Carbon dioxide rises beyond acceptable safety levels in children under nose and mouth covering: Results of an experimental measurement study in healthy children", *Environmental research*, 212 (Pt D), 113564. https://doi.org/10.1016/j.envres.2022.113564 [access: 19.07.2025].

full-face mask. Therefore, both studies indicate potential risks associated with the use of full-face snorkeling masks, especially in children.

Another aspect to consider is the tidal volume values in children. Based on calculations by the European Resuscitation Council and the relationship between tidal volume and body mass[9], their respiratory capacities should be compared with the technical limitations of full-face snorkeling masks.

Table 2. Respiratory volumes depend on the child's age and weight

Age in years	Body Weight	Tidal volume (TV)		Average tidal volume (TV)
		for 6ml/kg BW	for 8ml/kg BW	
3	14	84	112	98
4	16	96	128	112
5	18	108	144	126
6	20	120	160	140
7	22	132	176	154
8	24	144	192	168
9	26	156	208	182
10	28	168	224	196

Source: author's own compilation. Based on Resuscitation Procedures in Children[10].

The table presents respiratory values for 6 ml/kg of body mass, 8 ml/kg of body mass, and the average tidal volume for a specific age and child's weight. The data indicate that as the child gets older and the weight increases, the tidal volume also increases.

Among commercially available full-face masks on the market, depending on the manufacturer and model, their capacity ranges from 150 to 250 ml. Without detailed calculations, it is evident that these capacities significantly exceed the child's tidal volume. This brings us to the concept of dead space. Dead space refers to a specific portion of gas, in this case, air, that for various reasons does not participate in gas exchange. This phenomenon naturally occurs during breathing when exhalation does not empty the lungs of air. The remaining volume of air in the lungs is called residual volume. Due to its natural occurrence in the breathing mechanism, the body can function properly with this residual air in the lungs. However, the situation is different when considering the residual air trapped in the space within a full-face mask.

9 P. Van de Voorde, N. M. Turner, J. Djakow, „10 Resuscitation Procedures in Children…", op. cit., p. 385
10 Id.

The danger of this phenomenon lies in the fact that this gas does not disappear from inside the mask in any way. It remains within the mask's structural space between the face and the mask shell. If calculations of the mask's volume relative to the child's ventilatory capacity show that the child is unable to fully exchange the air they breathe for fresh air, this results in rebreathing the same air they have already exhaled.

Table 3. Ratio of mask face gas volume to children's volume in different age groups

Age	NTM	TV		Average TV	The ratio of the mask volume percentage to the child's average breath volume		Average percentage ratio of full-face mask volume to the child's average breath
		For 6 ml/kg NTM	For 8 ml/kg NTM		For mask 150 ml	For mask 250 ml	
3	14	84	112	98	153%	225%	204%
4	16	96	128	112	134%	223%	179%
5	18	108	144	126	119%	198%	159%
6	20	120	160	140	107%	179%	143%
7	22	132	176	154	97%	162%	130%
8	24	144	192	168	89%	149%	119%
9	26	156	208	182	82%	137%	110%
10	28	168	224	196	77%	128%	102%

NTM – nominal Total Mass
TV – Tidal volume – volume of breath
Source: author's own study. Based on measurements of full-face mask capacities.

From the above table, it can be inferred how much larger the gas volume of the mask is compared to the tidal volume of a child in various age groups. Therefore, it must be assumed that a single exhalation by the child through the snorkel, which is an integral part of the full-face mask, exchanges only a part of the air inside the mask. But what part? The answer depends: it varies depending on the individual predispositions of the child, lifestyle, diet, health conditions, level of training, etc. However, it is important to note that, regardless of these factors, this is certainly not the full volume of the mask. Consequently, some air remains inside the mask, which does not participate in gas exchange, leading to the accumulation of CO_2 within the mask space.

