Original articles

Epidemiology and treatment of decompression illness in children and adolescents in Hawaii, 1983–2003

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Key words
Children, adolescents, decompression illness, medical/diving, treatment, epidemiology

Abstract

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The advisability of children and adolescents engaging in scuba-diving activities remains a topic of debate. The advent of enhanced opportunities for divers of a younger age has intensified the controversy. Increased risks for physical injury and the psychological readiness of children and adolescents are at the heart of the debate. Recently, questions have arisen regarding the appropriateness of treating younger divers using the current medical management strategies employed to treat adult cases. This retrospective study reports on the 20-year experience at the University of Hawaii in treating child/adolescent cases. Twenty-two cases were evaluated and treated between 1983 and 2003. Six (27%) of these cases suffered an arterial gas embolism (AGE); the remainder had decompression sickness. Seventeen (77%) presented with moderately serious to severe injury. Nineteen (86%) were associated with lack of experience, and nine (41%) may have been related to poor judgement, and lack of self-control. Six cases (27%) suffered an AGE, three of whom had relevant histories of asthma. All cases were treated using treatment tables developed at the University of Hawaii for adult divers with twenty (90.9%) attaining complete resolution of symptoms. Five cases developed mild pulmonary oxygen toxicity resulting from treatment. The oxygen toxicity incidence rate of 8% was slightly higher than but not statistically different to that seen in our adult patients. Established adult treatment schedules appear to be safe and produce excellent outcomes when used to treat younger divers.

Introduction

Children and adolescents have been engaged in scuba diving since the 1960s, and interest has steadily grown since the mid-1980s with the advent of new dive programmes and diving opportunities designed for and marketed to divers of even younger ages.[1,2] Yet, there are questions about the appropriateness of this avocation for children and adolescents, based largely upon perceived concerns of enhanced risk for physical injury and their psychological readiness to undertake diving.[1–6] There have been a number of case histories and fatalities recorded over the years that suggest these concerns may be more than theoretical.[7–10]

More recently, questions regarding the appropriate medical management of diving injuries in children have also arisen.[6] Few published data are available to address these concerns. This study reports on our experience over the past twenty years in evaluating and treating diving injuries in children and adolescents in an attempt to answer some of the questions raised.

Methods

A retrospective review of 1,274 records of patients evaluated and/or treated for dysbarism, arterial gas embolism (AGE) and decompression sickness (DCS), at the Hyperbaric Treatment Center (HTC), University of Hawaii, John A Burns School of Medicine between 1983 and 2003 was conducted in 2004. The foci of this study were cases occurring in patients aged 17 years or younger. Based upon history of injury and presenting physical signs and symptoms, cases were categorised as either AGE or DCS, and the DCS cases were further classified as cerebral, spinal cord, or pain only. Diving-accident histories, including contributing operational diving factors and accident-related comorbid influences, medical histories, age, gender, certification level and diving experience, severity of injury, treatment schedules employed, outcomes per injury type, number of treatments per case, and complications of treatment were assessed and analysed.

Severity of injury was assessed as either mild, moderate, or severe, based upon the gravity of the injury effects upon the ability to conduct activities of daily living as determined at the initial evaluation irrespective of the site of injury. Severe injuries were defined as life threatening and/or had potential for profound residual impairment, i.e., coma, paraplegia, and/or complicated by life-threatening comorbidity. Moderate injuries were defined as those that resulted in a degree of impairment or loss of function sufficient to modify activities of daily living, i.e., motor weakness of a lower extremity, but maintenance of ability to ambulate. Mild cases were those where symptoms and findings were more subjective or would result in little significant impairment.

All cases had been treated using adult treatment schedules developed at the University of Hawaii. The specific tables employed in this study group were: 220 fsw (774 kPa) or 160 fsw (588 kPa) using mixed gases initially, then 100% oxygen; 60 fsw (283 kPa), which is a modified US Navy treatment table 6 (USN T6); and 47 fsw (242 kPa), our usual hyperbaric oxygen (HBO) table, the latter two of which tables employ only 100% oxygen.[11] Outcomes were defined as complete or partial resolution of symptoms.

Results

EPIDEMIOLOGY

Twenty-two patients met our case definition; 17 males and five females, ranging in age from 12 to 17 years (Table 1). There were six novice (in training) or resort course divers, 13 Open Water (OW) divers, two Advanced Open Water (AOW) divers, and one uncertified diver. Novice/resort course divers had undertaken two to eight lifetime dives, OW divers four to 20 lifetime dives, AOW divers 30 and 200 lifetime dives, and, astonishingly, the uncertified diver had undertaken 100 lifetime dives.

