Pediatric and Adolescent Injury in Ocean and Freshwater Sports (PWC, canoeing, kayaking, surfing, water skiing, snorkeling and scuba)

by

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Abstract

Drowning is a leading cause of death in children. Each year there are many thousands of injuries in children, some fatal, associated with aquatic adventure sports. Personal water craft rapidly accelerate children to high velocity, as does being towed behind boats on skis or tubes, whereupon children have no control of their speed or direction. Canoeing and white-water kayaking particularly stress the upper limbs and shoulder dislocations are a primary concern. Surfing and kite-surfing generate more injuries to the head and face than other parts of the body and, in scuba diving, children most frequently injure their ears due to the acute pressure changes experienced. Aquatic injuries cost more in children than in adults and residual functional deficits may last a lifetime. There is a pressing need for research into the prevalence and incidence of aquatic injuries in children, so the effectiveness of preventive interventions can be determined.

Keywords

Aquatic, children, trauma.

Introduction

The aquatic environment is less forgiving than many other recreational domains and globally drowning is one of the top three causes of death in children aged 10-14.[1] In Japan it is the second-leading cause of death in children aged 0-14 years.[2] In 2015 in Washington state there were 22 boating deaths in children aged less than 13 years, 12 by drowning.[3] Over four distinct survey years in Ontario, 2,154 catastrophic injuries were identified in children and adults, 631 (29%) of which were fatal.[4] Water-based sports accounted for the largest proportion of any group (n=525, 24%), and were also the deadliest, with 334 fatalities (53% of all fatalities).[4]

Personal water craft (PWC), also known as "Jet Skis", have gained popularity since the 1970's. The number of Emergency Department (ED) presentations in the U.S. for PWC injuries increased from 2,860 in 1990 to more than 12,000 in 1995.[6] PWC are powered by a pressurized jet of water that is directed to steer the vehicle. Speeds of 100 km/hr are not uncommon and, because the direction of travel is determined by the expelled jet of water, changing direction while decelerating is problematic.[7] Children as young as two years old have been treated for PWC injuries.[8]

The minimum age required to undertake scuba diver training was, until the late 1990's, often limited to 12 years.[9] Exceptions existed, however, such as through the Confederation Mondiale des Activites Subaquatiques.[10] At the end of the 1990's and the beginning of the 21st century the world's largest diver training organizations reduced the minimum age for certification as a junior diver to 10 years, and allowed children as young as 8 years old to scuba dive under supervision in a swimming pool.[11] Outside of these diver training organizations, children as young as four years old have been taught to

scuba dive.[12] Common concerns at the time of this change included the smaller stature and less physical strength of children compared with adults,[13] coordination and dexterity may not be fully developed, and children generally have a higher surface area to bodyweight ratio, leading to faster heat loss than adults, who also have greater heat reserves.[14-16] Though rare, fatalities in scuba diving children were observed to be typically three or less in the US each year in the late 1970's and early 1980's.[21] Between 1989 and 2002 the Divers Alert Network identified 1,248 scuba diving fatalities, 24 of them (1.9%) younger than 18 years old.[22] In the last ten years of published data from the Divers Alert Network, 2006-2015, there were 12/636 pediatric scuba diving fatalities in the US or Canada, (1.9%), all between the ages of 12-17.[23]

What is not clear, however, are how patterns of injuries in children (aged <18 years) compare between adventurous aquatic sports. It is useful to compare aquatic sports because methods of reducing injury in one sport may be pertinent to reducing injury in another. Therefore, a search was made of PubMed using the terms "(Kayak, canoe, personal watercraft, jet ski, surfing, recreational water sports, adventure sports, injuries, water skiing, scuba) and (children or pediatric)". Potentially relevant articles were obtained, and then included or excluded according to relevance. The reference lists of those were further examined and additional relevant research was obtained. Identified research was limited by varying study design and methodology, grouping of ages, and inclusion/exclusion criteria.

The National Electronic Surveillance System (NEISS) 1998-2015 was searched for injuries associated with scuba diving, surfing, water skiing and snorkeling. Identified data met U.S. Consumer Product Safety Commission (CPSC) criteria for reliability, I.E.

coefficient of variation <0.3, >20 actual cases and >1,200 estimated (weighted) cases nationally. Confidence intervals were estimated by Monte Carlo resampling with replacement. There were 3,050,019 product-related pediatric injuries in the dataset from 100 representative hospitals, weighted to yield national estimates, representing 94,684,362 injuries in children involving a product. For more information about NEISS see.[24]

Who is Affected by Injury?