In children aged 3 to 10 years, a full-face snorkel mask can have such a large capacity that it exceeds their single breath volume. In practice, this means that the child is largely breathing in air that has already been used, resulting in limited gas exchange. As a consequence, CO_2 may accumulate in the body, leading to hypercapnia, as well as hypoxia, which is a deficiency of oxygen. These gas exchange disturbances carry risks such as dizziness, loss of consciousness, and, in extreme cases, drowning.

Summary

Research has shown that the design of full-face snorkeling masks, which cover both the mouth and nose simultaneously, promotes the phenomenon known as rebreathing–re-inhaling exhaled air from the previous breathing cycle. This exhaled air, lingering in the dead space of the mask, is characterized by an elevated concentration of carbon dioxide (CO_2) and a reduced oxygen (O_2) content compared to atmospheric air. As a result, without proper venting of gases during exhalation and delivery of fresh air during inhalation, there is a gradual increase in CO_2 levels in the user's body (hypercapnia).

In one experimental study simulating snorkeling conditions, it was found that using full-face masks can cause both hypercapnia and hypoxia (low blood oxygen levels). This phenomenon was particularly pronounced during physical exertion, even at light or moderate intensity. Under such conditions, the body's metabolic demand for oxygen increases, while the rate of CO_2 production accelerates. If the mask's construction does not ensure effective ventilation and minimize dead space volume, CO_2 accumulation can occur faster than at rest, leading to symptoms such as headache, dizziness, concentration difficulties, increased heart rate, and in extreme cases, loss of consciousness, known as hypoxic blackout[11].

It is especially important to note that most existing studies have been conducted on adults, whose respiratory systems have greater capacity and better ability to compensate for gas exchange changes than children's. For younger users, due to smaller tidal volume and a higher ratio of dead space in the mask relative to lung capacity, the risk of rapid increases in CO_2 and decreases in oxygen levels is even more significant, even after short use.

Children, unlike adults, have a significantly smaller tidal volume, dependent on body mass and age. This means that in full-face snorkeling masks, the dead space (the volume of trapped air within the mask that is not effectively exchanged during each breathing cycle) constitutes a much larger proportion of a child's total lung capacity than in adults. Practically, this results in each inhalation drawing in some of the previously exhaled air, which is already enriched with CO_2 and contains less O_2. This phenomenon leads to a gradual increase in CO_2 levels (hypercapnia) and a decrease in blood oxygen (hypoxemia). The rate of these changes is faster in children due to their smaller lung volume and limited respiratory and circulatory compensatory mechanisms. Additionally, children's higher resting metabolic rate increases their oxygen requirements and CO_2 production. Coupled with less efficient mask ventilation, the risk of gas imbalance disturbances can occur after only a short period of use, even with minimal physical effort[12].

11 R. M. Bart, H. Lau, „Shallow Water Blackout", 2023 Jan 30. [in:] „*StatPearls. Treasure Island*" (FL): StatPearls Publishing; 2025 Jan. PMID: 32119507. [access: 02.08.2025].

12 E. Williams, T. Dassios, P. Dixon, A., „Greenough, Physiological dead space and alveolar ventilation in ventilated infants", *Pediatric Research,* 2022 Jan;91(1):218-222. doi: 10.1038/s41390-021-01388-8. Epub 2021 Feb 18. Erratum in: *Pediatric Research,* 2022 Jan;91(1):265. doi: 10.1038/s41390-021-01676-3., [access: 03.08.2025].

Consequently, in activities like playing in shallow water or slow surface swimming, a child using a full-face mask may experience a progressive and initially unnoticed deterioration in physiological state. Symptoms such as headache, drowsiness, disorientation, rapid breathing, or loss of consciousness can appear suddenly, posing an immediate drowning hazard. This issue is particularly critical if there is no strict supervision by an adult or if the mask is difficult to remove quickly in case of respiratory problems. Currently, there are no unified, precisely defined safety standards for full-face snorkeling masks at national or international levels. Unlike many other types of water sports equipment, which are certified according to clear standards (e.g., ISO, EN, or sports federation guidelines), these masks are not subject to a consistent regulatory system covering design parameters, materials, dead space volume, or ventilation efficiency.

