ACTIVE & SAFE

Evidence Summary: Scuba-Diving

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The British Columbia Injury Research and Prevention Unit (BCIRPU) was established by the Ministry of Health and the Minister's Injury Prevention Advisory Committee in August 1997. BCIRPU is housed within the Evidence to Innovation research theme at BC Children's Hospital (BCCH) and supported by the Provincial Health Services Authority (PHSA) and the University of British Columbia (UBC). BCIRPU's vision is *to be a leader in the production and transfer of injury prevention knowledge and the integration of evidence-based injury prevention practices into the daily lives of those at risk, those who care for them, and those with a mandate for public health and safety in British Columbia.*

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Evidence synthesis tool

SPORT:	Scuba-diving or snorkelling	Target Group:	Recreational divers (not occupational divers)	
Injury Mechanisms:	All injury/diving-related incidents, fatalities, decompression sickness (DCS) and orofacial barotrauma			
Incidence/Prevalence	**Risk/Protective Factors**	**Interventions**	**Implementation/ Evaluation**	**Resources**
All injury In a review of the epidemiology of injury in **all recreational divers**, the prevalence of incidents ranged from **7 to 35 injuries per 10,000 divers** and from **5 to 152 injuries per 100,000 dives**.[1] In a cross-sectional survey of **registered members of the Divers Alert Network** in 2010-2011, the overall rate of diving-related injury was 3.02 per 100 dives.[2] **Diving Fatalities** Recreational scuba diving fatalities account for 0.013% of all-cause mortality aged >15 years.[2] Annual fatality rates in Australia are 0.48 (0.37-0.59) deaths per 100,000 dives, or 8.73 (6.85-10.96) deaths per 100,000 divers for **Australian residents**; 0.12 (0.05-0.25) deaths per 100,000 dives, or 0.46 (0.20-0.91) deaths per 100,000 divers for **international visitors** to Queensland; and 1.64 (0.20-5.93)	**Risk Factors** **Age** As divers age, there is an increased risk for decompression illness and diving fatality.[11–14] Increased relative risks between older (>49 years) and younger divers are found for arterial gas embolism (RR=3.9), asphyxia (RR=2.5) and disabling cardiac injury (RR=12.9).[13] Greater age (>42 years) is also a prognostic factor for incomplete recovery from severe decompression illness.[11,14] **Sex** The annual fatality rate for males is greater than for females by 10 per 100,000 divers up to age 65 years, after which the rates are essentially the same for both sexes. Relative risk between males and females decreased from 6 at age 25 years to 1 at age 65 years.[13] **BMI** The odds of surviving arterial gas embolism are greater for divers with a normal BMI.[13] **Asthma** A systematic review in 2016 reported	Clinical data to support additional intervention measures on DCS development are lacking due in part to the great inter/intra-variability between individuals regarding susceptibility to DCS. Historically, preventing DCS has been based upon the slow ascent and increasing the duration of decompression stops, which dramatically reduced the incidence and severity of DCS in developed countries in the twentieth century.[26] **Education** Although not tested in recreational divers, education or ascent training is an important component of injury prevention. Educating **fisherman divers** in Vietnam on in-water recompression techniques, the incidence of severe DCS decreased by 75% in 3 years; from 8±2 per 1000 divers before 2009 to 2±1 per 1000 diver after the	No studies were found that have evaluated implementation/ evaluation strategies in this sport/activity.	Divers Alert Network (DAN) – the diving industry's largest association dedicated to scuba diving safety. http://www.diversalertnetwork.org/