Canoeists, rafters, and kayakers are predominately male.[25] An analysis of sea kayaker incidents in New Zealand found that males (85%) were more likely than females (10%) to be involved in an incident and, of the 21 known injuries to persons under the age of seventeen, 100% were male.[26] An analysis of 8,437 incident report forms completed by New Zealand lifeguards describing injuries/illnesses found that 57% involved males, and one half were aged 16 years or less.[27] The breakdown of age groups by gender for surfing, water skiing and snorkeling in the 1998-2015 NEISS dataset are given in Table 1. The national estimates are consistently higher for males than females in every age group and for every aquatic activity. An online survey of 1,348 surfers identified an incidence of 1.8 major surfing-related injuries (95% CI 1.67, 1.92) per 1000 hours of surfing.[28]

[Table 1]

There were 37 actual pediatric injuries in the NEISS data associated with scuba, yielding an estimate of 1,362 injuries nationwide 1998-2015 (95% CI 0, 2,924). This number of injuries is so low that further division by age group and sex was not possible. Of the 37 actual cases, 24 (65%) were male, 13 (35%) female, and the median age was 14

years (range 2-17). In 1986, it was estimated approximately 2,000 divers in the U.S. were aged 15 years or younger.[29] In 2014 it was estimated that 5% of all U.S. divers were aged 6-12 years (n~45,000 divers) and 9% aged 13-17 years (n~78,000 divers).[30] Of 22 cases of decompression illness in children (ages 12-17) treated at the University of Hawaii Hyperbaric Treatment Center, 17 were male and 5 females.[20]

Where Does Injury Occur?

Anatomical Location

Table 2 compares the distribution of trauma between surfing, water-skiing and snorkeling in children (age <18 years). The head, face, ears and eyes are clearly vulnerable to injury in children engaged in these aquatic activities.

[Table 2]

In Kansas and Oklahoma the most common injury associated with PWC was traumatic brain injury (TBI) (38%), followed by skeletal injury to the pelvis or extremity (29%).[31] TBI was the most common PWC injury (54%) seen at the University of Maryland Shock Trauma Center over five years.[32] When falling behind a fast moving PWC, (while the jet is propelling water to the rear of the craft), children have sustained forcible water ingress into the vagina or rectum, sometimes even fatally.[33] In Egypt, a 10 year old girl suffered severe blunt force neck trauma when she struck a rope tied between two boats while driving a PWC at high speed.[34] Handlebar straddle injuries occur when a PWC collides with a stationary object.[32]

The most commonly reported injuries associated with boating are lacerations, abrasions/contusions, fractures, head and back injuries.[35] Being towed behind a boat on a tube or wakeboard more commonly involves injuries to the head and neck, while water

skiing injuries are more likely to involve the hip and/or lower limbs.[36] Among 94 members of the Japan Canoe Association, 23% reported having experienced lumbago, 22% shoulder pain, 4% elbow pain and 11% wrist pain.[39] Anatomically, surfers, kite surfers and personal watercraft riders are most likely to suffer a head or lower extremity injury.[5, 40] Among New Zealand surfers who made injury claims to the Accident Compensation Corporation between July 2004 and June 2005, the most frequent body part affected was the face/head, followed by the back/spine, then the neck, shoulder, followed by the lower limbs (knee, then leg, then ankle respectively).[41] In New South Wales the incidence of surf-related eye injuries, including one fifth in children, is estimated at 8.3 per 10^5 person-years (95% CI 4.2, 14.8).[42] Among kite surfers the most common injuries to the upper body are shoulder dislocations and, for the lower body, fractures and soft tissue injuries are the most common overall (46%).[43] Shoulder dislocations are the most common among whitewater kayakers.[44]

In scuba diving the most common injuries are the result of expansion or compression of gas causing barotrauma,[45] the most common being barotrauma of the ear, and children have been found to have greater difficulty voluntarily equalizing the middle ear cavity by Valsalva maneuver.[46] In 16 children treated for decompression sickness at the University of Hawaii Hyperbaric Treatment Center, six complained of pain, five showed cerebral involvement and five the spinal cord.[20]

Environmental Location

In whitewater paddle sports the highest percentage of injuries occur in class III whitewater rivers.[47] Among children presenting at an ED in the U.S. 1998-2015 for injuries sustained is association with products for surfing, water skiing or snorkeling, the

environmental location where the injury occurred is shown in Table 3. Clearly snorkeling injuries are possible in a wider range of environments than either surfing or water-skiing, which require specific environments, but safe storage of sports equipment is important in all aquatic sports.

[Table 3]

When Does Injury Occur?

