REPORT USL R28-013

Decompression risks of excursions

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SUMMARY

Unimed Scientific has in recent years carried out a number of studies related to the decompression risk of excursions. One of these studies was done for Well-ops UK Ltd and was reported in USL 22-015. The major part of the work was carried out for UK Health and Safety Executive and the report is available from the HSE web site as research report number RR244. This short report derives from those earlier reports and is written to provide a greater understanding of the factors which influence the level of risk from excursions.

Most excursions cause decompression bubbles to form and as bubbles are known to cause damage within the body the fewer bubbles to form the better. The pattern of excursions, prolonged time at depth followed by a relatively rapid no-stop move to a lesser depth, means that the brain is specifically at risk. However it is relatively easy to protect the brain simply by taking longer to make the reduction in depth.

Safer excursions will result if the following guidelines are used:

Plan the job to minimise the number of depth changes and do not deviate from the plan without completing a risk assessment of the consequences of the change.

On downward excursions place the bell depth as close as possible to the working depth.

The diver should move at less than 10 msw/min through the water back to the bell.

The bell should be returned to storage depth at no more than 5 msw/min and preferably slower.

Likewise for upward excursions as much as possible of the move to lower pressure should be completed under controlled conditions, within the bell. This means the bell depth being as close as possible to the working depth. The change of pressure in the bell should be at a maximum of 5 msw/min and preferably slower. Once out of the bell the diver should continue the ascent to working depth slowly.

DECOMPRESSION RISKS OF EXCURSIONS

1.0 INTRODUCTION

Unimed Scientific has in recent years carried out a number of studies related to the decompression risk of excursions. One of these studies was done for Well-ops UK Ltd and was reported in USL 22-015. The major part of the work was carried out for UK Health and Safety Executive and the report is available from the HSE web site as research report number RR244. This short report derives from those earlier reports and is written to provide a greater understanding of the factors which influence the level of risk from excursions.

1.1 Excursions and decompression bubbles

Excursions are characterised by relatively rapid changes of depth and relatively long stays at maximum depth. For downward excursions the stay at maximum depth is usually 6 to 8 hours. For upward excursions if the maximum depth is the storage depth, travelling to the work site involves a reduction of pressure. For both, the time spent at the greater depth is always long enough for most of the body to become saturated with the inert gas, helium, at the higher pressure. It will become apparent by the end of this report that multiple depths changes during a work shift should be avoided.

Depth changes are made at something like 10 msw/minute with no decompression stops. These conditions, almost saturation at the greater depth and fast movement to the lesser depth without decompression stops, would not be tolerated in any other field of diving than saturation diving. Almost all excursions generate decompression bubbles. The extent of bubble formation can be reduced with careful planning of the work shift.

There is a misconception common in the saturation diving world that big changes in depth can be made safely because, being already at the storage pressure, any decompression bubbles which form will not be so big as if the dive were done from the surface. The same misconception has led to the common acceptance of bigger excursions for deeper storage depths.

However the excess of gas contained in the body following a stay at, for example, 10 msw is the same whether the excess 10 msw is from sea level or from 200 msw. This gas comes out of solution during the upward movement according to exactly the same physical laws for both cases. The maximum total volume of bubbles can only be that volume of excess gas which went into the tissue.

There is also an additional factor which means that application of Boyle's Law is inappropriate. During a pressure change the volume of gas which actually forms into bubbles is a balance between the pressure drop pulling the excess gas into the gas phase and the blood flow taking the excess gas safely away for removal through the lungs. Boyles law only applies to a closed system; the blood flow means that the body is an open system for inert gas.

1.2 The significance of decompression bubbles

Once the gas comes out of solution it is, in effect, a foreign body within the tissue or the blood stream.

Any bubbles formed within the body create damage. Bubbles within the bloodstream have one very important effect. They damage the blood vessel walls so that they become leaky. The blood vessel walls serve a very important purpose of regulating the distribution of substances between the blood and the tissue. Gases such as oxygen and carbon dioxide flow easily across the walls, other substances, such as glucose, do not.

If the vessel wall is damaged by bubbles it is easy for more substances to move across. A good example is water. The blood vessel walls normally regulate water content of tissue. If the blood vessels walls become leaky water will leak into the tissue. This explains the swelling seen with bruising and the swelling in an infected tissue.

Decompression bubbles cause a very similar situation, damage to the blood vessel walls, movement of water and other substances, a reaction similar to the response to infection and, subsequently, the processes which repair the vessel walls. This effect which bubbles have on blood vessel walls happens even with the smallest of bubbles, all bubbles are treated by the body as foreign bodies. The message is that decompression bubbles are to be avoided.

