

# Breath-Hold Diving – A Proposed 60-second Rule

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## CASE STUDY

*Late last year DAN SEAP was called in to assist one of our members who had nearly perished after attempting multiple, extended breathhold dives.*

The diver, a very experienced breathhold diver, had been attempting a series of breathhold dives near the rear of the boat. He decided to continue after his companions left the water. Fortunately he was noticed quickly after surfacing, unconscious. He was rapidly retrieved into the tender and rolled onto his side before vomiting his stomach contents. He was initially incoherent, but later became more responsive, was provided with supplemental oxygen and improved steadily. He was transported to hospital for assessment and later discharged. Luckily, he had only suffered from salt water aspiration syndrome. If he had not been seen and recovered so quickly and effectively, he could easily have drowned. He had done a series of 13 consecutive breathhold dives. This last dive was to around 21m for approximately 1 minute 28 seconds. Other dives in the series were deeper and significantly longer. The diver viewed this dive as an easy dive, well within his usual limits. He reported feeling no forewarning at all of the impending blackout.

***Breath-hold diving, also known as freediving, is an excellent (and less expensive) alternative to scuba diving for many people. Freed from the equipment requirements of compressed-gas diving, the breath-hold diver can enjoy an enhanced appreciation of the underwater environment.***

***Breath-hold diving also eliminates most of the risk of decompression illness, but presents another type of physiological hazard to the diver: hypoxia. It is all too possible to become unconscious from acute oxygen deficiency (hypoxia) and drown if breath-holding continues too long.***

***Knowing this, the key question that breath-hold divers should ask is: "How do you know when you've reached the safe limit of your breath-hold?"***

In contrast to carefully developed scuba courses, most divers don't get specific instruction in breath-hold dive techniques before they begin; they pretty much do what comes naturally, which is to take a deep breath and stay down until the urge to breathe becomes overpowering (the so-called "breakpoint").

This strategy works well - most of the time. Many deaths occur from breath-hold diving because some divers have enough willpower to suppress the urge to breathe long enough that they suffer an *underwater hypoxic loss of consciousness (HLOC)*. The competitive spirit common among freedivers probably increases



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the occurrence of these HLOC episodes: hardcore enthusiasts of the sport believe that the longer you can hold your breath, the better a freediver you are.

The risk of HLOC and death goes up significantly if one of your dive buddies teaches you about hyperventilation and you start to incorporate this technique into your own breath-hold diving.

Hyperventilation (deep, rapid breathing) before the breath-hold dive lowers the amount of carbon dioxide in the lungs. Since carbon dioxide buildup is the primary reason for the "gotta breathe right now" sensation that causes the diver to surface, hyperventilation makes it significantly easier for the diver to hold his or her breath longer and develop HLOC.

### **"Armchair" Breath-Holding**

Through the practice of "armchair breath-holding," divers overestimate their breath-hold potential. It is indeed easy to be a breath-hold star while sitting comfortably in your armchair (See Figure 1), but holding your breath for four minutes in this setting does not mean that you can safely do the same thing in the water. The two situations are quite different, primarily because of a difference in oxygen consumption.

Your maximum time of consciousness while breath-holding depends on the ability of the oxygen in your body to maintain adequate oxygenation of your brain. The amount of oxygen in your body can be viewed as a checking account. You take in a quantity of oxygen at the start of your breath-hold that

depends on your lung volume and how deep a breath you take. As your body starts to use this oxygen during your period of breath-holding, you will stay conscious as long as you have enough oxygen in your checking account to sustain mental function and keep the lights on.

Once you have taken enough oxygen out of your checking account to reach a critically low level, the lights go out, and you lose consciousness. If this happens underwater, you will drown if you are not rescued very quickly.

Although the amount of oxygen that you take in is relatively fixed, the rate at which you consume oxygen may vary widely. Sitting in your armchair, you burn oxygen at about 300cc / min. Just being immersed in cool water causes oxygen consumption to more than double. A study by Drs. John A. Sterba and Claes E. Lundgren at the State University of New York (SUNY) in Buffalo found oxygen consumption to be two and a half times (256 percent) higher in cool water than in thermoneutral water.