Injury Onset

The onset of injury varies by incident, for example collision trauma may be instantaneous whereas decompression sickness may take a number of hours to manifest, but some mechanisms are recurrent. Collision with other water craft,[5] impact with submerged objects, cold water, solar exposure, hazardous marine animals,[48] individual skill level, and preexisting acute and chronic medical conditions all provoke the onset of injuries.[49] Immersion injuries often become apparent immediately or soon after the child exits the water.[50] Falling off a fast moving PWC is the most common cause of immediate injury,[31] either by collision with a stationary object, another watercraft or by ingress of water into bodily cavities.[33] On the other hand, there may be some considerable delay between riding the PWC and symptom onset. For example, a 16 year old girl suffering bilateral lower extremity fractures following a PWC incident showed no evidence of head trauma, yet 30 hours later she became comatose.[51] Boat propeller strike is a hazard for water skiiers.[52]

Temporal Variations

In New Zealand the number of claims made by residents of all ages to the Accident Compensation Corporation for surfing injuries peak during January, at the height of summer.[41] Likewise, injuries seen in children after engaging in water-based activities peak in the U.S. in July, during the U.S. summer.[53] In Cornwall, UK, a 2-year surfing analysis of ED presentations by surfers of all ages showed that most injuries occur in summer months (April through September).[54] In regards to injury severity, this study found the most serious injuries occurred during the winter months when waves are larger.[54]

What is the Outcome?

Injury Type

A study in Greece of canoes and kayak paddlers found that sprains and strains were the most common acute injury, and tendinitis was the most common chronic injury while 15% of respondents also contracted Giardia.[47] Among children presenting at the ED for injuries associated with surfing, water skiing or snorkeling products, Table 4), the most common injuries, more common than drowning, were to the skin or involved fractures or internal injuries. Among water-tubers, where an inflated tube is towed behind a boat, children are more likely than adults to suffer traumatic brain injury or lacerations.[37] In 178 sea kayakers aged 16-69 years the most common complaints were sprains and pulled muscles (20%), cuts and abrasions (19%), back pain (12%), sunburn (12%), blisters (11%) and/or painful joints/tendons (11%).[38]

Between 1988 and 2002 a mean of 16 diving injuries per year (range 6-27) in divers aged 19 years or less required hyperbaric oxygen therapy in North America.[16] Among 22 cases

of decompression illness in children treated at the University of Hawaii, 27% had an arterial gas embolism, compared with 11% of the adults treated there.[20]

[Table 4]

Injury Severity

Of 212 surfing injuries in Cornwall of all ages, 90% were discharged immediately after treatment.[54] Similarly among children presenting at the ED in the U.S. between 1998-2015 with scuba diving injuries, 90% were treated and released or released without treatment. The remainder were admitted for hospitalization or observation. The disposition of children aged <18 years presenting to the ED for injuries associated with surfing, water skiing or snorkeling are presented in Table 5.

[Table 5]

Clinical Outcome

Much of what is known regarding catastrophic injuries in children engaged in aquatic sports comes from case reports. Following a collision between two PWC a nine year old boy died from atlanto-occipital dislocation and brainstem transection, while a 10 year old girl riding a PWC was lucky to survive a fracture/dislocation of the second on third cervical vertebrae (C2-C3) and transected trachea after a high speed collision with a rope tethered between two boats.[34, 55] In Ontario the most common environments where catastrophic injuries occurred were in lakes and rivers, and drowning was the most frequent at 310/525 cases (59%).[4] There were seven catastrophic injuries involving PWC in Ontario during four survey years all involving males, one of which was aged between 11-20.[7] Two were fatal, involving high speed collisions.[7] In other boating activities five children aged <11 suffered catastrophic

injuries and a further 19 were aged 11-20 years.[56] Three out of eight catastrophic sailing injuries were aged <20, one of those <11.[35] In a survey of 27 catastrophic canoeing injuries, all were fatal, with one in four fatalities occurring in the 11-20 age group.[57]

In the U.S. an analysis of the U.S. Coast Guard Boating Accident Report Database concluded the risk of death to be 86% higher if the incident involved a kayak or canoe.[58] Table 6 shows the minimum age of water sports participants suffering catastrophic injuries, and Table 7 shows the anatomical locations of catastrophic injuries during four years of surveys in Ontario (1986, 1989, 1992, 1995). Clearly, drowning accounts for at least half of all catastrophic injuries in the water, with head injuries a distant second.[4]

[Table 6]

[Table 7]

Much of what is known about clinical outcome in adventure and extreme aquatic sports arises from studies of drowning. Sixty children aged 1-18 years who had normal premorbid function survived for at least one year following cardiac arrest, (with chest compressions for ≥2 mins), due to drowning or other respiratory etiologies.[59] Follow up was obtained for 59 of them (30 in the drowned group) and 72% of the children showed well below-average cognitive function after one year.[59] In Japan, more drowning or near-drowning children who required cardiopulmonary resuscitation (CPR) on arrival at hospital suffered death or severe impairment than children who did not require CPR.[2] Of the 22 child scuba divers treated in Hawaii for decompression illness, all but two completely recovered. One of these was left with some weakness in the left leg while the

other's residual symptoms included problems with gait, sensory loss of the lower extremities and a neurogenic bladder.[20]

