

Risk Factors for Decompression Illness



Every diver intuitively understands that the depth, duration and ascent protocol of a dive are perhaps the most important determinants of the risk of decompression illness (DCI). In general, we assume that the longer and deeper the dive, the more nitrogen is absorbed, and the greater the risk; especially if the longer duration and deeper depth are not compensated for with a suitable ascent (decompression) protocol.

On top of this, there is a group of widely cited “factors” which are considered to increase risk, either by increasing the likelihood of nitrogen bubble formation, or by predisposing to the adverse effects of any bubbles that do form. The fact that such factors exist is suggested by studies which have used Doppler ultrasound to detect markedly variable numbers of venous bubbles after identical depth / time exposures, and studies which show that symptoms may occur even when relatively few bubbles are detected. Problem is, we really don’t know for sure what these factors are.

There are a number of ideas. For example, we all know that divers should lose weight, do the deepest dive first, and be more conservative if they are female in order to reduce risk. Right?? Well, maybe. Unfortunately, some of these “sacred cows” are rich in assumption and poor in supportive science. Indeed, in some cases, divers have been deceived into decades of bizarre practice on the basis of someone’s opinion alone.

Perhaps the biggest problem we face in assessing the significance of a “risk factor” is a lack of demographic data describing the diving habits of the recreational diving population. For example, we can look up treatment statistics that might tell us that 65% of all divers treated for DCI were repetitive diving. However, this figure of itself tells us nothing about the significance of repetitive diving as a risk factor for DCI. If 65% of all dives performed were repetitive dives, then, all other factors being equal, we would expect that 65% of DCI cases would come from repetitive dives. However, if only 40% of all dives were repetitive dives, but these dives produced 65% of our DCI cases, then we might begin to suspect that repetitive diving was a risk factor for DCI. Unfortunately, we usually do not have that critical denominator (the data that describe the activity of the general diving population) because there is no easy way of obtaining it.

With that in mind, this article reviews many of the so-called risk factors for DCI, and point out which are truly supported by sound science, and which should be treated with skepticism; and perhaps even ignored. The “risk factors” are most usefully divided into 3 categories: those relevant to the diver; those relevant to the dive; and those relevant to the post-dive period.

*Part 3 of a 3-part article by
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THE DIVER

Body fat

It has been suggested that since nitrogen is more soluble in fatty (lipid) than watery (aqueous) tissues, a greater percentage body fat results in greater nitrogen loading, more bubble formation, and higher risk of DCI. This sounds plausible, and some old studies of compressed air workers are supportive of the notion. But two more recent studies have failed to show a relationship between body fat or body mass index and DCI. It is probably fair to call this one “controversial” and conclude that divers are better off with a normal body mass index. But purging dive clubs or even the ranks of commercial divers of fatties on the basis of the available evidence is not justified.

Age

Advancing age may increase the risk of DCI, perhaps because of a general decline in physical fitness and ability to compensate for damage, or the presence of other possible risk factors such as previous DCI and higher percentage body fat. Several studies appear to confirm increased risk in older subjects and a recent study showed a positive correlation between advancing age and numbers of venous bubbles after decompression. Although one study in the late 1980s found that increasing age of itself was not a significant risk, it must be concluded that the weight of evidence supports age as a risk factor. Not surprisingly, no clear threshold age at which risk increases has been identified.

Previous DCI

Previous DCI may predispose to another episode by reducing the body’s ability to compensate for any subsequent bubble formation, or some unknown mechanism. This theory is supported by caisson work data, and there are limited supportive data from contemporary diving. Divers previously treated for DCI do appear over-represented in the Diver’s Alert Network database of divers treated for DCI. However, these divers may just dive more than everyone else, or they may repeatedly indulge in risk-taking behaviour. In general, we consider the risk of another episode after *successful treatment of mild DCI* to be only trivially greater than baseline. However, if recovery from either mild or more serious DCI is incomplete, then the risk of another episode is considered to be unacceptably high and cessation of diving is usually recommended.