Swimming underwater can cause oxygen consumption to further increase to a factor of up to 10 times as much as you consume while sitting in your armchair (from 300cc / min to 3,000cc / min), and your breath-hold time prior to HLOC will be reduced by approximately the same factor. A breath-holder who can achieve a 300-second breath-hold prior to HLOC at rest would theoretically be limited to a 30-second breath-hold prior to HLOC when exercising at 3 litres / minute.

### **Increasing the Time Before HLOC**

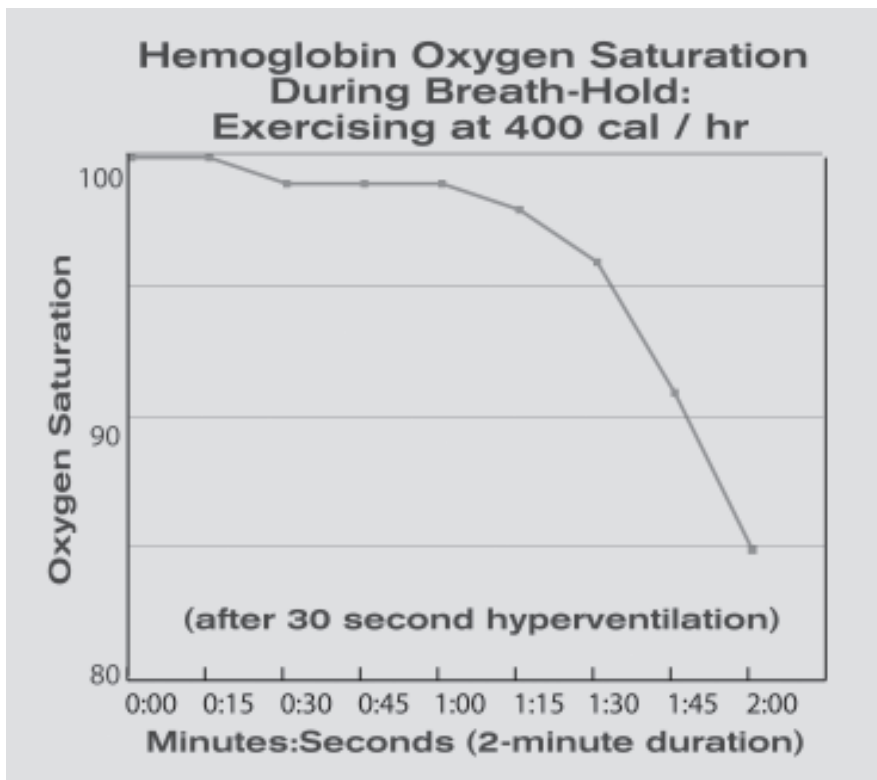
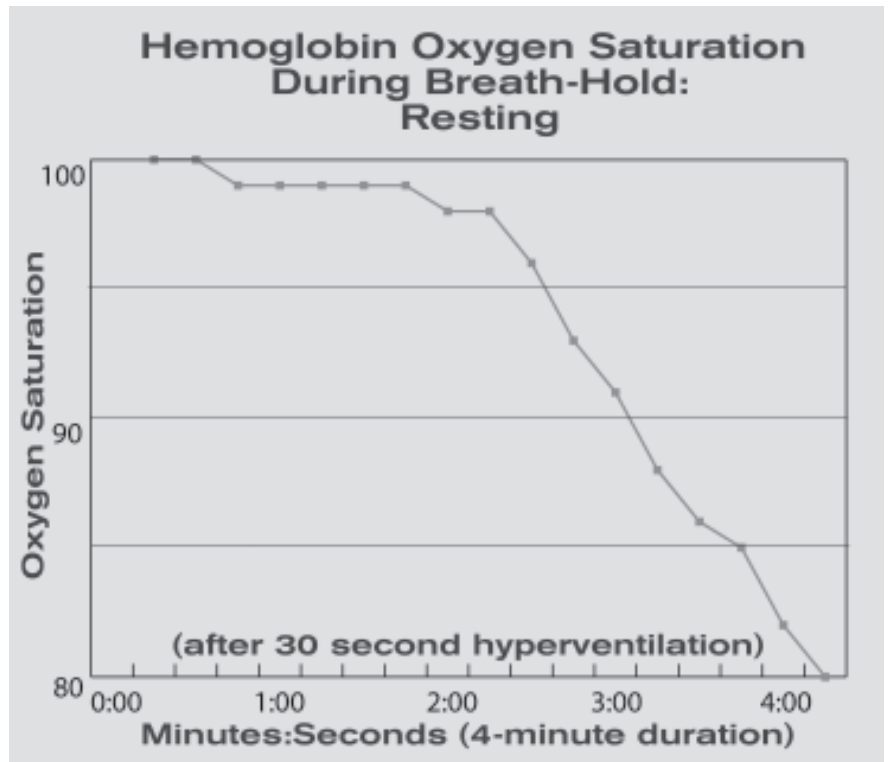
Let's return to the question of how long you can hold your breath before you become unconscious. Many studies have looked at factors that increase or decrease the time to breakpoint but, quite understandably, there are no good studies that look at the maximum breath-hold time prior to unconsciousness for breath-hold divers. Manoeuvres that increase the time to breakpoint (repetitive dives, hyperventilation) have not usually been shown to increase the time to HLOC, so that the extended time to breakpoint brings you ever closer to the threshold of HLOC and makes the dive more dangerous.