Economic Cost

By 1999 the estimated annual economic impact of PWC injuries in all ages in the U.S. was more than $235 million.[60] In 2003, the inpatient costs for an estimated 2,490 pediatric submersion-related injuries in the U.S. were approximately $10 million.[61] Children with permanent submersion-related morbidity accounted for 6% of admissions and 37% of hospital costs, while children who died in hospital as a result of submersion-related injuries accounted for 12% of admissions but 20% of the hospital costs.[61] It was estimated in 2005 that for every five prevented drowning deaths the cost savings to the Australian community would approach AU$8 million.[62]

In New Zealand, injury claims paid under a national accident compensation program received 16,592 new claims for surfing related injuries between 2007-2012 resulting in payments of almost NZ$20 million.[63] An analysis of adventure tourism and adventure sports injury claims made to the Accident Compensation Corporation (ACC) in New Zealand identified a third of all claims to be associated aquatic sports and surfing as the fourth highest activity for injury claims, with an injury rate of 11 per 1,000 participants of all ages.[41] Table 8 shows the economic costs of aquatic sports, and the three most common sports, that claims were made for by New Zealand residents aged 16 years or over between July 2004 and June 2005. Aquatic sports accounted for 6,061 claims (32.4%) and seven fatalities.[41] Of the 18,590 claims, 2,435 (13%) were aged 16-20 years.[41] Since the data arise primarily from injured adults, it is likely the cost per case

would be higher among injured children, but the total cost for all adventure tourism and adventure sports claims, (which excluded overseas visitors and children <16 years old), was more than NZ$12 million during this single year.[41]

[Table 8]

What Are the Risk Factors?

The most common methodology employed in aquatic sports injury risk factor research has been to employ observational or descriptive studies. Prospective cohort studies are far rarer.

Intrinsic Factors

Children have a lower body mass index and weight, a larger surface area to weight ratio, and relatively less subcutaneous fat tissue causing them to lose heat faster than adults.[64, 65] Children who are prone to fainting or have a history of neurocardiogenic syncope may have heightened sensitivity to facial cooling or hypothermia, and may have exaggerated bradycardic reactions to scuba diving or even mere facial immersion (known as the "diving reflex").[64] Cardiovascular responses to facial cooling are known to be age dependent,[66] and facial cooling has been shown to cause greater exercise-induced bronchoconstriction in asthmatic children than merely breathing cold air.[67]

An analysis of 22 cases of decompression illness in Hawaii noted that 19 (86%) were associated with a lack of diving experience, (they had made 20 or less dives).[20] Children have smaller relative diameter airways and greater compliance, predisposing them to expansion barotrauma during ascent.[68] A study of the respiratory function of 16 healthy child divers (mean age 12, range 10-13) in Austria found, after 25 minute dives to either 1m or 8m depth in water ranging from 16-22ºC, there were significant decreases in

FEV_1, FVC, FEV_1/FVC, MEF_{25} and MEF_{50}.[69] In three children, the decrease in FEV_1 exceeded 10%.[69] Similar results were observed in 41 children aged 8-14 years after making a single dive in 28ºC water.[70] Again, a decrease in $FEV_1 \geq 10\%$ was observed in five children.[70]

When the compressed air in a scuba tank expands as it is delivered to the diver, the temperature of the gas falls due to adiabatic cooling. Because of this, and because the air is very dry, asthmatic children should be carefully evaluated for scuba diving.[17] A study comparing 18 diving children (aged >8 and <14 years) with 18 non-diving controls found that, after a scuba dive to just 3m depth for 25 minutes, the diving children had decreased 1-second forced expiratory volume (FEV_1), maximal voluntary ventilation (MVV), peak expiratory flow (PEF), maximal expiratory flow (MEF) and forced mid-expiratory flow rate ($FEF_{25-75\%}$), indicating airway narrowing.[18] Among children of different ages, measurement of static resistance found the weakest pulmonary elasticity among the youngest children.[19] For a similar level of activity, *ceteris paribus*, the child will have a higher level of ventilator work than an adult and the risk of air trapping, (with barotrauma the consequence), is highest in children less than 8 years old.[14] Barotrauma is often the cause of an arterial gas embolism and children receiving hyperbaric oxygen therapy at the University of Hawaii presented with 2.5 times more arterial gas embolisms than adults treated there.[20]

Extrinsic Factors

Children do not always have properly sized equipment but it is important for safety that they do.[16] Of the 333 boating fatalities that occurred in Australia between 1992-1998, which included around 10% children and adolescents aged <20 years, only

9% were wearing personal flotation devices (PFD) and yet the survivors were twice as likely to have been wearing them (OR 2.1, 95% CI 1.3, 4.1).[62] Poor early design contributed to many PWC injuries, such as long stopping distances and the inability to steer when off the throttle.[31]