deaths per 100,000 dives for the **dive operator** in Victoria.[3] The mean annual fatality rate for insured **members of the Divers Alert Network** was 16.7 deaths per 100,000 divers with 95% CI 14.2-19.0 over the period 2000-2006 (1 death in 6,000 per annum).[4] **Decompression Sickness (DCS)** Incidence of self-reported DCS symptoms was 1.55 per 1,000 dives and treated DCS was 5.72 per 100,000 dives amongst **Divers Alert Network** members.[4] Rate of occurrence (per dive) for **recreational divers** in the USA is estimated as 0.017 to 0.2%.[5] Following DCS, the prevalence of **dysbaric osteonecrosis** in hyperbaric centres in Southern France was 19%, suggesting MRI for routine screening is justified in recreational divers treated for musculoskeletal DCS before they return to diving.[6] In a meta-analysis of MRI studies, results suggest that repeated hyperbaric exposure increases the **prevalence of white matter injury** in experienced healthy divers without neurological decompression illness (OR 2.654,	that there are indications that recreational divers with asthma may be at increased risk for diving-related injuries compared to non-asthmatic divers. However, limited high quality evidence was available.[15] **Diabetes** Divers with diabetes mellitus may be at greater risk of (a) death due to chronic cardiac disease and (b) unexplained loss of consciousness.[13] **Right-to-left shunt** In a 2009 meta-analysis, the combined odds ratio of neurological decompression sickness in divers with right-to-left shunt (RLS) was 4.23 (3.05-5.87). The systematic screening of RLS in recreational divers seems unnecessary. In professional divers, because of a chronic exposition and unknown consequences of cerebral asymptomatic lesions, screening is appropriate.[16] **Spinal Stenosis** Divers with cervical and thoracic spinal canal stenosis, mainly due to disk degeneration, are at increased risk for the occurrence of spinal cord decompression sickness.[17] **Training/Experience factors** Fatal arterial gas embolism was associated with divers in their first year of certification.[13] The relative	intervention.[27] **Pre-dive Checklist** Compared with a control group, use of a pre-dive checklist decreased the incidence of major mishaps in the intervention group by 36%, minor mishaps by 26% and all mishaps by 32%. On average, there was one fewer mishap in every 25 intervention dives amongst 1,043 **experienced divers** during 2,041 dives.[28] **Pre-conditioning methods** Experimental evidence suggests that, for a population of **trained and military divers**, endurance exercise (even in a warm environment) associated with oral hydration prior to the dive is beneficial in vascular bubble reduction. These methods have not been tested in the form of a randomized controlled trial.[29]		

95% CI 1.718 to 4.102).[7] **Orofacial Injury** An investigation of **orofacial barotrauma symptoms** in 163 Saudi divers reported a prevalence 51.9% for dry mouth, 32.5% for clenching and 19.5% for temperomandibular pain during a dive. The most frequent symptoms after a dive were dry mouth (22.7%) followed by clenching and facial pain (16.9%).[8] In a survey of 100 certified recreational divers, 41% percent of the respondents experienced **dental symptoms** during a dive. Barodontalgia was the most frequently experienced dental symptom during a dive.[9] **Lower back pain** Lifetime and 1-year prevalence of LBP among 181 recreational Flemish scuba divers were 55.8% and 50.3%, respectively.[10]	risk for non-certified divers reporting diving injury vs. certified divers is 1.31 (95% CI 1.16-1.48).[18] However, risk of lower pack pain in divers is associated with a higher dive certificate (p=0.007).[10] Greatest risk of fatal arterial gas embolism occurred on the first dive of the day. A study in Belgium found 100–400 times increased risk of pulmonary barotrauma during training dives. Emergency free-ascent training is associated with 500-1,500 times greater risk of pulmonary barotrauma.[13] **Exercise after diving** Exertive exercise following a dive increases the risk of arterialization from 13% at rest to 52%.[19] Evidence suggests arterialization likely increases relative risk of neurological DCS.[20] **Flying after diving** For a single no-decompression dive, one should wait at least 12 hours before flying; for multiple dives per day or multiple days of diving, 18 hours is suggested, and for any decompression dives, substantially longer than 18 hours appears prudent to reduce risk of DCS.[21] **Equipment factors** Arterial gas embolism and asphyxia are associated with buoyancy trouble, equipment trouble, gas			

	supply trouble and ascent time/trouble.[12] Biting on the mouthpiece (OR=1.598), clenching (OR=2.466) and the quality rating of the mouthpiece (OR=0.887) are risk factors for presence of temperomandibular pain in divers.[22] Scuba divers with *lower back pain* use significantly more weights on their weight belts during indoor training (p=0.003) and during outdoor dives with a dry suit (p=0.044) as compared to asymptomatic scuba.[10] **Protective Factors** **Repetitive diving** Completion of identical daily dives resulted in progressively decreasing odds of having relatively higher grade bubbles on consecutive days. The odds on Day 4 were half that of Day 1 (OR 0.50, 95% CI: 0.34, 0.73).[23] **Exercise before diving** A single bout of exercise 2 h before diving reduces microparticle counts and some indicators of platelet and neutrophil activation which are correlated with DCS in mice. The effect was observed following both aerobic interval training and anaerobic cycling.[20,24,25]			