The only ways to increase time to HLOC are to increase the amount of oxygen available (increased volume of inhalation or percentage of oxygen in your breathing gas), or to decrease oxygen consumption during the dive. Elite record-setting freedivers achieve remarkable breath-hold times, but their technique often involves achieving the minimal possible exertion during the dive (a heavy sled to take them down and a flotation device to bring them up). This allows the oxygen consumption on their dives to more closely approximate that of "armchair breath-holding" than that seen with underwater swimming. In addition, an enhanced "diving reflex," other long-term physiological adaptations and adequate thermal protection may serve to further slow oxygen consumption and prolong time to HLOC in elite competitive freedivers.

A word of caution: freedivers who may be tempted to breathe oxygen prior to breath-hold should realise that this is not without risk. Preliminary studies conducted at Duke University indicate that the drive to breathe stimulated by carbon dioxide is blunted when 100 percent oxygen is inspired prior to breath-hold. Hypercapnic intoxication may precede the urge to end the breath-hold. This is a potentially life threatening complication.

### HLOC and Fatalities

OK, so HLOC may be a theoretical problem for breath-hold divers, but



maybe that's all it is. Maybe freedivers can respond to the "gotta breathe right now" sensation appropriately and reliably return to the surface before they black out. A brief review of some recent freediving fatalities suggests otherwise:

- The 31-year-old son of a champion freediver dies while practicing breath-holding in a warm-water pool, chest-deep.
- Drs. Edmonds and Walker report 12 deaths in breath-hold snorkel divers in Australia between 1987-

1996. (Ed: This doesn't include general snorkelers)

- While performing breath-hold dives, a 22-year-old student dies in June 2001, in Florida, USA.
- The 19-year-old son of a famous freediver dies in October 2001 while performing a breath-hold dive in Hawaii.
- A woman who was a world-class freediver dies in October 2002 while attempting a deep breath-hold dive in the Dominican Republic.
- Two experienced breath-hold divers die in December 2002 and January 2003 in Queensland, Australia.
- An experienced 25-year-old freediver dies in January 2003 while breath-hold diving in Florida, USA.
- An experienced breath-hold diver died near Koh Tao, Thailand in December 2004.

Nobody that I am aware keeps a comprehensive record of breath-hold diving fatalities, and the above deaths may be only the tip of the

iceberg. There are approximately 7,000 deaths in the United States each year from drowning. Deaths resulting from breath-hold diving are probably a very small fraction of this number, but the exact figure is unknown.

For its 2005 Report on Decompression Illness, Diving Fatalities and Project Dive Exploration, DAN America will begin annual reports on freediving fatalities and injuries.