All aquatic activities share common risk factors such as proximity to other boating activity,[31, 71] the speed at which the water flows, wave height, water temperature,[72] sharks or other hazardous marine life,[48, 73] wearing of ill-fitting safety equipment, ropes in the water,[74] and sunburn. Among injured beachgoers in New Zealand, children aged <16 years old were more likely to suffer marine stings than children aged 16 or over (χ^2=402.8, P<0.0001).[27] Canoe, kayak, raft, and PWC injuries are all additionally impacted by hazards such as submerged rocks, logs, etc, strength of eddies, rapids, or falls in water level. Rapidly moving powerful waves, hard fiberglass boards, sharp fins, shallow reefs and rocks all present potentially injurious hazards for the surfer.[75] Being struck by one's own board or striking the seafloor were the two most common mechanisms of injury in a survey of surfers, and surfing in competition was identified as associated with increased risk of knee injury (χ^2=13.9, P=0.001).[28] Similarly, the risk of suffering a kite-surfing injury during competition was 2.5 times that during training (95% CI 1.15, 5.29).[76]

Of the children treated for decompression sickness in Hawaii, three developed post-dive symptoms after getting into a hot tub or ascending to altitude,[20] both of which are known to exacerbate the risk of decompression sickness. Arterial gas embolism is a condition that follows ascending after breathing compressed gas underwater, and can

occur after ascending from as little as 1m depth.[77] Consequently, children suffer arterial gas embolisms during scuba lessons in a swimming pool or their first dive in the sea.[78, 79]

What are the Inciting Events?

A peculiar hazard associated with high speed on a PWC is the risk of striking a taught rope.[34] Propeller strike is another particularly serious hazard whenever a boat approaches a child in the water, for example when water skiing.[52, 71] Towed tubing incidents are responsible for serious traumatic injuries and relatively long hospital stays. Children towed upon inflatable tubes do not have control over the speed or direction of the tube and, when the watercraft turns, centrifugal forces direct the tube to travel outside of the wake.[74] Among an estimated 69,000 injuries treated at U.S. EDs, children and adolescents were found more than twice as likely to have been injured by colliding with another water-tubing participant (OR=2.5, 95% CI= 1.6, 3.8).[37] Head injuries following contact with another water tuber were more likely than other mechanisms of injury (OR=12.4, 95 CI 7.1, 21.7).[37] It is likely for this reason tubing injuries are often more severe, (defined as hospitalization, transfer or observation), than injuries from water skiing (OR 2.3, 95% CI 1.2-4.3).[36] Among the children treated for decompression illness in Hawaii, nine (41%) had made rapid or uncontrolled ascents, four (18%) reported panicking, three (14%) had reached or exceeded accepted no-decompression time limits for the depths they were diving to, two (9%) had run out of air, and one reported being extremely cold in the water.[20] Panic was noted as the inciting event in four out of six children treated for arterial gas emboli,[20] and scoring high in trait anxiety was found to be predictive of propensity for panic in college-age beginner divers.[80]

Injury Prevention

Few studies have been undertaken with the aim of measuring effectiveness of interventions to reduce aquatic sport injuries (e.g. randomized control trials). The American Academy of Pediatrics Committee on Injury and Poison Prevention recommend a minimum age of 16 years before operating PWC.[81] Furthermore, wearing PFDs is recommended, as is formal training in PWC use, operating PWC during daylight hours only, observing posted speed restrictions and "no-wake" zones, and avoiding areas where people swim. Mandatory speed limit regulations have been recommended to decrease the risk of serious injuries due to watercraft use, particularly when children are to be towed on inflatable tubes.[74] Newer PWC have many safety features not developed until recent years, for example kill switches, or intelligent control brake systems.[31] Unfortunately, many of the older PWC are still in use and are now often cheaper to buy. In all boating activities parents are important role models for children and it is recommended they wear properly fitting PFDs at all times.[56] Adults who are supervising children during aquatic activities, such as boating, PWC use or water skiing, should refrain from alcohol.[56] Of 224 Australian boating fatalities, and of 129 vessel operators involved in boating fatalities, 42% (n=93) and 40% (n=52) respectively tested positive for alcohol.[62]

Bailey, (2010) posited that sea kayakers who carry a means of signaling, especially after capsizing, may have expedited rescues and, thus, reduced likelihood of fatal outcomes.[26] Wearing a PFD may have reduced the severity of many sea kayaking injuries in New Zealand.[26] Making the wearing of a PFD mandatory has been shown to

be far more effective than education alone.[82] Canoeing preventive tips include never to canoe alone, always wear a personal floatation device (PFD), canoe only in fair weather conditions, be in adequate physical shape for the activity, be trained, and know how to swim well.[57] In sailing, the wearing of a PFD is highly recommended,[35] as are shoes or sailing boots, warm layers of clothing, and checking the weather.[35] It has been estimated that a 20% increase in wearing a life jacket could have prevented 1721/3047 boater drownings and 1234/2185 other drownings in the U.S. between 2008-2011.[58] Personal protective equipment has also been suggested as a potential preventive aid when children are towed behind boats, and many surfing injuries could be avoided if surfers wore headgear, however such protective equipment is rarely worn.[54, 74] In water skiing it is always recommended that, in addition to the vehicle operator and the skier, a third person be employed to watch the skier. One study suggests a pre-participation evaluation including a functional assessment tailored to the particular watersport should be requested by guiding agencies, instructional camps, or by patients presenting for an annual visit.[49] In surfing the adoption of leg ropes has reduced the likelihood of surfers being struck by other surfers' boards, while increasing the likelihood of being struck by their own board.[83] Improvements in elastic recoil and rope length continue toward reducing these risks.[84]