Three of the six AGE cases and three of the DCS cases had a pre-existent history of asthma, two of whom (Cases 1 and 6) were actively using non-steroidal medi-halers for control of symptoms at the time of injury. One asthmatic (Case 3), though not symptomatic or taking medication, had experienced an episode of altered consciousness, mental confusion and weakness (suggestive of an AGE) immediately upon surfacing from a dive three weeks prior to the occurrence of this second reported event and for which she did not seek treatment. Two of the DCS cases (Cases 12 and 16) were actively taking medications for behavioural disorders.

Operationally, during the incident dives, there were nine patients (41%) who experienced rapid or uncontrolled ascents, four (18%) who demonstrated panic, two (9%) who experienced an out-of-air (OOA) situation; two pushed the limits of the dive tables and one missed a required decompression stop (14%), two (9%) had buoyancy-control problems, one had an ear squeeze, another hit his head on the underside of the dive boat, and one was extremely cold in the water.

Three divers (14%) developed symptoms only after going to altitude or getting into a hot tub shortly upon completion of their dives. The uncertified diver (Case 7) developed symptoms after the third of four dives on the day of injury.

Treatment

There were six cases of AGE and 16 cases of DCS (six pain, five cerebral, five spinal cord; Table 2). Five cases were initially characterised as having severe life-threatening or debilitating symptoms (three AGE, two DCS), 12 cases were determined to have moderately serious symptoms (two AGE, 10 DCS). Five cases were defined as mild severity (one AGE, four DCS).

Two of the six AGE cases (33%) experienced significant pulmonary barotrauma during the incident dive, and two (33%), including one of the pulmonary barotrauma cases (Case 4), also suffered near drowning. Delays to treatment ranged from 20 minutes to 72 hours (mean 14.25 hours, median 5.5 hours).

All patients had been treated using the HTC treatment tables until either complete resolution of symptoms was attained or until no further change in condition was evident for at least two consecutive treatments. The number of treatments ranged from one to 22 (mean 2.8, median 1).

All but two cases (2 and 11), achieved complete recovery (Table 3). Case 2 was left with some left-leg weakness, while Case 11 was left with a gait abnormality, some sensory loss of both lower extremities, and a neurogenic bladder.

Five patients developed mild symptoms of pulmonary oxygen toxicity (incidence, 8%) during treatment.

Discussion

In the past twenty years, the HTC, which is the only facility in the State to treat decompression illness, has evaluated and treated only 22 divers aged 17 years or younger. This is an average of about one case per year in a state surrounded by the Pacific Ocean and which serves as a haven for all manner of water sports. The latest case was seen in 2000.

Between 1990 and 2000, the Professional Association of Dive Instructors' (PADI) statistics show that 70% of all certified divers are PADI divers, and approximately 15% of their certified divers are in our age group of interest. Hawaii has ranked third in the United States (US) in certifying new PADI divers. It would be reasonable to assume, therefore, that the percentage of divers aged 17 or less in Hawaii, including the transient tourist population, is close to 15%. Without reliable denominator data consisting of the total number of dives undertaken by those in our study group during this period of time (1983–2003), a true estimate of incidence of injury is not calculable. However, in terms of frequency of occurrence, dysbarism in this age group in Hawaii has not occurred in proportion to their representative percentage of the certified diving population, accounting for only 1.7% of our total case load, and 2.2% of all cases diagnosed. A more complete assessment of potential risk would also include fatalities associated with diving. In that regard, we have been fortunate to have not seen, nor are we aware of, any fatalities in this age group related to compressed-gas diving in Hawaii. Others have reported such occurrences in other regions of the globe.[7–10]

Divers Alert Network (DAN) located at Duke University, based upon their systematic collection of diving accident information from reporting sites throughout the US, have

Table 1

Epidemiology of cases of arterial gas embolism (6 cases) and decompression sickness (16 cases)

ADHD – Attention deficit/hyperactivity disorder; AOW – Advanced Open Water; deco – decompression; hx – history; OOA – out of air; Ops – operational; OW – Open Water; uncert - uncertified