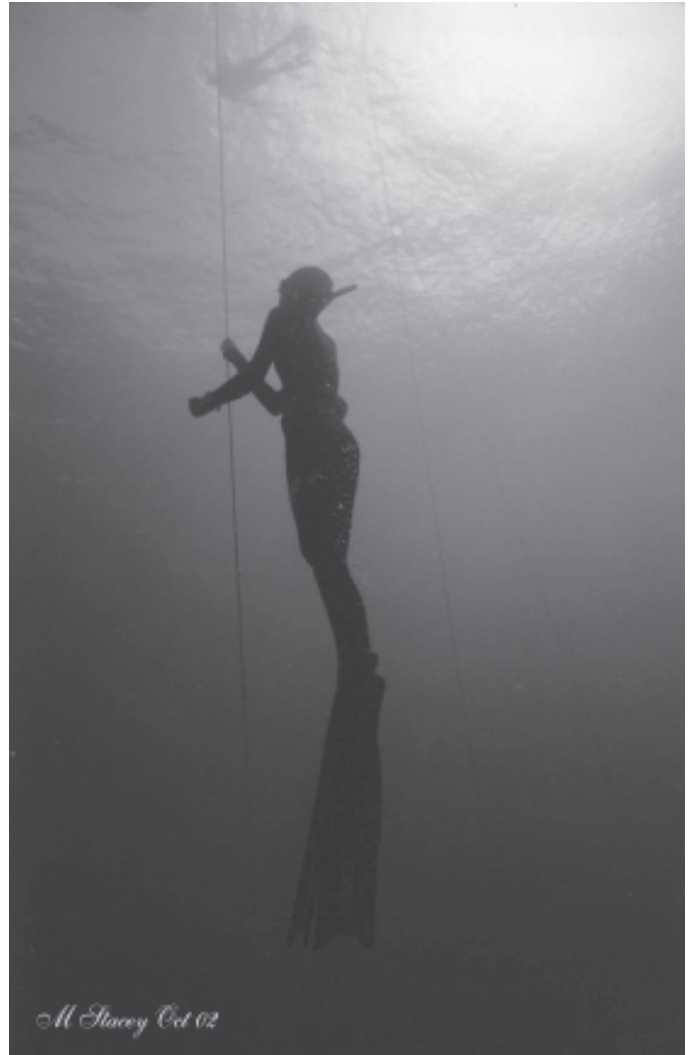
### **Taking a Lesson from the Ama Divers**

If physiological clues are unreliable, is there a better approach to determining when to surface from a free dive? Maybe we should take a lesson from the pros. Not the elite, world record-setting breath-hold divers who make a career out of operating on the edge, but the famous women breath-hold Ama divers of Korea and Japan. These women have found from long experience that NOT pushing the limits of breath-holding allows them to dive safely for the duration of their careers.

In a 1990 study by the Department of Anesthesiology of Harvard Medical School and others, four Ama divers showed no significant reduction from their mean pre-dive arterial oxygen saturation (98 percent) at any time during 92 routine dives lasting from 15 to 44 seconds. Of the seven dive subjects, four participating Korean divers performed their dives in Pusan, Korea, while three Japanese subjects performed their dives near Ise-Shima, Japan. Three divers were then asked to dive and hold their breaths as long as possible. Mean arterial oxygen saturation at the conclusion of breath-holding decreased to 73 percent after an average dive lasting 69 seconds.

In another study, from 1963, E.H. Lanphier, M.D. and Hermann Rahn, M.D. at SUNY Buffalo found that exercising divers could achieve breath-hold times of 80 seconds, but with some divers displaying symptoms of hypoxia near the end of the breath-hold.

If the Ama divers have an oxygen saturation of 73 percent after 69 seconds of breath-holding, how close is that to the level at which the lights go out? In the acute hospital setting, it is not uncommon to see oxygen saturations in the 70s with the patients still conscious. As oxygen saturations drop into the 60s, however, the risk of unconsciousness increases. Dr. Chris Lambertsen,



a noted researcher at the University of Pennsylvania, has described an oxygen saturation of 65 percent as predictive of "imminent collapse" during altitude exposures.

Two additional factors make one wary of desaturating breath-hold divers. The first is that oxygen desaturation during breath-holding is progressive, as opposed to stable hypoxia of aviation exposures. Further, the rate of oxygen desaturation during breath-holding is not linear.

As seen in Figure 2 (above), a two-minute breath-hold in a person exercising at a mild exercise rate (400 calories per hour - probably significantly less than most underwater swimmers), the oxygen saturation remains steady throughout the initial part of the breath-hold. Once it starts to drop, however, it drops rapidly.

