Decompression practice

The practice of decompression by divers comprises the planning and monitoring of the profile indicated by the algorithms or tables of the chosen decompression model , to allow asymptomatic and harmless release of excess inert gases dissolved in the tissues as a result of breathing at ambient pressures greater than surface atmospheric pressure , the equipment available and appropriate to the circumstances of the dive , and the procedures authorized for the equipment and profile to be used . There is a large range of options in all of these aspects .

Decompression may be continuous or staged , where the ascent is interrupted by stops at regular depth intervals , but the entire ascent is part of the decompression , and ascent rate can be critical to harmless elimination of inert gas . What is commonly known as no @-@ decompression diving , or more accurately no @-@ stop decompression , relies on limiting ascent rate for avoidance of excessive bubble formation . Staged decompression may include deep stops depending on the theoretical model used for calculating the ascent schedule . Omission of decompression theoretically required for a dive profile exposes the diver to significantly higher risk of symptomatic decompression sickness , and in severe cases , serious injury or death . The risk is related to the severity of exposure and the level of supersaturation of tissues in the diver . Procedures for emergency management of omitted decompression and symptomatic decompression sickness have been published . These procedures are generally effective , but vary in effectiveness from case to case .

The procedures used for decompression depend on the mode of diving , the available equipment , the site and environment , and the actual dive profile . Standardized procedures have been developed which provide an acceptable level of risk in the circumstances for which they are appropriate . Different sets of procedures are used by commercial , military , scientific and recreational divers , though there is considerable overlap where similar equipment is used , and some concepts are common to all decompression procedures .

Decompression

Decompression in the context of diving derives from the reduction in ambient pressure experienced by the diver during the ascent at the end of a dive or hyperbaric exposure and refers to both the reduction in pressure and the process of allowing dissolved inert gases to be eliminated from the tissues during this reduction in pressure . When a diver descends in the water column the ambient pressure rises . Breathing gas is supplied at the same pressure as the surrounding water , and some of this gas dissolves into the diver 's blood and other fluids . Inert gas continues to be taken up until the gas dissolved in the diver is in a state of equilibrium with the breathing gas in the diver 's lungs , (see : " Saturation diving ") , or the diver moves up in the water column and reduces the ambient pressure of the breathing gas until the inert gases dissolved in the tissues are at a higher concentration than the equilibrium state , and start diffusing out again . Dissolved inert gases such as nitrogen or helium can form bubbles in the blood and tissues of the diver if the partial pressures of the dissolved gases in the diver gets too high above the ambient pressure . These bubbles and products of injury caused by the bubbles can cause damage to tissues known as decompression sickness , or " the bends " . The immediate goal of controlled decompression is to avoid development of symptoms of bubble formation in the tissues of the diver , and the long @-@ term goal is to also avoid complications due to sub @-@ clinical decompression injury .

Common procedures

The descent , bottom time and ascent are sectors common to all dives and hyperbaric exposures .

Descent rate

Descent rate is generally allowed for in decompression planning by assuming a maximum descent rate specified in the instructions for the use of the tables , but it is not critical . Descent slower than the nominal rate reduces useful bottom time , but has no other adverse effect . Descent faster than the specified maximum will expose the diver to greater ingassing rate earlier in the dive , and the bottom time must be reduced accordingly . In the case of real time monitoring by dive computer , descent rate is not specified , as the consequences are automatically accounted for by the programmed algorithm .

= = = Bottom time = = =

Bottom time is the time spent at depth before starting the ascent . Bottom time used for decompression planning may be defined differently depending on the tables or algorithm used . It may include descent time , but not in all cases . It is important to check how bottom time is defined for the tables before they are used . For example , tables using Bühlmann 's algorithm define bottom time as the elapsed time between leaving the surface and the start of the final ascent at 10 metres per minute , and if the ascent rate is slower , then the whole of the ascent time needs to be considered part of the bottom time for the algorithm to remain safe .