In scuba diving proper supervision by a qualified instructor is paramount to the safety of children when trying scuba for the first time.[13] It is essential for the scuba diving child to be in good health and evaluation by a physician is recommended.[9, 13, 68] Consideration of the asthmatic child for scuba diving remains controversial. It is also thought that children more commonly have patent foramen ovale than are found in

adults,[85] and these allow circulating venous bubbles to pass through the heart without being filtered by the pulmonary system.[16] For this reason many experts recommend shallow dives, to reduce the potential for bubble formation.[86] Exposure protection needs to fit correctly otherwise excessive heat loss is certain. Winkler *et al* recommend making only a single dive in any day for children under 14 years old, a maximum depth of 2-5 m for ages 8-12, and 3-10m for ages 12-14, no diving for children in water less than 12ºC, and a maximum time limit of 10 minutes in 12ºC water.[15] Likewise, Cilveti *et al* recommend dives to no deeper than 10m in children, short immersions to prevent hypothermia, dives during daylight only, and children to be accompanied by one or two adults.[68]

Slow ascent rates (<10m.min^{-1}) and 3-5 minutes safety stops at 3-5m depth were recommended by Lemaitre *et al* after evaluating children divers for circulating bubbles using Doppler ultrasound.[86] Slow ascent rates are a particular concern during emergency ascent training where a trainee diver is required to simulate an out-of-gas ascent to the surface from at least 6m depth.[69] Diving with a buddy has been the recommendation of Divers Alert Network and the Professional Association of Diving Instructors since at least 1980 but, considering the potential limitations of a child if called upon to render assistance to an adult diving buddy, it is recommended children dive with pairs of adult divers.[16]

In summary, while injury prevention measures are most effective when specific to each activity,[87] in general it can be seen that certain safe practices are common to most, if not all, aquatic sports and never more so than when the participants are children:

- be a capable swimmer
- be in good health
- wear a properly fitting personal floatation device (or buoyancy control device when scuba diving)
- ensure the water conditions are suitable for the capability of the participants
- be under the supervision of a sober adult
- ensure the required equipment fits correctly
- engage in the activity during daylight hours
- carry a means of signaling distress

Further Research

There is a pressing need for future aquatic sports research to determine injury rates relative to exposure and, when studying all ages, to separate out children and adolescents from adults in the analysis. Comparison between sports is problematic and would be assisted by the widespread adoption of standardized injury classifications.

Looking at specific sports, many whitewater kayaking instructors advocate keeping the arms in close to the torso, to minimize the risk of shoulder dislocation, but the effectiveness of this technique requires confirmation.[44] The optimal helmet design for water-tubing also requires confirmation through research.[37] Helmets that protect the ears, for example, might prevent tympanic membrane injuries when the rider contacts the water at high speed, but this is speculative. Such helmets may even prevent exostoses in cold water surfers but helmets remain unpopular. What are the barriers to wearing head protection in PWC when the most common serious injury is to the head? Other material

improvements waiting to be tested include fins that break away upon impact, rounded-nose surfboards and compressible shock absorbers on the edges of surfboards.[83] In kitesurfing the quick-release harness has the potential to reduce injuries (OR=0.7, 95% CI 0.3, 1.4; P=0.3), but this remains to be proven in a large prospective study.[76]

The absolute number of diving fatalities in children divers in the U.S. appears to have fallen over the last three decades but without reliable denominators for participation (number of participants and number of dives per year) we cannot know if the mortality rate itself has fallen or if participation has, or both. The percentage of fatalities involving children (1.9%) has not changed in a quarter of a century. Injury prevention over the last three decades in scuba diving includes the development of enriched air diving (with blends of gas containing concentrations of oxygen in excess of that found in air), personal dive computers, safety stops, flying after diving guidelines, and more, but which hazards are currently the most deserving for preventive interventions remain unclear, as they do in other aquatic adventure sports. A long-term prospective monitoring project is sorely needed to address this issue, as it is in all aquatic adventure sports.

Finally, while it is certain improvements can be made to the collection and availability of data concerning aquatic injuries in children, of equal importance is the collection and dissemination of non-fatal incident reports. The Divers Alert Network actively collect non-fatal incident reports through their website and these are summarized each year in the DAN Annual Diving Report, plus anonymous versions are made available online. In addition to informing the design of interventions, these are used by instructors when teaching safe diving practices and are currently viewed around 20,000

times per month. Similar work should be undertaken in other aquatic adventure sports, most urgently in PWC near-misses.