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Review of Sport Injury Burden, Risk Factors and Prevention

Scuba-Diving

Incidence and Prevalence

Scuba diving, an activity that involves the use of a self-contained underwater breathing apparatus (scuba) to breathe underwater, may be done recreationally or professionally in a number of applications. Injuries that occur while scuba diving are typically due to changes in pressure during ascent from deeper water.

Incidence and/or prevalence data is often limited by a lack of injury reporting in recreational diving and is mainly dependent on reports from registered divers from the Divers Alert Network (DAN). In a review of the epidemiology of injury in all recreational divers, the prevalence of incidents ranged from 7 to 35 injuries per 10,000 divers and from 5 to 152 injuries per 100,000 dives (P. L. Buzzacott, 2012). In a cross-sectional survey of registered members of the Divers Alert Network in 2010-2011, the overall rate of diving-related injury was much higher; 3.02 per 100 dives (Ranapurwala, Bird, Vaithiyanathan, & Denoble, 2014).

Recreational scuba diving fatalities account for 0.013% of all-cause mortality in people ages 15 years and older (Ranapurwala et al., 2014). The Divers Alert Network identified 188 fatalities worldwide in 2014; sixty of these fatalities took place in North America (50 in USA, 4 in Canada and 6 in Mexico) (Peter L. Buzzacott, 2016). Variations in fatality rates reported between and within countries are likely due to differences in diving conditions and practices between areas, data reliability and differences in diver characteristics. The mean annual fatality rate (AFR) for insured members of the Divers Alert Network in the USA was 16.7 deaths per 100,000 divers with 95% CI 14.2-19.0 over the period 2000-2006 (1 death in 6,000 per annum) (P J Denoble et al., 2008). Similarly, British Sub-Aqua Club membership and fatality data indicate an AFR of 14.4 (95% CI 10.5-19.7) per 100,000 members over the same period and, more recently, a fatality rate of 18.3 per 100,000 members for the year 2016 (Cumming & Watson, 2016). Annual scuba diving fatality rates in Australia are reported at 0.48 (0.37-0.59) deaths per 100,000 dives, or 8.73 (6.85-10.96) deaths per 100,000 divers for Australian residents; 0.12 (0.05-0.25) deaths per 100,000 dives, or 0.46 (0.20-0.91) deaths per 100,000 divers for international visitors to Queensland; and 1.64 (0.20-5.93) deaths per 100,000 dives for the dive operator in Victoria (John Lippmann, Stevenson, McD Taylor, & Williams, 2016). Comparable to Victoria, measured data from British Columbia, Canada in 2000 indicated an AFR of 2.05 (95% CI 0.0 to 6.0) per 100,000 dives (Ladd, Stepan, & Stevens, 2002). More recent data on fatality rates related to number of divers or dives has not been published.

Decompression Sickness (DCS) is the most common diving-related injury; however, the type of complications reported, vary across cases. Incidence of self-reported DCS symptoms was 1.55 per 1,000 dives and treated DCS was 5.72 per 100,000 dives amongst Divers Alert Network members (P J Denoble et al., 2008). Rate of occurrence (per dive) of DCS for recreational divers in the USA is estimated at 0.017 to 0.2% (Godden et al., 2003). Following

DCS, the prevalence of dysbaric osteonecrosis (a form of avascular necrosis - death of a portion of the bone, thought to be caused blockage of the blood vessels from diving) in hyperbaric centres in Southern France was 19%, suggesting MRI for routine screening is justified in recreational divers treated for musculoskeletal DCS before they return to diving (Emmanuel Gempp, Blatteau, Simon, & Stephant, 2009). In a meta-analysis of MRI studies, results suggest that repeated hyperbaric exposure increases the prevalence of white matter injury in experienced healthy divers without neurological decompression illness [Odds Ratio (OR)=2.65, 95% CI 1.72 to 4.10] (Connolly & Lee, 2015).