= = = Ascent rate = = =

The ascent is an important part of the process of decompression , as this is the time when reduction of ambient pressure occurs , and it is of critical importance to safe decompression that the ascent rate is compatible with safe elimination of inert gas from the diver 's tissues . Ascent rate must be limited to prevent supersaturation of tissues to the extent that unacceptable bubble development occurs . This is usually done by specifying a maximum ascent rate compatible with the decompression model chosen . This will be specified in the decompression tables or the user manual for the decompression software or personal decompression computer . The instructions will usually include contingency procedures for deviation from the specified rate , both for delays and exceeding the recommended rate . Failure to comply with these specifications will generally increase the risk of decompression sickness .
Typically maximum ascent rates are in the order of 10 metres (33 ft) per minute for dives deeper than 6 metres (20 ft) . Some dive computers have variable maximum ascent rates , depending on depth . Ascent rates slower than the recommended standard for the algorithm will generally be treated by a computer as part of a multilevel dive profile and the decompression requirement adjusted accordingly . Faster ascent rates will elicit a warning and additional decompression stop time to compensate .

= = No decompression dives = =

A " no decompression " , or " no stop " dive is a dive that needs no decompression stops during the ascent according to the chosen algorithm or tables , and relies on a controlled ascent rate for the elimination of excess inert gases . In effect , the diver is doing continuous decompression during the ascent .

= = = Safety stop = = =

As a precaution against any unnoticed dive computer malfunction , diver error or physiological predisposition to decompression sickness , many divers do an extra " safety stop " in addition to those prescribed by their dive computer or tables . A safety stop is typically 1 to 5 minutes at 3 to 6 metres (10 to 20 ft) . They are usually done during no @-@ stop dives and may be added to the obligatory decompression on staged dives . Many dive computers indicate a recommended safety stop as standard procedure for dives beyond specific limits of depth and time . The Goldman decompression model predicts a significant risk reduction following a safety stop on a low @-@ risk dive

No decompression limit

The no decompression limit (NDL) or no stop time , is the interval that a diver may theoretically spend at a given depth without having to perform decompression stops . The NDL helps divers plan dives so that they can stay at a given depth and ascend without stopping while avoiding unacceptable risk of decompression sickness .

The NDL is a theoretical time obtained by calculating inert gas uptake and release in the body , using a model such as the Bühlmann decompression algorithm . Although the science of calculating these limits has been refined over the last century , there is still much that is unknown about how inert gases enter and leave the human body . In addition , every individual 's body is unique and may absorb and release inert gases at different rates . For this reason , dive tables typically have a degree of safety built into their recommendations . Divers can and do suffer decompression sickness while remaining inside NDLs , though the incidence is very low . Each NDL for a range of depths is printed on dive tables in a grid that can be used to plan dives . There are many different tables available as well as software programs and calculators , which will calculate no decompression limits . Most personal decompression computers (dive computers) will indicate a remaining no decompression limit at the current depth during a dive . The displayed interval is continuously revised to take into account changes of depth as well as elapsed time .

Continuous decompression

Continuous decompression is decompression without stops . Instead of a fairly rapid ascent rate to the first stop , followed by a period at static depth during the stop , the ascent is slower , but without officially stopping . In theory this is the optimum decompression profile . In practice this is very difficult to do manually , and it may be necessary to stop the ascent occasionally to get back on schedule , but these stops are not part of the schedule , they are corrections . For example , USN treatment table 5 , referring to treatment in a decompression chamber for type 1 decompression sickness , states " Descent rate - 20 ft / min . Ascent rate - Not to exceed 1 ft / min . Do not compensate for slower ascent rates . Compensate for faster rates by halting the ascent . "

To further complicate the practice , the ascent rate may vary with the depth , and is typically faster at greater depth and reduces as the depth gets shallower . In practice a continuous decompression profile may be approximated by ascent in steps as small as the chamber pressure gauge will resolve , and timed to follow the theoretical profile as closely as conveniently practicable . For example , USN treatment table 7 (which may be used if decompression sickness has reoccurred during initial treatment in the compression chamber) states " Decompress with stops every 2 feet for times shown in profile below . " The profile shows an ascent rate of 2 fsw every 40 min from 60 fsw (feet of sea water) to 40 fsw , followed by 2 ft every hour from 40 fsw to 20 fsw and 2 ft every two hours from 20 fsw to 4 fsw .