This practical lack of regulation leads to significant variability in design and manufacturing quality, resulting in notable differences in performance and safety features across products from different brands and even among models from the same manufacturer. Some masks may feature well-designed breathing channels that minimize re-inhalation of CO_2, while others–due to simplified construction or cost-cutting–may not provide adequate gas exchange. The absence of mandatory independent laboratory testing means that consumers–especially parents purchasing masks for children–often rely solely on marketing, online reviews, or price, without a reliable assessment of safety. As a result, the market offers both relatively safe models and potentially dangerous designs, which, particularly for children with limited respiratory capacity, can lead to serious health consequences.

The lack of standardization and certification poses significant challenges for user safety and restricts effective communication about risks, as well as the implementation of uniform requirements for design, testing, and marking of this equipment. Due to their full-face design and straps that secure behind the head, these masks can be considerably more difficult and time-consuming to remove quickly in emergencies compared to traditional mask and snorkel sets. In critical situations–such as flooding of the mask, sudden unconsciousness, laryngospasm, panic attack, or breathing difficulties caused by CO_2 buildup–rapid removal of the mask from the face becomes crucial for safety.

For adults, and even more so for children, this process can be complicated if straps are too tight or twisted, or if wet hands, cold water, or limited visibility hinder manipulation of buckles or flexible materials. Every additional second needed to remove the mask in an emergency increases the risk of unconsciousness and, ultimately, drowning.

Children are especially vulnerable for several reasons: they have less manual strength, poorer panic control, and limited experience in handling sudden aquatic situations. Furthermore, for very young users, removing the mask may require adult assistance, which may not be feasible quickly in real conditions (e.g., when in water some distance from the shore).

From a rescue safety perspective, the longer it takes to remove a full-face mask in a critical situation, the greater the risk, and this factor should be carefully considered when selecting snorkeling equipment, especially for children and inexperienced users.

Full-face snorkeling masks should not be used by children under 7 years old, and in many cases, it is advisable to avoid them altogether until about age 10. This is because younger children have much smaller lung volumes and reduced respiratory compensatory capacity, and the large dead space typical of these masks significantly increases the risk of CO_2 accumulation, hypercapnia, or hypoxia[13]. Exceptions may include designs specifically developed for children, with dead space reduced to safe levels and subjected to independent, certified safety testing by qualified institutions.

However, in practice, such specialized equipment is rarely available on the market, and manufacturers' claims are often not supported by thorough testing. Therefore, for the youngest users, traditional mask and snorkel sets are recommended. This classic gear allows better control over breathing, facilitates quick and intuitive removal in emergencies, and minimizes the risk of uncontrolled CO_2 buildup. Additionally, a traditional snorkel enables easier clearing of water from the airway, which is particularly important for children still learning safe water environment navigation.

Regardless of the type of equipment chosen and the child's swimming skills, the fundamental safety rule should be constant, direct supervision by an adult who can swim and respond in emergencies. The presence of a responsible guardian or instructor significantly reduces the risk of tragic incidents such as unconsciousness underwater or drowning.

It is also important to remember that diving–whether recreational or sport–is widely regarded as an activity with increased risk of injury or death. Proper equipment, adequate preparation, awareness of potential hazards, and cautious behavior are essential. For children, this means selecting age-appropriate gear, strictly adhering to safety rules, which should take precedence over comfort or fashion. Attention should also be paid to the child's health conditions, as chronic or temporary illnesses can permanently or temporarily exclude them from diving. Common contraindications include respiratory, cardiovascular, ear and sinus disorders, eye diseases, and neurological or psychological conditions[14].

13 Trapani, L., Poropat, F., Cattaruzzi, E., Barbi, E., Zanchi, C., „Full-Face Snorkeling Masks Carry a Risk of Hypercapnia and Drowning in Younger Children: a Case Series", *Children* 2025, 12, 1148. https://doi.org/10.3390/children12091148

14 J. Krzyżak, K. Korzeniewski, *Medycyna dla nurkujących*, wyd. 4fotn, Poznań 2022, p. 14

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