In addition, hypoxia limits established for aviators, even if the hypoxia of breath-holding were constant, may not apply to breath-hold divers because the latter group has the superimposed phenomenon of carbon dioxide buildup, which is not a factor in aviation hypoxia and may increase the risk of unconsciousness.

## Setting the Breath-Hold Limit at 60 Seconds

We don't have a really definitive study on the issue of a safe breath-hold limit for exercising freedivers, but the number best supported by the data at this time is 60 seconds. This fact is not news to the physiologists. In the 1990 Harvard study of the Ama divers, K.S. Stanek noted that "...it seems that at least 60 seconds of breath-holding preceded the onset of desaturation of arterial blood in these divers."

Drs. Richard Vann and Neal Pollock of the Centre for Hyperbaric Medicine and Environmental Physiology at Duke University suggested in a breath-hold study published in March 2000 that "hypoxia can be avoided during air breath-hold by restricting bottom time.... restricting breath-hold times to the 50th percentile of our subject populations, for example, air dives would be limited to two minutes at rest and one minute with exercise."

The problem is that the findings of breath-hold diving researchers have not yet become part of the information base for most freedivers.

So, here is the recommendation: Breath-hold divers should limit their

breath-hold time to 60 seconds or less - the proposed "60-Second Rule" mentioned in the title of this article. Freediving spearfishers and elite freediving depth record-setters will probably reject this sort of limit out of hand. That's fair enough, because such a limit interferes with their achieving some specific objectives (a white sea bass or a world record), and because it strikes at the competitive heart of what makes them elite freedivers.

But for the non-elite rest of us, the 60-second rule will make freediving much safer (if, in fact, you are good enough to have exceeded that limit to begin with). You can perform your dive without having to wonder if ignoring the urge to breathe places you in danger. Anyone able to routinely breath-hold beyond a minute underwater and depressed at being limited to 60 seconds can take heart in the fact that they will, on the average, be out-freediving the Ama divers.

One caveat about the 60-second rule is that it has not been shown to be safe for very high exercise levels while swimming, so freedivers should maintain their exertion at a mild level while diving.

One additional positive aspect of having a finite limit for breath-holding time is that the freediver can now safely hyperventilate before the dive. Since he or she now knows better than to use the reduced level of carbon dioxide in the blood to stay down for more than 60 seconds, the concern about the safety of hyperventilation is alleviated. The reduced level of carbon dioxide throughout the dive serves to make

breath-holding more comfortable and the dive more enjoyable.

To accomplish many safe open-water breath-hold dives in the last year, the author has used a 30-second period of hyperventilation in conjunction with the 60-second rule. The 60-second rule should of course be used in conjunction with other basic free diving safety measures, such as diving with a buddy and ensuring that you are positively buoyant at depths of about 10-15 feet (3-4.5 meters).

## Beyond the 60-Second Rule

What is the next step? A study could be done that better defines the safe limit for exercising breath-hold divers. Maybe 60 seconds is too conservative, and the safe limit for breath-holding should be 90 seconds. A large study with attempted breath-holds of 90 seconds would help to prove (or disprove) this point.

**There will never be one number that answers this question for all divers, however. Factors such as cold water, being in hot pursuit of a large snapper, or a relatively shallow breath taken at the start of breath-holding could potentially decrease the safe time limit to something less than 60 seconds.** DAN might be able to help get such a study started.

As long as the diving public continues to freedive, the safe limit of breath-holding is an area ripe for investigation. These research measures will help our understanding of freediving injuries to continue to grow and our ability to provide good diving medical advice on this topic to improve. □

## ABOUT THE AUTHOR

Capt. Frank Butler is a Navy ophthalmologist and diving medical officer. He has served previously as a platoon commander in the Navy Underwater Demolition and SEAL (Sea/Air/Land commando) teams. Butler spent five years as a Diving Medical Research officer at the Navy Experimental Diving Unit. He is the co-author of the chapter on U.S. Navy Diving Techniques and Equipment in the well-known Bove and Davis textbook, *Diving Medicine*. He also is an ophthalmology consultant to Divers Alert Network.

*Alert Diver is a forum for ideas. The opinions and assertions expressed by the author are his alone and do not necessarily reflect the views of the US Navy or Defense or Divers Alert Network.*

## Breath-Hold Pros

### The Ama of Japan

By the late Dr. Ed Thalmann

When examining the practice of breath-hold diving, it is advisable to consider divers who do this for a living: not the record-setting divers who are on the verge of unconsciousness as they surface or the spearfisher who will push limits to get the big fish, but those who dive day in and day out as a matter of survival.