Case	Age (gender)	Certification level	(# dives)	Ops factors	Medical hx (pre-dive)
Arterial Gas Embolism					
1	12 (F)	Novice	(3)	Panic; rapid ascent	Asthma
2	13 (M)	OW	(15)	OOA; panic; rapid ascent	–
3	14 (F)	OW	(10)	–	Asthma; prior neuro event
4	14 (M)	Novice	(4)	Emergency ascent training; uncontrolled ascent	–
5	15 (M)	OW	(6)	Panic; rapid ascent	–
6	16 (M)	OW	(15)	Panic; rapid ascent	Asthma
Decompression Sickness					
7	13 (M)	Uncert	(100)	OOA; rapid ascent	–
8	13 (M)	OW	(4)	Pushed tables; rapid ascent	–
9	14 (F)	OW	(9)	Hot tub post dive	–
10	14 (M)	Resort	(8)	–	–
11	15 (M)	OW	(20)	Buoyancy problem; rapid ascent	–
12	15 (M)	Novice	(3)	Very cold in water	ADHD on meds
13	16 (M)	OW	(20)	–	–
14	16 (M)	OW	(20)	–	–
15	16 (M)	OW	(20)	Altitude post dive	–
16	16 (M)	OW	(8)	Ear squeeze	Anxiety on meds
17	16 (F)	AOW	(30)	Pushed tables; rapid ascent	–
18	16 (M)	Novice	(4)	Altitude post dive	–
19	17 (M)	Novice	(2)	–	Asthma
20	17 (F)	OW	(10)	–	Asthma
21	17 (M)	AOW	(200)	Head injury	–
22	17 (M)	OW	(15)	Missed deco stop	Asthma; migraines

Table 2
Treatment summary of arterial gas embolism cases and decompression sickness cases
Tx – Treatment; Comp – complications; POT – pulmonary oxygen toxicity

Case	Severity/type	Delay	Tx table (kPa)	(# txs)	Tx comp	Comorbid injury	Recovery
Arterial Gas Embolism							
1	Moderate	3 hrs	588	(1)	–	–	Complete
2	Severe	20 mins	774 242	(2) (10)	–	Pneumomediastinum/ pericardium	Partial
3	Severe	1.5 hrs	588 242	(1) (2)	–	–	Complete
4	Severe	5 hrs	774 588	(1) (1)	Mild POT	Pneumothorax/mediastinum; near drowning	Complete
5	Mild	1 hr	283	(1)	–	–	Complete
6	Moderate	2 hrs	774 283	(1) (2)	–	Near drowning	Complete
Decompression Sickness							
7	Moderate/pain	30 hrs	774	(1)	Mild POT	–	Complete
8	Mild/pain	8 hrs	283	(1)	–	–	Complete
9	Moderate/spinal	24 hrs	774 283	(2) (1)	–	–	Complete
10	Moderate/spinal	6 hrs	283	(1)	–	–	Complete
11	Severe/spinal	4 hrs	774 283 242	(1) (6) (15)	–	–	Partial
12	Mild/pain	1.75 hrs	283	(1)	–	–	Complete
13	Moderate/cerebral	1.5 hrs	774	(1)	–	–	Complete
14	Moderate/cerebral	1.5 hrs	774	(1)	–	–	Complete
15	Moderate/cerebral	8 hrs	283	(1)	–	–	Complete
16	Moderate/pain	72 hrs	283	(1)	–	–	Complete
17	Moderate/pain	14 hrs	774	(2)	–	–	Complete
18	Mild/pain	45 hrs	283	(1)	Mild POT	–	Complete
19	Moderate/spinal	18 hrs	774	(1)	Mild POT	–	Complete
20	Moderate/spinal	26 hrs	774	(1)	Mild POT	–	Complete
21	Mild/cerebral	10 hrs	774	(1)	–	–	Complete
22	Severe/cerebral	1 hr	774	(1)	–	–	Complete

Table 3
Treatment outcomes by severity and type of injury and incidence of pulmonary oxygen toxicity
AGE – arterial gas embolism; DCS – decompression sickness

Severity:	Severe*	Moderate	Mild	Total	O_2 toxicity
AGE	3 (1)	2	1	6	1
DCS – pain	–	3	3	6	2
– cerebral	1	3	1	5	–
– spinal	1 (1)	4	–	5	2
Total DCS	–	–	–	16	–
Total divers	5	12	5	22	5

*only two children (in parenthesis) did not achieve full recovery

consistently reported over the years that the risk of dysbaric injury is greatest in the least experienced divers.[12]

Certification level does not necessarily correlate with experience and, more importantly, competency in diving. The total number of lifetime dives may be a better indicator. In our study population, 19 (86%) had 20 or fewer lifetime dives, reflective of their relative inexperience. Additionally, other indicators of inexperience may be inferred by the panic events and rapid ascents, the pushed tables and missed deco stops, and out-of-air situations seen in 9 (41%) of the cases.