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Table 1: Age-group by sex for Emergency Department presentations in the U.S. 1998-2015 for children injured in association with surfing, water skiing or snorkeling[a]

		Surfing		Water Skiing		Snorkeling	
	Age Group	Rec[b]	Total[c]	Rec[b]	Total[c]	Rec[b]	Total[c]
Males	≤ 5	X	X	X	X	21,558	68,028
	6-10	12,102	13,333	1,947	2,443	67,175	162,292
	11-15	34,794	39,294	8,077	9,747	70,692	155,188
	16-17	15,041	16,360	7,377	8,725	23,272	45,204
Females	≤ 5	X	X	X	X	21,852	59,534
	6-10	3,497	3,868	X	X	63,441	168,827.45
	11-15	11,623	12,997	4,506	5,308	61,248	145,091
	16-17	4,526	4,655	2,233	2,582	15,932	33,680
Total	≤ 5	X	1,208	X	X	43,416	127,634
	6-10	15,598	17,202	2,433	3,165	130,616	331,120
	11-15	46,416	52,291	12,582	15,054	131,940	300,279
	16-17	19,567	21,015	9,611	11,307	39,203	78,884
Total	0-17	82,443	91,716	24,866	30,110	345,176	837,917

[a] National estimates, [b] Occurred in a location for sports or recreation, [c] Occurred in any location, including at home, X Number of cases <20

Table 2: Body part involved in Emergency Department presentations in the U.S. 1998-2015 for children (age <18 years) injured in association with surfing, water skiing or snorkeling[a]

	Surfing		Water Skiing		Snorkeling		**Overall**
Body Part	Rec[b]	Total[c]	Rec[b]	Total[c]	Rec[b]	Total[c]	**Total[c]**
Ear	X	X	1,421	1,642	162,755	447,419	**449,061**
Foot	14,602	15,208	1,329	1,482	35,151	57,221	**73,911**
Face	10,389	11,816	4,384	5,474	16,862	44,308	**61,598**
Head	10,134	12,024	6,632	7,829	15,854	34,998	**54,851**
All of body	X	X	X	X	15,410	34,809	**34,809**
Upper trunk	1,371	1,544	X	X	11,084	26,169	**27,713**
Eyeball	X	X	X	X	9,347	25,237	**25,237**
Lower trunk	3,137	3,648	X	1,227	7,214	19,187	**24,062**
Shoulder	2,864	3,514	X	X	7,060	17,852	**21,366**
Knee	2,967	3,195	<1,200	1,260	9,502	16,774	**21,229**
Toe	4,223	4,439	X	X	9,410	15,400	**19,839**
Neck	5,354	5,693	X	<1,200	5,972	14,136	**19,829**
Lower leg	3,489	3,870	X	X	7,789	12,404	**16,274**
Ankle	5,585	6,110	<1,200	<1,200	3,766	7,599	**13,709**
Finger	1,863	1,946	X	X	5,265	10,351	**12,297**
Wrist	5,216	5,878	1,361	1,695	2,410	4,616	**12,189**
Pubic region	X	X	0	X	3,744	11,876	**11,876**

Lower arm	3,296	3,585	1,451	1,754	2,650	6,091	**11,430**
Hand	X	1,547	X	X	3,415	7,042	**8,589**
Mouth	1,716	2,052	X	X	1,938	6,388	**8,440**
Upper leg	1,698	1,859	X	X	2,751	5,378	**7,237**
Elbow	X	<1,200	X	X	1,639	4,197	**4,197**
Upper arm	X	X	X	X	<1,200	2,158	**2,158**
25-50% body	0	0	0	0	X	1,646	**1,646**
Internal	0	0	0	0	X	1,513	**1,513**
Not stated	X	X	0	X	1,787	3,148	**3,148**

[a] National estimates, [b] Occurred in a location for sports or recreation, [c] Occurred in any location, X Number of cases <20

Table 3: Environment where surfing, water skiing or snorkeling injuries[a] occurred in children leading to Emergency Department presentations in the U.S. 1998-2015

Location Type	Surfing	Water skiing	Snorkeling
Place of Recreation or Sports	82,443	24,866	345,176
Home	<1,200	<1,200	81,384
Other Public Property	2,820	<1,200	47,808
School/Day Care	0	0	14,330
Farm/Ranch	0	0	<1,200
Street/Highway	<1,200	<1,200	<1,200
Mobile/Manufactured Home	0	0	<1,200
Not Recorded	5,206	3,379	348,199
Total	91,716	30,110	837,917

[a]National estimates

Table 4: Diagnosis among Emergency Department presentations in the U.S. 1998-2015 for children injured in association with surfing, water skiing or snorkeling[a]

