Guideline

Children and diving, a guideline

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Abstract

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Scuba diving is an increasingly popular recreational activity in children and adolescents. During the dive medical examination aspects of human physiology, anatomy, and psychology, that differ between adults and children, deserve our special attention. For example, lack of mental maturity, diminished Eustachian tube function and heat loss can pose problems during diving. It is important that children who wish to take up scuba diving are seen by a dive physician, with extra attention to Eustachian tube function. In children, asthma, bronchial hyperreactivity, pulmonary hypertension, and right-to-left shunts are contra-indications for scuba diving. Attention deficit hyperactivity disorder is a relative contra-indication. This article provides a review of the current literature and presents recommendations for recreational diving in children and adolescents. These recommendations are based solely on 'expert' opinion and were accepted by the Dutch Society of Diving and Hyperbaric Medicine in 2020.

Introduction

The issue of children and diving is still an emotional one, with little scientific evidence.[1] The South Pacific Underwater Medicine Society (SPUMS) Committee on Medical Standards for Recreational Diving recommended in 1990 a minimum age of 16 years for scuba diving training and this advice was purely based on safety factors.[2] The 2010 (current) SPUMS guideline does not recommend diving for children under the age of 14 years[3] and is solely founded on the belief that younger children do not have the emotional maturity and confidence to safely manage underwater emergencies.[4]

However, along the years, the age at which children (were allowed to) start scuba diving decreased steadily. Facilitated by the dive industry who developed courses especially aimed at children, more and more children took up scuba diving. The Professional Association of Diving Instructors (PADI) changed its minimum age requirement from 12 to 10 years after evaluating their own data from 30 years training children younger than 12 in combination with data obtained from other organisations, like the Confédération Mondiale des Activités Subaquatiques (CMAS), during the same time period.[5] The CMAS has a junior programme with a minimum age of 8 years, while currently American scuba training agencies have agreed on age limits of 8–12 years.[1]

In 2003 The Dutch Society of Diving and Hyperbaric Medicine (DSDHM) issued a national guideline in which the minimum age for scuba diving was set at 14 years.[6] However, younger children do dive and need to be assessed by sports dive physicians for medical examination and advice. The DSDHM felt it necessary to evaluate the minimum age for diving and they tasked us with undertaking this review on their behalf. These new guidelines are officially accepted by the board and members of the DSDHM. In order to update the guideline for children and diving we performed a PubMed search to see if there are new insights on scuba diving in children.

Methods

Author ALQ performed a PubMed search with the search terms: ("*Diving*"[Mesh] OR "*diving*"[tiab] OR "*scuba*"[tiab]) AND ("Child"[Mesh] OR "*Adolescen*t"[Mesh] OR Child*[tiab]). It resulted in 750 titles from which 11 were judged to be relevant. We did not include non-English publications. In addition, existing guidelines and handbooks on diving medicine and diving medical books which discussed medical examinations were screened to identify additional information.

Results

From the 11 titles judged to be relevant there were three observational studies, three opinions, two reviews, one original article, one case report, and only one prospective study with children. The last review dated from eight years ago. Chapters devoted to diving and children in the various dive medical textbooks were brief and provided little background information. Recreational scuba diving incidents, injuries and fatalities of children were reported in several retrospective case series, case reports and in several annual dive medical statistics reports. Unfortunately, those reports usually only mentioned the ratio of accidents in young and adult divers. For a better understanding of the child's physiology and psychology we have chosen to review the literature on the basis of the organ systems.

COGNITIVE AND PSYCHOLOGICAL ASPECTS

Brain development begins in utero and continues into adolescence,[7] however, lateral regions of the prefrontal cortex are the latest developing areas involved in executive functions.[8] Because of incompletely developed prefrontal cortex, executive functioning is only fully established late in the second decade. The executive functions are the cognitive processes that help to regulate, control and manage thoughts and actions.

The cognitive, social and emotional development of an adolescent (12 to about 16 years of age) is stormy. Their ability to suppress and regulate impulses is not yet well developed, there is an increase in risk behaviour, they often have intense mood swings and, partly as a result, a reduced concentration. Considering these processes, one may assume that diving requires good executive functioning, in particular good response inhibition (ability to inhibit one's own response to distractions), sustained attention and cognitive flexibility (human ability to adapt the cognitive processing strategies to face new and unexpected conditions in the environment).[9]

There are five types of situations where normal routine behavioural activation is not sufficient, and executive functions are required to achieve optimum performance.[10] These are: 1) Situations involving planning or decision-making; 2) Situations involving error-correction; 3) Situations where the response is novel and not well-learned; 4) Situations judged to be difficult or dangerous; and 5) Situations that require overcoming habitual responses.