Such a group can be found in the Ama diving women of Japan, whose legacy as breath-hold seafood and pearl harvesters goes back some 2000 years. Rahn and Yokoyama\* published a collection of in-depth studies on the diving practices of the Ama in 1965 and, although somewhat dated, many of the observations are still applicable today.

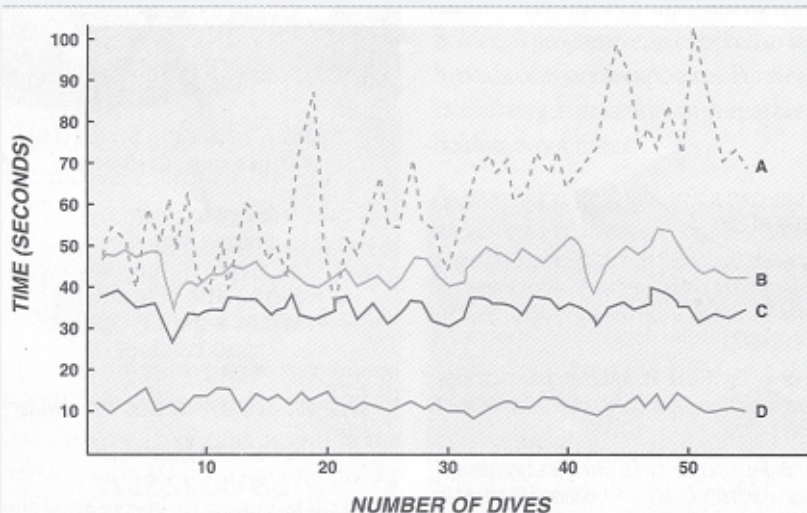
Given the importance of breath-hold diving to their survival, it stands to reason that the Ama have had plenty of time to develop their diving patterns to minimise the chance of injury. This includes hypoxic loss of consciousness. In developing their diving patterns it is unlikely they used the physiological techniques outlined by Dr. Butler, but they did seem to come to the same conclusions: that breath hold dives should be limited to no more than one minute.

The Ama had a hierarchy of divers, with the most experienced being called Ooisodo. The Ooisodo Ama will typically be 20-25 years old and dive to depths of 10-25 meters of sea water (approximately 32-80 feet of sea water). Water temperature would typically be about 20°C, and the Ama will typically make 50 dives in the morning and 50 in the afternoon. The figure below shows the dive times of a typical Ooisodo for a single 50 consecutive dive set. Line B plots the total dive time for each of the 50 dives. (Total dive time is the time from descending from the surface until reaching the surface again at the end of the dive.) Notice that it tends to stay between 40 and 50 seconds.

At the time the report was published the Ama were still wearing goggles, although some were beginning to use regular dive masks. At that time they usually used no sort of thermal protection, but some were beginning to use light wetsuits. The changes in cold

adaptation from no protection to wetsuits have been of great interest to thermal physiologists, who have also studied the Ama intensively.

The diving pattern of the Ama seems largely limited by the rest phase. If they dive too long, they have to remain at the surface longer between dives to recover from fatigue (line A of the graph). It might be argued that longer dives might be possible if the diving frequency was decreased. Unfortunately this is not necessarily the case: the time to significant oxygen desaturation is not influenced by the previous dive unless the surface interval is very short, on the order of a few seconds. The Ama dive pattern shown below keeps them on the safe side oxygen desaturation and well away from any in-water blackouts.



The time schedule of the Ooisodo, showing the total diving time (line B) and the resting time (line A).

- The distance between the x-axis (horizontal) and line B indicates the total dive time;
- Lines C and D indicate the subdivision of the total diving time;
- The distance between the x-axis and line D indicates the descending time;
- The distance between lines D and C indicates the bottom time;
- The distance between lines C and B indicates the time for ascent.

\* Rahn H, Yokoyama T, eds. *Physiology of Breath-Hold Diving and the AMA of Japan*. National Academy of Sciences National Research Council Pub. 1341. Wash DC, 1965.