Staged decompression

Decompression which follows the procedure of relatively fast ascent interrupted by periods at constant depth is known as staged decompression . The ascent rate and the depth and duration of the stops are integral parts of the decompression process . The advantage of staged decompression is that it is far easier to monitor and control than continuous decompression .

Decompression stops

A decompression stop is a period a diver must spend at a relatively shallow constant depth during ascent after a dive to safely eliminate absorbed inert gases from the body tissues to avoid decompression sickness . The practice of making decompression stops is called staged decompression , as opposed to continuous decompression .

The diver identifies the requirement for decompression stops , and if they are needed , the depths and durations of the stops , by using decompression tables , software planning tools or a dive computer .
The ascent is made at the recommended rate until the diver reaches the depth of the first stop . The diver then maintains the specified stop depth for the specified period , before ascending to the next stop depth at the recommended rate , and follows the same procedure again . This is repeated until all required decompression has been completed and the diver reaches the surface .
Once on the surface the diver will continue to eliminate inert gas until the concentrations have returned to normal surface saturation , which can take several hours , and is considered in some models to be effectively complete after 12 hours , and by others to take up to , or even more than 24 hours .
The depth and duration of each stop is calculated to reduce the inert gas excess in the most critical tissues to a concentration which will allow further ascent without unacceptable risk . Consequently , if there is not much dissolved gas , the stops will be shorter and shallower than if there is a high concentration . The length of the stops is also strongly influenced by which tissue compartments are assessed as highly saturated . High concentrations in slow tissues will indicate longer stops than similar concentrations in fast tissues .
Shorter and shallower decompression dives may only need one single short shallow decompression stop , for example 5 minutes at 3 metres (10 ft) . Longer and deeper dives often need a series of decompression stops , each stop being longer but shallower than the previous stop .

= = = = Deep stops = = = =

A deep stop was originally an extra stop introduced by divers during ascent , at a greater depth than the deepest stop required by their computer algorithm or tables . This practice is based on empirical observations by technical divers such as Richard Pyle , who found that they were less fatigued if the made some additional stops for short periods at depths considerably deeper than those calculated with the currently published decompression algorithms . More recently computer algorithms that are claimed to use deep stops have become available , but these algorithms and the practice of deep stops have not been adequately validated . Deep stops are likely to be made at depths where ingassing continues for some slow tissues , so the addition of deep stops of any kind can only be included in the dive profile when the decompression schedule has been computed to include them , so that such ingassing of slower tissues can be taken into account . Nevertheless , deep stops may be added on a dive that relies on a personal dive computer with real @-@ time computation , as the PDC will track the effect of the stop on its decompression schedule . Deep stops are otherwise similar to any other staged decompression , but are unlikely to use a dedicated decompression gas , as they are usually not more than two to three minutes long .
A study by Divers Alert Network in 2004 suggests that addition of a deep (c . 15 m) as well as a shallow (c . 6 m) safety stop to a theoretically no @-@ stop ascent will significantly reduce decompression stress indicated by precordial doppler detected bubble (PDDB) levels . The authors associate this with gas exchange in fast tissues such as the spinal cord and consider that an additional deep safety stop may reduce the risk of spinal cord decompression sickness in recreational diving . A follow @-@ up study found that the optimum duration for the deep safety stop under the experimental conditions was 2 @.@ 5 minutes , with a shallow safety stop of 3 to 5 minutes . Longer safety stops at either depth did not further reduce PDDB .
In contrast , experimental work comparing the effect of deep stops observed a significant decrease in vascular bubbles following a deep stop after longer shallower dives , and an increase in bubble formation after the deep stop on shorter deeper dives , which is not predicted by the existing bubble model .
A controlled comparative study by the Navy Experimental Diving Unit in the NEDU Ocean Simulation Facility wet @-@ pot comparing the VVAL18 Thalmann Algorithm with a deep stop profile suggests that the deep stops schedule had a greater risk of DCS than the matched (same

total stop time) conventional schedule . The proposed explanation was that slower gas washout or continued gas uptake offset benefits of reduced bubble growth at deep stops .