Diving is a safe sport, but it does require good executive functions to be able to anticipate unexpected situations, for example a buddy who gets into trouble because of equipment failure. As the ability to pay attention is the key executive function, testing the child's attention must be an essential part of the diving medical examination. In case of doubt, the dive medical examiner could obtain information from the teachers, diving instructor and parents, or ask for further psychological testing.

Finally, executive dysfunction mainly occurs in children with a diagnosis of attention deficit hyperactivity disorder (ADHD), attention deficit disorder (ADD), autism or dyslexia. For example, in a child with ADHD, executive functions such as: response inhibition, sustained attention, working memory, time management, task initiation and goal-oriented behaviour are insufficiently developed. Therefore, ADHD is a relative contraindication for diving.[11]

ENT ASPECTS

The Eustachian tubes are relatively narrow and run a more horizontal path in young children.[12] This may affect the ability to equalise up to eight years, the age after which we allow children to dive in swimming pools. Middle ear diseases in childhood play an important role in daily ENT practice due to their high incidence.[13] The most important factor is dysfunction of the Eustachian tubes.[14] Children have shorter, more horizontal tubes, immature floppy elastic cartilage and larger adenoids compared with adults. Although most children 'grow out' of this, previous ENT surgery, an atopic constitution, frequent ear infections and problems during air flights should alert the diving physician to a possible persisting tube dysfunction. Also, in young divers, middle ear squeeze is the most common dive medical problem.[15] In a five-year prospective study of 205 children aged 8–13 years, there were four tympanic membrane ruptures after pool and open water dives.[16]

The dive medical examiner should pay extra attention to the historical indicators of Eustachian tube function mentioned above. The ability to equalise should be checked by asking for 'clicking' sounds and by otoscopic examination of the ears. The dive medical exam in the presence of the parents is a good opportunity to explain and practise equalising techniques. If possible, the ability to equalise should be checked in an introductory dive in the swimming pool before embarking on the full course.

PULMONARY ASPECTS

At eight years of age the number of alveoli reaches its maximum.[17] However, a relatively low lung elasticity and airway diameter lead to a higher breathing effort and increased airway collapse at the end of expiration compared to adults.[18] This makes young children in theory more vulnerable to air trapping and pulmonary barotrauma. During subsequent adolescence, the alveoli and airways grow until they reach adult size at approximately 16 years of age.[17]

Adults with mild, well-controlled asthma can, with some precautions, dive safely.[19] However, children seem to be more susceptible to bronchoconstrictive stimuli such as

exertion and cold dry air. In a study of 16 healthy children (age 10–13 years) pulmonary function tests were done pre- and post-breathing cold dry air during a cycle ergometer test and before and after two dives at 1 m and 8 m depth, with a total dive time of 25 min. Water temperatures ranged between 21.5 (SD 1.1)°C at the surface and 15.9 (0.4)°C at 8 m depth. The forced vital capacity (FVC), forced-expiratory volume in 1 s (FEV 1), FEV1 / FVC and mid expiratory flow at 50 and 25% of FVC (MEF 50, MEF 25) were all significantly decreased after the cold-air exercise test and after the dives. There were no clinical signs of airway obstruction. The three children with the largest bronchoconstrictive responses had the lowest BMI. The response to the cold air challenge was not predictive for the post-dive pulmonary function.[20] In case of a history of asthma, complaints or symptoms, pulmonary function tests should be performed.

CARDIOVASCULAR ASPECTS

The foramen ovale usually closes in the third month of life. The incidence of a patent foramen ovale (PFO) decreases with age from 36% at 10–19 years to 25% at 30–79 years.[21] The slightly increased incidence of a PFO in children is probably not relevant because of the depth restrictions advocated by the international diving agencies.

Children with congenital heart disease such as atrial septal defect (ASD), ventricular septal defect (VSD), pulmonary stenosis (PS), coarctation of the aorta (CoA), tetralogy of Fallot (ToF), transposition of the great arteries (TGA) and the like are usually operated upon at young age.[22,23] As surgical techniques for congenital heart disease have improved considerably these last decades, children have a better prognosis and life expectancy and most will reach adulthood. Consequently, it is possible that children who have been operated in the past, may want to start scuba diving. After extensive surgery they are usually asymptomatic, but the possibility exists that they still have a reduced exercise capacity.[24] Also, there is an increased risk of atrial and ventricular arrhythmias, heart failure, and other complications, and in some cases, reoperation is indicated.[25] Children with congenital heart disease with pulmonary hypertension and/or existing right-to-left shunts are considered ineligible for scuba diving.