Being female

For many years it has been proposed that women might be at higher risk of DCI than men. This notion has been based on a variety of hypotheses. Most popular has been the concept that their higher mean body fat percentage might put them at risk (see above). It has also been suggested that hormonal changes during menstruation can result in fluid retention (oedema) and fluid shifts, and that some oral contraceptive pills can cause a microsludging or slowing of the circulation. All these factors theoretically suggest that women might be more prone to DCI than

men. Results of surveys comparing the relative rates of DCI between men and women have been inconclusive, and the results of actual experiments comparing the risk of DCI between the sexes have often been contradictory. There has been some interesting recent work, as yet unpublished, that supports the notion that the risk of DCI for women may change in different phases of the menstrual cycle. However, there is no conclusive answer on the question of how their risk compares to men. Most diving physicians agree that if there is a difference, it is likely to be trivial.

Dehydration

Pre-dive dehydration may exacerbate DCI because blood will tend to be “thicker” and flow less easily through any small blood vessels damaged by bubbles. Despite the conviction with which this theory is taught, there are no supportive data from actual diving, and the two best animal studies drew opposite conclusions. Nevertheless, in view of the strong theoretical basis for this risk factor and the known potentiation of dehydration during immersion, it is probably appropriate to encourage divers to actively maintain good hydration. Since alcohol has a diuretic effect, concerns over dehydration constitute reason enough to advise against moderate to heavy use of alcohol on an evening prior to diving.

Physical fitness

There is an intriguing and growing body of recent evidence that animals subjected to exercise conditioning regimens over days prior to diving are substantially more resistant to decompression illness than unconditioned animals. Even more intriguing is the finding that a single episode of heavy exercise about a day prior to diving appears to reduce bubble formation (in humans) and decompression illness (in animals). The mechanism responsible for this protection is not established, and nor is the relevance of these data to human divers completely clear. Nevertheless, it will be an interesting area of research to watch. In the meantime, remaining physically fit for diving makes sufficient intuitive sense to warrant it being a goal for all divers.

Fatty food

It has long been suggested that the high concentration of lipo-protein complexes in the blood after a fatty meal may be disadvantageous in diving because interactions between bubbles and these complexes might result in the release of insoluble fatty emboli. All that can be said is that this mechanism is of highly uncertain relevance in human DCI.

Patent foramen ovale

For completeness, it must be mentioned that there are compelling human data suggesting that a patent foramen ovale (PFO) is a risk factor for serious neurological DCI. This communication between the two upper chambers of the heart (the atria) was discussed in the earlier two articles of this series.

THE DIVE

Repetitive diving and multi-day diving

Repetitive recreational dives, multiple ascents to the surface within a single “dive”, and multi-day diving are considered to increase risk of DCI. The suggested basis for increased risk in closely spaced sequential dives is bubble formation from dissolved inert gas after the first ascent to the surface. During any subsequent dive, these bubbles may affect inert gas kinetics (thus making the diver’s tables or computers less accurate) and may act as seeds for larger bubbles. In addition, it has been demonstrated in animals that venous bubbles trapped in lung capillaries after diving will redistribute into the arterial circulation during another dive if the surface interval is short. This sounds disadvantageous, but it is of unknown relevance in human DCI.

These concerns warrant attention to conservatism during repetitive and multi-day programs of diving, but they do not mandate avoidance of repetitive or multi-day diving. Indeed,

once daily dives on sequential days have repeatedly been shown to progressively *lower* the risk of DCI as the sequence proceeds; a phenomenon referred to “acclimatization”. The mechanism is uncertain but it may relate to consumption of gaseous micronuclei by bubble formation on each single daily dive, but with sufficient time for most bubbles to decay and disappear before the next dive, thus leaving less nuclei available for bubble initiation. The protective effect seems to disappear after about 5 days without diving, and this is interpreted as the time it takes for micronuclei to be replaced.

Interestingly, this phenomenon has not been recorded in recreational divers. This may be because recreational multi-day diving frequently involves multiple dives on each day of the multi-day program. This may not allow sufficient time for bubbles to resolve prior to the next day’s first dive. Just to complicate matters further, recent unpublished studies from the DCIEM in Canada suggest that closely spaced repetitive dives may

actually be a good thing because the subsequent dive resolves bubbling from the previous one before the process reaches a peak. Not surprisingly however, their work suggests that the final decompression the day is the one that needs to be particularly conservative because that is when the day’s “sins” will catch up with you.