Orofacial injuries are also common in scuba diving. An investigation of orofacial barotrauma symptoms in 163 Saudi divers reported a prevalence of 51.9% for dry mouth, 32.5% for clenching and 19.5% for temperomandibular pain during a dive. The most frequent symptoms after a dive were dry mouth (22.7%) followed by clenching and facial pain (16.9%) (Yousef, Ibrahim, Assiri, & Hakeem, 2015). In a survey of 100 certified recreational divers, 41% of the respondents experienced dental symptoms during a dive. Barodontalgia (tooth pain caused by a change in ambient temperature) was the most frequently experienced dental symptom during a dive (Ranna, Malmstrom, Yunker, Feng, & Gajendra, 2016).

Decompression injuries aside, musculoskeletal injuries are also prevalent in scuba diving. The lifetime and 1-year prevalence of lower back pain among 181 recreational Flemish scuba divers was reported at 55.8% and 50.3%, respectively (Knaepen, Cumps, Zinzen, & Meeusen, 2009).

Risk and Protective Factors

Many risk factors for scuba diving injury have been reported, including non-modifiable factors such as age, sex, asthma, diabetes, right-to-left shunt and spinal stenosis. Modifiable risk factors for scuba injury include body mass index (BMI), training/experience factors, exercise after diving, flying after diving and equipment factors.

Non-modifiable Risk Factors

As divers age, there is an increased risk for decompression illness and diving fatality (J. E. Blatteau et al., 2011; Petar J Denoble, Marroni, & Vann, 2008; J. Lippmann, Baddeley, Vann, & Walker, 2013; Smerz, 2006). Increased relative risks (RR) between older (>49 years) and younger divers are found for arterial gas embolism (RR=3.9), asphyxia (RR=2.5) and disabling cardiac injury (RR=12.9) (Petar J Denoble et al., 2008). Greater age (>42 years) is also a prognostic factor for incomplete recovery from severe decompression illness (J. E. Blatteau et al., 2011; Smerz, 2006). The annual fatality rate for males is greater than for females by 10 per 100,000 divers up to age 65 years, after which the rates are essentially the same for both sexes. The relative risk between males and females decreases from 6 at age 25 years to 1 at age 65 years (Petar J Denoble et al., 2008).

The presence of underlying conditions also places scuba divers at increased risk for injury. A systematic review in 2016 reported that recreational divers with asthma may be at increased risk for diving-related injuries compared to non-asthmatic divers; however, there is limited high quality evidence available to support this (Ustrup & Ulrik, 2017). Divers with diabetes mellitus may be at greater risk of death due to chronic cardiac disease and unexplained loss of consciousness (Petar J Denoble et al., 2008). In a 2009 meta-analysis, the combined odds ratio of neurological decompression sickness in divers with right-to-left shunt (RLS) was 4.23 (95% CI 3.05 to 5.87) (Lairez et al., 2009). In addition, divers with cervical and thoracic spinal canal stenosis, mainly due to disk degeneration, are at increased risk for the occurrence of spinal cord decompression sickness (E Gempp et al., 2014).

<u>Modifiable Risk Factors</u>

With regards to body composition, an increased body fat leads to increased nitrogen storage and hence possible excessive nitrogen bubble formation and increased risk of development of DCS (Mouret, 2006). The odds of surviving arterial gas embolism are greater for divers with a normal BMI, compared to those with higher BMIs (Petar J Denoble et al., 2008). Those 25% or more overweight have been estimated to have a tenfold increased risk of developing DCS (Mouret, 2006).

Training and experience are important modifiable risk factors for scuba diving injury. Divers in their first year of certification, particularly divers on their first dive, are at increased risk of injury (Denoble et al., 2008; Beckett & Kordick, 2007).