MUSCULOSKELETAL ASPECTS

The weight of full diving gear depends on thickness of the wetsuit, tank and buoyancy compensating device (BCD) size, and weight belt requirements; on average a child will carry about 15 kg. There is an obvious limit of weight that a child can carry on his/ her back. The American Occupational Therapy Association (AOTA) recommends that backpacks weigh no more than 10% of the student's body weight.[26] There are no international guidelines on the maximum weight of dive equipment used by children who venture scuba diving. Some diving medicine experts have suggested body size limits (145 cm and 40 kg approximately) but this would also preclude some small frame adults.[1]

A long and persisting myth was that growth plates in long bones would be extra susceptible to bubbles in children. This purely theoretical concept kept on being copied in articles and textbooks. The effects of scuba diving on growth plates in both children and adolescents have neither been studied nor reported in the medical literature.[12]

Children usually have a thin subcutaneous fat layer and a rather straight body profile around the waist. This makes them more vulnerable to hypothermia. The weight belt can easily slip off resulting in an uncontrolled ascent with the risk of pulmonary barotrauma. Therefore, the DSDHM advises, for safety reasons, to use a BCD with an integrated lead system.

HYPOTHERMIA

The risk of hypothermia usually begins in water colder than 25°C (77°F).[12] Children generally have a higher surface area to body weight ratio, a lower body mass index and weight and relatively less subcutaneous fat tissue. This results in a faster heat loss than adults, who also have greater heat reserves.[27] Until the mid-teens, children are far more vulnerable to hypothermia than adults. Hypothermia in children (as well as in adults) not only affects bronchomotor tone but locomotor and cognitive abilities as well. During mild hypothermia (central temperature of 35–33°C) symptoms may include confusion, disorientation and amnesia.[28] The cooling of peripheral muscles and nerves can have detrimental effects on function of the hands and function of the legs in swimming.[29]

Increased heat loss in children compared to adults necessitates exposure protection that needs to fit correctly to avoid hypothermia during diving. Children have a natural tendency to grow and, as wetsuit sizes are limited, the young diver may very well end up with loose wrist, ankle and collar seals. Adequate hydration with hot drinks and changing out of the diving suit in a warm environment immediately after diving minimises the likelihood of hypothermia.

Hypothermia prevention in young divers is especially important in regions with a moderate climate such as the Netherlands and the North European countries. The average seasonal water temperature of Dutch rivers, lakes and coastal waters range between four and 20°C. The minimum water temperature at which wetsuits are optional is 14°C,[30] which is therefore advised as safe boundary. This limits the annual period in which young divers are allowed to dive.

DIVE ACCIDENTS IN YOUNG DIVERS

Lethal and non-lethal dive accidents in children are reported in several retrospective case series, case reports and in the

annual dive medical statistics published by the Divers Alert Network (DAN).[27,31,32] One study retrospectively described 22 dive accidents in children below the age of 18 who were treated for arterial gas embolism (AGE) (six cases) and decompression sickness (DCS) (16 cases) at the University of Hawaii between 1983 and 2003.[32] Half of the AGE cases had a history of asthma or had to make an emergency ascent because they panicked underwater. Nine out of the 16 DCS cases (41%) were caused by being out of air.

The incidence rate of diving accidents in children is unknown. Dive statistics usually only mention the ratio of accidents in young and adult divers. For example: In data from DAN 2012–2015, there were 12/636 (1.9%) paediatric scuba diving fatalities in the US or Canada, all between the ages of 12–17.[31]

Drowning and AGE seem to be the cause of death in most cases. Running out of air and uncontrolled ascents are common accident mechanisms. Most accidents are caused by insufficient or total lack of training or high-risk diving (too deep, wreck, cave).[27]

ARE CHILDREN MORE PRONE TO DCS?

Age, body mass index and poor exercise tolerance are correlated to circulating venous bubbles.[33] The question arises whether children have less venous bubbles after diving and/or are less susceptible for DCS compared to adults. This question is difficult to answer as our literature search revealed only three studies looking at DCS and venous gas embolism. In a prospective study from 2003, 205 divers aged 8–13 years were diving to 5–10 m depth. As may be expected, due to limited diving depth, there were no clinical signs of DCS.[16] A limitation of this study was a high dropout rate (25%/year).

In a study that evaluated the occurrence of venous bubbles in 10 young divers (13.1 (SD 2.3) years) after a shallow dive (12 (3) m) for a short time (26 (7) min) no circulating venous bubbles were detected after the children surfaced.[34] A more recent study used standardised dives to look at bubble formation in children.[35] Bubbles were seen on echocardiography in six out of 28 (21%) young divers (13.5 (1.1) years) who made two standardised dives of 25 minutes to 10 metres' seawater. There were no symptoms. This small study demonstrated that bubbles also form during relatively short and superficial dives in children and adolescents.