= = = = Profile determined intermediate stops = = = =

PDISs are intermediate stops at a depth above the depth at which the leading compartment for the decompression calculation switches from ongassing to offgassing and below the depth of the first obligatory decompression stop , (or the surface , on a no @-@ decompression dive) . The ambient pressure at that depth is low enough to ensure that the tissues are mostly offgassing inert gas , although under a very small pressure gradient . This combination is expected to inhibit bubble growth . The leading compartment is generally not the fastest compartment except in very short dives , for which this model does not require an intermediate stop .

The 8 compartment Bühlmann - based UWATEC ZH @-@ L8 ADT MB PMG decompression model in the Mares Galileo dive computer processes the dive profile and suggests an intermediate 2 @-@ minute stop that is a function of the tissue nitrogen loading at that time , taking into account the accumulated nitrogen from previous dives . Within the Haldanian logic of the model , at least three compartments are offgassing at the prescribed depth - the 5 and 10 minute half time compartments under a relatively high pressure gradient . Therefore , for decompression dives , the existing obligation is not increased during the stop .

A PDIS is not a mandatory stop , nor is it considered a substitute for the more important shallow safety stop on a no @-@ stop dive . Switching breathing gas mix during the ascent will influence the depth of the stop .

The PDIS concept was introduced by Sergio Angelini .

= = = Decompression schedule = = =

A decompression schedule is a specified ascent rate and series of increasingly shallower decompression stops ? often for increasing amounts of time ? that a diver performs to outgas inert gases from their body during ascent to the surface to reduce the risk of decompression sickness . In a decompression dive , the decompression phase may make up a large part of the time spent underwater (in many cases it is longer than the actual time spent at depth) .

The depth and duration of each stop is dependent on many factors , primarily the profile of depth and time of the dive , but also the breathing gas mix , the interval since the previous dive and the altitude of the dive site . The diver obtains the depth and duration of each stop from a dive computer , decompression tables or dive planning computer software . A technical scuba diver will typically prepare more than one decompression schedule to plan for contingencies such as going deeper than planned or spending longer at depth than planned . Recreational divers often rely on a personal dive computer to allow them to avoid obligatory decompression , while allowing considerable flexibility of dive profile . A surface supplied diver will normally have a diving supervisor at the control point who monitors the dive profile and can adjust the schedule to suit any contingencies as they occur .

= = = Missed stops = = =

A diver missing a required decompression stop increases the risk of developing decompression sickness . The risk is related to the depth and duration of the missed stops . The usual causes for missing stops are : not having enough breathing gas to complete the stops , or accidentally losing control of buoyancy . An aim of most basic diver training is to prevent these two faults . There are also less predictable causes of missing decompression stops . Diving suit failure in cold water may force the diver to choose between hypothermia and decompression sickness . Diver injury or marine animal attack may also limit the duration of stops the diver is willing to carry out .

A procedure for dealing with omitted decompression stops is described in the US Navy Diving Manual . In principle the procedure allows a diver who is not yet presenting symptoms of decompression sickness , to go back down and complete the omitted decompression , with some extra added to deal with the bubbles which are assumed to have formed during the period where the decompression ceiling was violated . Divers who become symptomatic before they can be returned to depth are treated for decompression sickness , and do not attempt the omitted decompression procedure as the risk is considered unacceptable under normal operational circumstances .

If a decompression chamber is available , omitted decompression may be managed by chamber recompression to an appropriate pressure , and decompression following either a surface decompression schedule or a treatment table . If the diver develops symptoms in the chamber , treatment can be started without further delay .

= = Accelerated decompression = =

Decompression can be accelerated by the use of breathing gases during ascent with lowered inert gas fractions (as a result of increased oxygen fraction) . This will result in a greater diffusion gradient for a given ambient pressure , and consequently accelerated decompression for a relatively low risk of bubble formation . Nitrox mixtures and oxygen are the most commonly used gases for this purpose , but oxygen rich trimix blends can also be used after a trimix dive , and oxygen rich heliox blends after a heliox dive , and these may reduce risk of isobaric counterdiffusion complications . Doolette and Mitchell showed that when a switch is made to a gas with a different proportion of inert gas components , it is possible for an inert component previously absent , or present as a lower fraction , to in @-@ gas faster than the other inert components are eliminated (inert gas counterdiffusion) , sometimes resulting in raising the total tissue tension of inert gases in a tissue to exceed the ambient pressure sufficiently to cause bubble formation , even if the ambient pressure has not been reduced at the time of the gas switch . They conclude that " breathing @-@ gas switches should be scheduled deep or shallow to avoid the period of maximum supersaturation resulting from decompression " .