In a study by Beckett & Kordick (2007), the reported relative risk for diving injury in non-certified divers was 1.31 (95% CI 1.16 to 1.48), compared to certified divers. Two studies reported increases in injury in new divers from ascent training; a study in Belgium found 100–400 times increased risk of pulmonary barotrauma during training dives, and in Denoble et al. (2008), the risk of pulmonary barotrauma associated with ascent training, increased by 500-1,500 times (Petar J Denoble et al., 2008). There was one study that demonstrated that the risk of lower back pain was higher in divers with a higher dive certificate (i.e., divers with greater diver training) (p=0.007) (Knaepen et al., 2009).

Exertive exercise following a dive increases the risk of arterialization from 13% at rest to 52% (Madden, Lozo, Dujic, & Ljubkovic, 2013). Evidence suggests arterialization likely increases the relative risk of neurological DCS (Madden, Thom, & Dujic, 2016). Additionally, for a single no-decompression dive, divers should wait at least 12 hours before flying; for multiple dives per day or multiple days of diving, 18 hours is suggested, and for any decompression dives, substantially longer than 18 hours appears prudent to reduce risk of DCS (Sheffield & Vann, 2004).

Equipment factors also play a role in risk of injury. Arterial gas embolism and asphyxia are associated with buoyancy trouble, equipment trouble, gas supply trouble and ascent time/trouble (J. Lippmann et al., 2013). Biting on the mouthpiece (OR=1.60), clenching

(OR=2.47) and the quality rating of the mouthpiece (OR=0.89) are risk factors for presence of temperomandibular pain in divers (Lobbezoo et al., 2014). Scuba divers with lower back pain have reported to use significantly more weights on their weight belts during indoor training (p=0.003) and during outdoor dives with a dry suit (p=0.044) as compared to asymptomatic scuba divers (Knaepen et al., 2009).

Some evidence of protective factors for scuba diving injury has been reported in the injury prevention literature. A decrease in post-dive circulating venous gas emboli (VGE or bubbles) represents successful acclimatization. Zanchi et al., (2016) found that the completion of identical daily dives results in progressively decreasing odds of having DCS (measured by higher-grade VGE) on consecutive days. The odds of having higher grade VGE on a Day 4 dive were half that of a Day 1 dive (OR=0.50, 95% CI: 0.34 to 0.73) (Zanchi et al., 2014). This indicates that certain adaptations take place after more dives. There is also evidence that an exercise bout prior to a dive has protective effects. A single bout of exercise 2 hours before diving reduces microparticle counts and some indicators of platelet and neutrophil activation, which are correlated with DCS in mice. The effect was observed following both aerobic interval training and anaerobic cycling (Madden, Thom, Milovanova, et al., 2014; Madden, Thom, Yang, et al., 2014; Madden et al., 2016).

Opportunities for Prevention: Effective Interventions, Cost-Effectiveness, Implementation and Evaluation

Historically, preventing DCS has been based on slow ascent and increasing the duration of decompression stops. This has dramatically reduced the incidence and severity of DCS in developed countries in the twentieth century (Boycott, Damant, & Haldane, 1908). Other effective interventions include education, use of a pre-dive checklist and use of pre-conditioning methods.

Although not tested in recreational divers, education or ascent training is an important component of injury prevention. After educating fisherman divers in Vietnam on in-water recompression techniques, the incidence of severe DCS decreased by 75% in 3 years; from 8 per 1000 divers before 2009 to 2 per 1000 divers after the intervention (J.-E. Blatteau et al., 2016).

Compared with a control group, use of a pre-dive checklist decreased the incidence of major mishaps in the intervention group by 36%, minor mishaps by 26% and all mishaps by 32%. On average, there was one fewer mishap in every 25 intervention dives amongst 1,043 experienced divers during 2,041 dives (Ranapurwala et al., 2016).

Experimental evidence suggests that for a population of trained and military divers, endurance exercise (even in a warm environment) associated with oral hydration prior to the dive is beneficial in vascular bubble reduction. These methods; however, have not been tested in the form of a randomized controlled trial (Emmanuel Gempp & Blatteau, 2010). Clinical data to support additional intervention measures on DCS development are lacking due in part to the great inter/intra-variability between individuals regarding susceptibility to DCS.

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