The symptoms of decompression sickness are what happens when the effects of bubbles have become great enough to cause a significant amount of damage to the body. Obviously the more gas which forms into bubbles the more likely it is that symptoms will occur. Traditionally a dive, or an excursion, is judged to be safe if the diver has no symptoms of decompression sickness however, it is well established that the absence of symptoms does not mean the absence of bubbles.

It is possible, using ultrasound, to detect bubbles in the major blood vessels returning blood to the heart. Information about the level of bubbling, as "seen" by the Doppler ultrasonic technique, has been accumulating all over the world in the last decade or so. The main contribution relating the extent of bubbling detected by Doppler to the incidence of decompression sickness has come from the Canadian military research establishment, DRDC Toronto.

The main conclusion from the DRDC work is the obvious one that more bubbles give a higher incidence of symptoms. The corollary is more interesting; even with quite high levels of Doppler detectable bubbles the majority of divers do not have symptoms.

For divers with Doppler grade 3 bubbles (the maximum grade being 4) following a heliox dive only about 7.4% have symptoms, which means 92.6% do not.

There have been cases of divers with no **detectable** bubbles but who have had decompression symptoms. The absence of detected bubbles does not mean the absence of bubbles only that the level of bubble formation is below the threshold of Doppler detection . The absence of decompression sickness symptoms does not mean the absence of bubbles.

1.3 Conclusions

From what has been said it must be apparent that everything possible should be done to reduce the formation of decompression bubbles and that the absence of DCS symptoms is not an indication of a bubble-free decompression.

2.0 BUBBLE LEVELS FOLLOWING EXCURSIONS

The reports listed above relate to work done using a mathematical model to evaluate the extent of bubble formation following depth changes, mainly those relating to excursions. The predictions of the model have been calibrated against 760 dives from the DRDC work so that it is possible to convert the predictions from the model to Doppler scores. The predictions have also been calibrated against the incidence of decompression sickness using a data base containing about 500,000 decompressions.

From the report published by UK HSE (RR244) the following table shows the predicted percentage of divers who will have bubbles somewhere in the body after the given downward excursions.

Table 1
Percentage of divers who will have bubbles after excursions

Saturation depth	Excursion Depth			
	38 msw	**30 msw**	**15 msw**	**13 msw**
180 msw	99	95	63	56
	35 msw	**26 msw**	**13 msw**	
150 msw	99	93	56	
	31 msw	**24 msw**	**12 msw**	
120 msw	100	95	56	
	26 msw	**20 msw**	**10 msw**	
90 msw	99	93	44	
	23 msw	**18 msw**	**9 msw**	
60 msw	100	96	37	
	17 msw	**12 msw**	**6 msw**	
30 msw	99	69	5	

Predictions by the model lead to the following conclusions relating to the excursions listed in the first column, the maximum for each depth.

With a depth change of 10 msw/minute at least 99% of divers will form gas bubbles somewhere in the body on return to storage depth.

The level of bubble formation is much the same for all of these excursions.

The risk of a diver having Doppler detectable bubbles is between 3 and 5%.

The risk of Doppler grade 2 or above is between 2 and 4%.

The risk a diver will have Doppler grade 3 and above is between 1 and 2%.

At these levels of bubble formation the risk of having decompression symptoms is very low; of the divers who have no detectable bubbles 0.6% may have symptoms, an estimate based on the DRDC information. This gives a DCS rate of about 1 in every 3000 excursions, which is approximately the rate actually found in North Sea diving.

For the middle list of allowed excursions the risk that a diver will have detectable bubbles is around 2% and the risk of having grade 3 bubbles is below 1%.

For the lowest set of excursions the risk that a diver will have Doppler detectable bubbles is considerably less than 1%. At this level the risk of DCS symptoms becomes about 1 in every 16,000 excursions.

When considering these figures it has to be remembered that the lack of Doppler detectable bubbles does not mean there are no bubbles. Ultrasonic techniques for measuring decompression bubbles do not "see" all the bubbles.

2.1 Decompression bubbles in the brain

Because the depth change from the maximum excursion depth is relatively rapid at 10 msw/min, brain tissue is particularly at risk of decompression bubble formation.

The predictions indicate that the percentage of divers who will have decompression bubbles forming in the brain will be as shown in Table 2.