= = = Oxygen decompression = = =

The use of pure oxygen for accelerated decompression is limited by oxygen toxicity . In open circuit scuba the upper limit for oxygen partial pressure is generally accepted as 1 @.@ 6 bar , equivalent to a depth of 6 msw (metres of sea water) , but in @-@ water and surface decompression at higher partial pressures is routinely used in surface supplied diving operation , both by the military and civilian contractors , as the consequences of CNS oxygen toxicity are considerably reduced when the diver has a secure breathing gas supply . US Navy tables (Revision 6) start in @-@ water oxygen decompression at 30 fsw (9 msw) , equivalent to a partial pressure of 1 @.@ 9 bar , and chamber oxygen decompression at 50 fsw (15 msw) , equivalent to 2 @.@ 5 bar .

= = Repetitive dives = =

Any dive which is started while the tissues retain residual inert gas in excess of the surface equilibrium condition is considered a repetitive dive . This means that the decompression required for the dive is influenced by the divers decompression history . Allowance must be made for inert gas preloading of the tissues which will result in them containing more dissolved gas than would have been the case if the diver had fully equilibrated before the dive . The diver will need to decompress longer to eliminate this increased gas loading .

= = = Surface interval = = =

The surface interval (SI) or surface interval time (SIT) is the time spent by a diver at surface pressure after a dive during which inert gas which was still present at the end of the dive is further eliminated from the tissues . This continues until the tissues are at equilibrium with the surface pressures . This may take several hours . In the case of the US Navy 1956 Air tables , it is considered complete after 12 hours , The US Navy 2008 Air tables specify up to 16 hours for normal exposure. but other algorithms may require more than 24 hours to assume full equilibrium .

= = = Residual nitrogen time = = =

For the planned depth of the repetitive dive , a bottom time can be calculated using the relevant algorithm which will provide an equivalent gas loading to the residual gas after the surface interval . This is called " residual nitrogen time " (RNT) when the gas is nitrogen . The RNT is added to the planned " actual bottom time " (ABT) to give an equivalent " total bottom time " (TBT) which is used to derive the appropriate decompression schedule for the planned dive .

Equivalent residual times can be derived for other inert gases . These calculations are done automatically in personal diving computers , based on the diver 's recent diving history , which is the reason why personal diving computers should not be shared by divers , and why a diver should not switch computers without a sufficient surface interval (more than 24 hours in most cases , up to 4 days , depending on the tissue model and recent diving history of the user) .

Residual inert gas can be computed for all modeled tissues , but repetitive group designations in decompression tables are generally based on only the one tissue , considered by the table designers to be the most limiting tissue for likely applications . In the case of the US Navy Air Tables (1956) this is the 120 minute tissue , while the Bühlmann tables use the 80 minute tissue .

= = Diving at altitude = =

The atmospheric pressure decreases with altitude , and this has an effect on the absolute pressure of the diving environment . The most important effect is that the diver must decompress to a lower surface pressure , and this requires longer decompression for the same dive profile . A second effect is that a diver ascending to altitude , will be decompressing en route , and will have residual nitrogen until all tissues have equilibrated to the local pressures . This means that the diver should consider any dive done before equilibration as a repetitive dive , even if it is the first dive in several days .

The US Navy diving manual provides repetitive group designations for listed altitude changes . These will change over time with the surface interval according to the relevant table .

Altitude corrections (Cross corrections) are described in the US Navy diving manual . This procedure is based on the assumption that the decompression model will produce equivalent predictions for the same pressure ratio . The " Sea Level Equivalent Depth " (SLED) for the planned dive depth , which is always deeper than the actual dive at altitude , is calculated in inverse proportion to the ratio of surface pressure at the dive site to sea level atmospheric pressure .