Deep diving

There is some reasonable data from carefully controlled military operations that suggests deeper dives are associated with more risk. U.S. Navy experience, between 1968 and 1981 was that the accident rate for dives of 15m (50ft) or less was 0.06%. The accident rate for dives to between 15.5-30m (51-100 ft) was 0.23%, nearly four times the rate for shallow dives. The accident rate for dives between 30-61 m (101-200 ft) was 0.54%, more than double the 15.5-30m rate and nine times the rate for shallower dives. This is probably also true for recreational diving.

Reverse profile diving

The performance of several dives in shallow to deep sequence, commonly referred to as “reverse profile” diving, is a particular form of repetitive diving that has been considered to increase the risk of DCI. This is perhaps the classical (almost) baseless sacred cow. When the distinguished participants at a recent conference on the issue searched the literature to find the basis for the rule, guess what; they found nothing. It was someone’s

good idea that has become both enshrined in dive training dogma, and adhered to with almost religious fervour. The conference concluded there was no need for such a rule *provided: the dives are conducted without the need for decompression stops, the dives are within the recreational diving depth range (0 – 40m); and the reverse profile gradient does not exceed 12 metres..*

Heavy exercise

Exercise during diving accelerates absorption of inert gas in those tissues whose perfusion is increased during work. Not surprisingly, moderate to heavy exercise during a dive has been clearly shown to increase decompression requirements and the risk of DCI in both animals and humans. This is one of the few unequivocal risk factors. Interestingly, blood flow to the legs and inert gas elimination is enhanced, and the risk of DCI reduced, if *mild* exercise is performed during decompression.

Cold

Exposure to cold is often cited as a risk factor for DCI. There is human

data to support this contention, and the explanation is not so much the cold per se, but the change in the diver’s temperature during the dive. If uptake of nitrogen occurs while the diver is warm and blood flow to the peripheries is good, and elimination occurs while the diver is cool and peripheral blood flow has reduced, then nitrogen elimination will be slower (than uptake) and the risk of DCI increased. Thus, divers are best advised to keep their temperature as stable as possible through the dive. In cold water, this is best achieved by wearing a dry suit.

POST-DIVE

Exercise

Human data suggest that exercise after diving may hasten onset, and increase both severity and incidence of DCI. The mechanism is not certain but may involve the generation of momentary areas of depressurisation in working tissues, thus promoting bubble formation. Some forms of exercise, particularly lifting heavy weights have a tendency to raise right heart pressures and may

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promote the passage of venous blood (and any bubbles) across a latent patent ovale.

Rewarming

As has been mentioned previously, the solubility of dissolved nitrogen falls as the temperature of a tissue rises. The main implication of this is that if rewarming of cold peripheral tissues is conducted too quickly (for example, by jumping straight into a hot shower), then it may precipitate bubble formation and DCI. There are at least several published case reports of DCI arising under such circumstances.

Altitude exposure

Ascent to altitude following diving favours nitrogen bubble formation and growth, and is an undisputed precipitant for DCI. Ascent to as little as 300m soon after diving has precipitated DCI in sport divers leaving dive sites by road. However, the most troublesome altitude issue is the prescription of a safe interval between diving and flying in passenger aircraft, most of which are pressurised to the equivalent of approximately 2400m altitude. Limited human data suggest that a 12 hour delay is sufficient following a single no-decompression dive, and a longer but undetermined period is required after multiple dives. Unfortunately, no pragmatic recommendation will prevent all cases. Unequivocal DCI has occurred in sport divers with no pre-flight symptoms, who delayed flying more than 48 hours after diving.

We can see from the above that some of the so-called risk factors for DCI (such as heavy underwater work) are undisputed and should be carefully considered in our diving planning strategies. Others (such as dehydration) are less well established, but given the uncertainty we should probably assume they are significant and act accordingly. Finally, one or two (such as *conservative* reverse profile dives) have been discredited. *Not everything is always as it seems.*

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