	Surfing		Water Skiing		Snorkeling		**Overall**
Diagnosis	Rec[b]	Total[c]	Rec[b]	Total[c]	Rec[b]	Total[c]	**Total[c]**
Laceration	28,420	31,755	8,994	11,140	53,275	96,605	**139,500**
Sprain or strain	16,564	18,039	4,447	5,420	18,192	42,112	**65,571**
Contusions/ abrasions	10,053	11,502	2,740	3,199	17,750	39,660	**54,361**
Dermatitis/ conjunctivitis	X	X	X	X	17,560	42,960	**42,960**
Fracture	15,915	17,708	3,017	3,571	6,565	13,900	**35,179**
Puncture	X	X	X	X	11,515	22,865	**22,865**
Internal organ injury	3,127	3,554	1,609	1,651	5,977	14,743	**19,948**

Submersion / drowning	X	X	0	0	6,196	12,398	**12,398**
Radiation burns	X	X	0	0	4,259	10,526	**10,526**
Foreign body	X	X	X	X	5,191	10,346	**10,346**
Concussions	1,522	1,750	1,729	1,921	3,442	5,792	**9,463**
Dislocation	<1,200	<1,200	X	X	2,921	7,424	**7,424**
Avulsion	X	X	X	X	<1,200	1,861	**1,861**
Hemorrhage	X	X	0	0	X	1,624	**1,624**
Poisoning	0	0	0	0	X	1,622	**1,622**
Dental injury	X	X	X	X	<1,200	1,224	**1,224**
Aspirated foreign object	0	0	0	0	X	1,201	**1,201**
Hematoma	0	0	0	X	X	<1,200	**<1,200**
Other / Not stated	2,348	2,837	1,595	2,274	188,059	507,377	**512,488**
Total	82,443	91,716	24,866	30,110	345,176	837,917	**959,743**

[a] National estimates, [b] Occurred in a location for sports or recreation, [c] Occurred in any location, X Number of cases <20

Table 5: Outcome following Emergency Department presentations in the U.S. 1998-2015 for children aged <18 years injured in association with surfing, water skiing or snorkeling[a]

	Surfing		Water Skiing		Snorkeling	
Disposition	Rec[b]	Total[c]	Rec[b]	Total[c]	Rec[b]	Total[c]
Treated and released or examined and released without treatment	80,998	90,067	23,816	28,835	336,655	819,524
Treated and hospitalized in the same facility	<1,200	<1,200	<1,200	<1,200	3,325	7,402
Left without being seen or against medical advice	X	X	X	X	1,854	4,687
Treated and transferred to another hospital	X	X	X	X	2,151	4,077
Held for observation	X	X	X	X	X	<1,200
Fatality, including DOA, died in the ED, brain dead	0	0	X	X	X	<1,200
Not recorded	0	0	0	0	X	X

[a] National estimates, [b] Occurred in a location for sports or recreation, [c] Occurred in any location, X Number of cases <20

Table 6: Catastrophic injuries in aquatic adventure sports in Ontario during four survey years (1986, 1989, 1992, and 1995)[7]

	Fatalities (n)	Non-fatal (n)	Youngest (yrs)	Age <20
Boating	72	40	5	24 (22%)
Canoeing	27	0	15	7/27 (26%)
Scuba diving	10	0	17	1/10 (10%)
Sailing	7	1	6	3/8 (37%)
Water skiing	2	7	16	6/9 (67%)
PWC*	2	5	15	1/7 (14%)

*Personal water craft

Table 7: Anatomical location in catastrophic injuries, Ontario, 1986-1995[4]

Activity	Head	Spine	Drown	Eye	Abdomen	Chest	Face	Misc.	Limb
Jet skiing/PWC[a]	3	1	1	2	2	1	1	0	0
Canoeing	3	0	24	0	0	0	0	2	0
Waterskiing	2	2	1	4	1	1	0	0	1
Scuba Diving	1	0	9	0	0	3	0	1	0
Total	9	3	35	6	3	5	1	3	1
(%)	(14%)	(5%)	(53%)	(9%)	(5%)	(8%)	(2%)	(5%)	(2%)

[a]Personal Watercraft

Table 8: Median cost per case aged 16 years or over (NZ$) by activity[41]

	Activity	Claims n (%)	Fatalities	Median cost per case (NZ$)
Top three activities	Horse riding	3810 (20.4)	3	134.4
	Mountain biking	2618 (14.0)	0	148.2
	Tramping/Hiking	2468 (13.2)	2	127.4
Aquatic activities	Surfing	2238 (12.0)	0	103.7
	Waterskiing	1110 (5.9)	0	128.9
	Kayaking/Canoeing	864 (4.6)	0	110.7
	Wakeboarding/Sea biscuit	650 (3.5)	0	92.4
	Diving/Snorkeling	491 (2.6)	3	72.7
	Wind surfing/Kite surfing	287 (1.5)	1	109.1
	Jet skiing	229 (1.2)	0	106.0
	Whitewater rafting	106 (0.6)	2	74.3
	Jet boating	86 (0.5)	1	140.4