Unfortunately, both the recent British Sub-Aqua Club and DAN annual reports about the incidence rate of DCS do not differentiate age.[36,37] There are some case reports in the literature, but we have to conclude that the incidence of DCS in young divers is unknown but presumably very low.[12,38,39,32] Also, the question, whether young divers are more vulnerable to decompression stress compared to adult divers, cannot be answered. This will not change in the foreseeable future, as age-related restrictions in depth and duration of diving issued by international diving organisations and ethical considerations do not allow for prospective studies using 'adult' nitrogen loads.

UNRESOLVED ISSUES

There are still many gaps in our knowledge and a lack of evidence about young divers and several such 'loose ends' may warrant future research efforts.

First, a buddy pair consisting of a parent and a 12 year-old child is not rare. Young children are probably not able to help their parent-diver in distress, not only because of a not fully developed executive functioning, but also because of a lack of physical strength. It is suggested that the dive medical examiner will also advise parents in this matter. This advice could be, for instance, to dive under guidance with a diving professional.

Second, children with a mental or physical disability might not be accepted in mainstream dive clubs or courses. The International Association for Handicapped Divers (IAHD) offers courses for children and adults with a disability as well as for instructors.[40] The judgment whether a child with a disability is eligible for an IAHD course requires special expertise and experience from the dive physician.

Finally, adult diabetics can dive with necessary precautions and restrictions. Dive medical organisations do not allow diabetic patients < 18 years to dive[41] although there is support for allow diabetics > 16 years to dive if in a special training programme.[42] A small study in seven 16–17 year-old novice divers with insulin dependent diabetes did not show symptoms or complications of hypoglycemia.[43] This study showed that in closely monitored situations some diabetic adolescents can dive safely. Whether this also holds true for younger diabetic divers is unknown.

Summary

The DSDHM felt it necessary to update their guideline on children and diving. A literature search did not reveal much new knowledge to have emerged over the last 20 years. Most, if not all guidelines, are still expert or consensus based. We believe that, with the necessary precautions, it is safe to lower the minimum age for scuba diving from 14 years to 12 years (or 10 years depending on the circumstances). We have tried to present an overview of the current knowledge and have formulated some recommendations.

Recommendations

These recommendations are based on expert opinions from the diving medical physicians of DSDHM and the best knowledge from existing literature.

1. The DSDHM strongly advises a diving medical examination for all children who would like to take up scuba diving. The self-declaration form, which is used by some diving organisations, is designed for adults. If used for children, it will most probably be completed by the parents. It is not uncommon for children to be put under pressure by the parents to take up scuba diving. It is important confirm there is no parental pressure on the child to start diving.

2. Good executive functioning is important in scuba diving, in particular good response inhibition, sustained attention and cognitive flexibility. Because (some) symptoms of ADHD and ADD may be due to underlying executive functioning, those conditions can be a relative contraindication for scuba diving. If in doubt about executive functioning, it is advisable to obtain information from the teachers, the diving instructor and parents or a psychiatrist/sports diving physician may be asked to carry out a specialist examination.

3. The dive medical examiner should pay extra attention to Eustachian tube function. One should ask about previous glue ears, tympanic membrane surgery, frequent ear infections and an atopic constitution. If possible, the ability to equalise should be checked in a swimming pool try dive before embarking on the full course.

4. The DSDHM advises to preclude children from diving who have asthma or signs of bronchial hyperreactivity (with or without medication). Above the age of 14, adult guidelines apply.

5. Children with operated congenital heart disease should be carefully screened by a cardiologist with expertise in scuba diving. Children with residual pulmonary hypertension and/or residual atrial or ventricular septum defects are unfit for scuba diving.

6. Children should use integrated weight pockets.

7. This guideline for diving and children differentiates between diving in the relatively cold Dutch (and Northern European) waters and diving abroad in tropical waters. While diving for children aged 10–12 years in the Dutch (and Northern European) waters is discouraged, the risk of hypothermia may be much lower in the Red Sea or Thailand. Children from ages 12–14 years can dive in the Dutch lakes provided the water temperature is > 14°C and they wear an adequately fitting wetsuit.

8. Certified sports diving physicians should also be trained to examine children and form an opinion on whether a young candidate should be regarded fit or unfit for diving. In case of doubt or a complicated underlying condition a specialist may be asked for consultation or to carry out an additional examination.

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