These operational missteps may also have extended from faulty judgement, a loss of self-control, an inability to cope with a stressful circumstance or management of multiple tasks at once, and/or lack of emotional maturity. However, these same operational miscues were also prevalent at similar rates in our adult-diver injury cases. DAN reports these same findings in their data in which over 95% of cases were adults.[12] One might conclude, therefore, that their rate of occurrence in the children and adolescents of this study was typical and expected statistically. Although we do not have experience data on all of our adult cases, those we do have indicate that the percentage of our adult population who presented with 20 or fewer dives was substantially less than that of our study group.

This study underscores the absolute need to screen children and adolescents carefully in regards to their emotional and psychological maturity as well as their ability to comprehend the inherent risks associated with diving before undertaking this sport. A validated sense of responsibility, self-confidence and ability to deal with the stressors of diving should be in evidence prior to undertaking this avocation. These considerations are probably more important in young divers where there is likely to be less parental involvement or supervision than is required in the dive programmes designed for even younger divers, and where the environmental conditions are often more challenging, and an unwarranted sense of immortality is pre-eminent.[13]

Twenty-seven per cent of the study population suffered an AGE, a diving injury in which statistically 20% of cases result in fatality, hence not insignificant. It most often occurs secondary to pulmonary barotrauma, which in itself can be life threatening. Two patients sustained significant barotrauma. AGE was seen in 27% of our study group as compared with 11% in our adult-diver injury population. Hence the frequency of this injury in the study group was almost 2.5 times as great. Fifty per cent of the AGE cases in this study had a history of asthma, which probably led to the barotrauma that resulted in their injury.

Some diving physicians have relaxed their views over the years with respect to advising asthmatics against diving based upon concerns about pulmonary barotrauma and AGE. This has been predicated upon the fact that there are reportedly a substantial number of asthmatic divers who have never experienced such events.[14] Based upon the small sampling of cases in this study, there may be a need to be more circumspect about this matter with younger divers. Their lungs are less mature, the airways may be more sensitive and less compliant, are of smaller diameter, and may cause greater expiratory resistance and air trapping, thereby paving the way for a barotraumatic event with air embolisation. This study supports other recent work.[15–17]

Seventeen (77%) cases presented with moderate to severe symptoms. All patients were treated using the usual HTC treatment tables, which were developed at the University of Hawaii in the early 1980s and have been used ever since. They typically employ a deep spike to 220 fsw (774 kPa) or 160 fsw (588 kPa) using nitrox 65/35 and/or 50/50, followed by a gradual staged ascent to 60 fsw (283 kPa) where the patient is treated on 100% oxygen to the conclusion of the treatment schedule. The HTC also employs a treatment table commencing at 60 fsw (283 kPa) which is a modified USN T6 with oxygen treatment periods at 60, 45, 30 and 15 fsw. The 47 fsw (242 kPa) table is a two-hour HBO treatment table. Over the twenty years of their usage these tables have resulted in complete functional recovery in 92.9% of all cases treated,[11] which is about 20% better than that reported nationally by DAN for all reporting sites combined.[12] In this study group, 90.9% achieved complete functional recovery.

Compared with the USN T6, which runs 4.75 hours in duration and generates a unit pulmonary toxicity dose (UPTD) of 645, the HTC tables run from 5.25 hours for the 283 kPa table to 6.5 hours for the 774 kPa table and generate UPTDs of 791 to 904.[18] The study group amassed 62 treatment exposures from which five resulted in the development of mild pulmonary oxygen toxicity (incidence, 8%). This was a slightly higher, but not statistically significant, rate than was seen in our adult patients. Thus, concerns regarding the need to modify or reinvent a 'paediatric' set of treatment tables appear to be unwarranted.[4] Delay to treatment did not appear to affect outcomes.

Conclusions

Decompression accidents in this younger population were rare events but, when they did occur, significant injury was usual. Most were associated with poor judgement, lack of attention, loss of self-control, and inexperience. Children and adolescents may be at increased risk for suffering an AGE overall. It is clear that patients in this age group who have reactive airway disease are at greater risk of experiencing pulmonary barotrauma, which may result in arterial gas embolisation, and, therefore, should be advised that diving should not be undertaken. Treatment tables developed for adults produced excellent outcomes in the vast majority of cases, did not present an increased risk of untoward events, and should continue to be used in lieu of developing new and unproven treatment regimens.

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