Table 2
The percentage of divers who will form bubbles in the brain

Saturation depth	Excursion Depth			
180 msw	**38 msw**	**30 msw**	**15 msw**	**13 msw**
	90	84	56	50
150 msw	**35 msw**	**26 msw**	**13 msw**	
	93	84	50	
120 msw	**31 msw**	**24 msw**	**12 msw**	
	96	84	50	
90 msw	**26 msw**	**20 msw**	**10 msw**	
	93	84	38	
60 msw	**23 msw**	**18 msw**	**9 msw**	
	90	87	32	
30 msw	**17 msw**	**12 msw**	**6 msw**	
	90	50	4	

2.2 Upward excursions

The results quoted above are for downward excursions. In general terms all that has been said applies also to upward excursions the only difference being the bubbles are present during the work-shift rather than after return to storage.

2.3 Variability of response

No two individuals are exactly the same and no individual remains constant, unchanging with time. Take some time to watch very carefully the central area of the palm of your hand when the hand is laid flat on the surface of a table. The central area is usually paler than the surrounding tissue indicating a lower blood flow. Over time you will see pink areas within the pale area and the location of these pink areas will change as time goes by. This is a visible demonstration of the changes in blood flow which occur at a local level in tissues

The pattern of blood flow through the tissues is the critical determinant for the formation of decompression bubbles. A momentary reduction in blood flow through a tissue coinciding with a pressure change, can cause decompression bubbles to form where none would have formed had the blood flow remained constant.

This variability both between and within individuals means that there is always the possibility of the unexpected happening within a diver. Whereas well practised decompression procedures will work well most of the time the potential is always there for a bad outcome on the odd occasion. The best way to minimise this is to plan excursions to minimise the risk for all. The lower the risk for all the lower the risk to the individual.

3.0 PROTECTING THE BODY AGAINST DECOMPRESSION BUBBLES

It is apparent from the information given in the two tables that the simplest way to protect against bubble formation is to reduce the magnitude of the excursion. Careful planning of the job to minimise the difference between storage depth and work depth reduces the risk of decompression bubbles.

In the late 1980s and early 1990s a data base of decompression history and outcome was constructed with the support of a consortium of Norwegian oil companies. The only conclusion to come out from all this data collection, published in 1997, was that the likelihood of decompression symptoms related only to the number of depths changes experienced by an individual during a saturation exposure.

Obviously this means that jobs should be planned so that the number of depth changes is minimised. Depth changes as small as 2 or 3 metres can be significant in some situations. Not only is it a bad idea to go down to pick up a dropped spanner, the whole pattern of activity during the shift should be designed to minimise the number of depth changes.

3.1 Protecting the brain

The relatively rapid decompression rate used in excursions means that bubble formation in the brain is a particular problem.

The brain is what is known as a fast tissue, gas enters and leaves it relatively quickly. This means that the extent of bubble formation in the brain can be considerably reduced simply by reducing the rate of ascent to give the blood flow longer to remove the excess gas from the tissue. If moving at 10 msw/minute gives a certain level of bubble formation, taking a little longer over the return to storage depth will reduce both the number of divers who will have bubbles in the brain and the extent of bubble formation in all divers.

> Moving at 5 msw/minute reduces the gas forming into bubbles in the brain by 20%.
>
> Moving at 18 msw/minute causes 10% more cause to form bubbles and a greater proportion of divers to have brain bubbles.
>
> A bubble-free return to storage depth for the brain would require about 25 minutes.

It is often difficult to know the rate of movement of the diver through water but it is possible to consciously return more slowly than has been the practise in the past and it is also possible to make short stops at constant depth during the return. Stopping for a minute once or twice during the return to the bell can make a useful difference to the amount of gas which forms into bubbles.

Slowing the rate of return from excursion is the single biggest improvement which can be made. The slower rates should be applied to all upward movements whether for the mid-shift drink break, to carry out work at a shallower depth or to return to the bell at the end of the shift or to start work when the working depth is less that the storage depth.

3.2 Practical considerations.

Reference has already been made to the fact that it is difficult to know the rate of movement through the water but it is not difficult to consciously return more slowly than has been the practise in the past.

It also has to be remembered that pressure changes in the bell are part of the movement. If the bell pressure can be set at a depth intermediate between the maximum depth of the excursion and the storage depth then the time taken to move the bell back to the surface can be used to complete the pressure change to storage pressure slowly.

If it is not desirable to change the pressure in the bell whilst it is physically moving through the water then once the bell has been locked on to the system its pressure should be brought to storage depth slowly.

A great reduction of risk could be brought about by the diver moving back to the bell more slowly than 10 msw/min and the bell taking at least 10 minutes to reduce pressure to match storage depth.

3.3 Planning a safer excursion

Plan the job to minimise the number of depth changes and do not deviate from the plan without completing a risk assessment of the consequences of the change.

On downward excursions place the bell depth as close as possible to the working depth.

The diver should move at less than 10 msw/min through the water back to the bell.

The bell should be returned to storage depth at no more than 5 msw/min and preferably slower.

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