Journal of Human Performance in Extreme Environments

Volume 15 | Issue 1 Article 3

Published online: 5-29-2019

Technical Freediving: An Emerging Breath-Hold Diving Technique

Derek Covington
University of Florida, dcovington@anest.ufl.edu

Robert H. Lee

Steven Toffel

See next page for additional authors

Recommended Citation

Covington, Derek; Lee, Robert H.; Toffel, Steven; Bursian, Alberto; Krack, Kirk; and Giordano, Chris (2019) "Technical Freediving: An Emerging Breath-Hold Diving Technique," *Journal of Human Performance in Extreme Environments*: Vol. 15 : Iss. 1 , Article 3.
DOI: 10.7771/2327-2937.1122
Available at: https://docs.lib.purdue.edu/jhpee/vol15/iss1/3

Technical Freediving: An Emerging Breath-Hold Diving Technique

Derek Covington, Robert H. Lee, Steven Toffel, Alberto Bursian, Kirk Krack, and Chris Giordano

University of Florida

Abstract

Technical freediving can be defined as freediving augmented by the use of oxygen-enriched gases or oxygen before, during, or after a freedive. As a result of these techniques, breath-hold divers can visit and enjoy underwater wrecks, reefs, and other diving locations previously located at depths unreachable to apnea divers. By pre-breathing oxygen-enriched gases in conjunction with hyperventilation—which decreases the partial pressure of carbon dioxide (PCO2)—the technical freediver now has additional oxygen to facilitate aerobic respiration during the dive. In addition, pre-breathing oxygen decreases tissue nitrogen tensions, which limits inert gas loading and decreases the risk of decompression sickness (DCS). Finally, this technique decreases PCO2, which diminishes the urge to breathe. Consequently, a diver may be able to dive longer before critical hypoxia or hypercarbia forces an ascent. Technical freediving can also be complemented by the use of a diver propulsion vehicle to increase the speed of descent and ascent and minimize exertion. The techniques of technical freediving may be associated with increased risks in central nervous system oxygen toxicity, DCS, and arterial gas embolism. As the boundaries of apnea diving continue to expand, there will be considerable opportunities to investigate the physiological limits of the human body and to determine the safest methodologies to practice this evolving discipline.

Keywords: freediving, apnea, breath-hold, hypoxia, decompression sickness

Introduction and Definition of Technical Freediving

Unlike breath-hold diving, scuba diving relies on cylinders containing compressed breathing gases to allow divers to breathe underwater and therefore stay submerged longer. Most often, scuba diving utilizes air as a breathing gas and tends to be limited to depths of less than 40 meters of water (msw) and to diving profiles that do not accrue mandatory decompression. However, technical scuba diving employs varied breathing gases (enriched air nitrox (EANx), trimix, heliox), closed-circuit rebreathers, depths greater than 40 msw, and diving in overhead environments, which can prevent a direct ascent to the surface in the event of an emergency.

Despite continued advances in the depth and time records for apnea diving, hypoxia, hypercarbia, and inert gas loading continue to be the limiting factors for breath-hold divers. A recent development referred to as "technical freediving" uses some aspects of advanced scuba diving techniques to address the physiological barriers to deeper, longer, and more frequent apnea dives. One of the authors (K.K.), a professional freediver and founder of Performance Freediving International (PFI), developed these techniques in small groups of divers for many years. Eventually, he unveiled technical freediving in 2014 at the Deja Blue freediving competition. According to the author, technical freediving can be defined as freediving augmented by the use of oxygen-enriched gases or oxygen before, during, or after a freedive. These non-air gas mixtures may be used to increase breath-hold and dive time and to speed metabolic recovery after a freedive and/or in preparation for another freedive.

Technical freediving greatly expands the recreational diving opportunities for freedivers. Underwater wrecks, reefs, and other diving locations previously located at depths unreachable to apnea divers are now being visited and enjoyed by technical freedivers. For instance, technical freedivers repeatedly dove for three to five minutes on the wreck of the Nippo Maru, which rests at a depth of 47 msw in Micronesia (see Figure 1). In addition, the extended diving depths and lengthened durations will prove advantageous for commercial freediving, such as spear fishermen and sponge divers. Nonetheless, as these emerging techniques introduce additional complexity and risks to freedivers, they should be reserved for select participants who are trained to understand and to mitigate these risks.

http://dx.doi.org/10.7771/2327-2937.1122

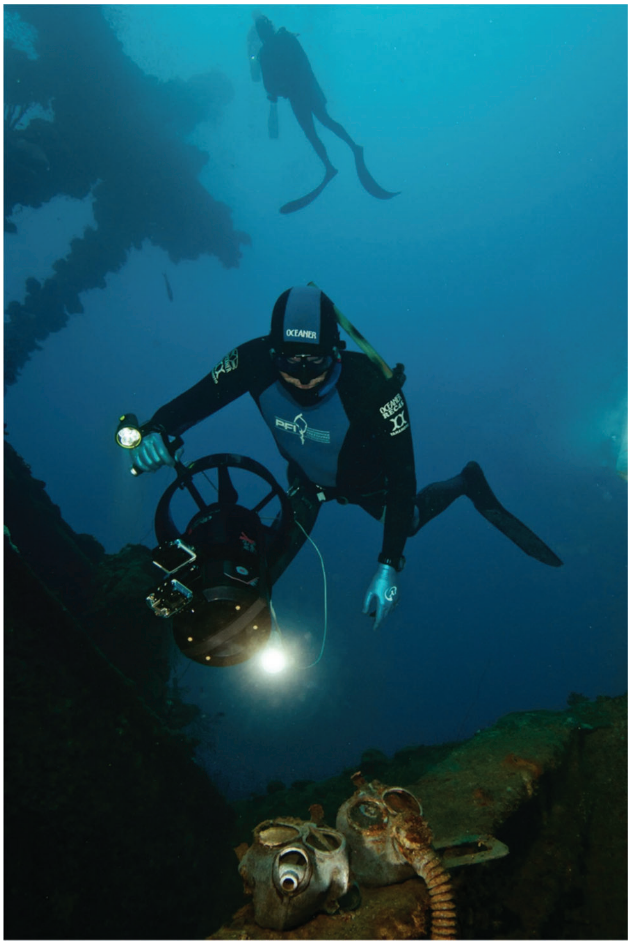

Figure 1. A technical freediver admiring the gas masks present on a wreck dive on the Nippo Maru (47 msw) in Chuuk Lagoon, Micronesia. [Photo credit: Bill Coltart]

Physiology and Techniques

Breathing an oxygen-enriched gas mixture prior to a freedive increases the partial pressure of oxygen (PO2) and decreases the partial pressure of nitrogen (pN2) in the diver's lungs, bloodstream, and other tissues, such as muscles. By pre-breathing oxygen-enriched gases in conjunction with hyperventilation, which decreases the partial pressure of carbon dioxide (PCO2), the technical freediver now has additional oxygen to facilitate aerobic respiration during a dive, a decreased amount of nitrogen to limit inert gas loading and the risk of decompression sickness (DCS), and a decreased PCO2 to decrease the urge to breathe (see Figure 2). As a result, the diver may be able to dive longer before critical hypoxia or hypercarbia mandate ascent. Although various oxygen-enriched gases may be utilized, K.K. most commonly utilizes 32% EANx, 36% EANx, 40% EANx, and 50% EANx, as these are frequently used by scuba divers and are available at many diving centers.

In addition to the pre-dive breathing of oxygen-enriched gases, K.K. pioneered the use of these gases during the initial descent phase of the dive. By inhaling gas from a

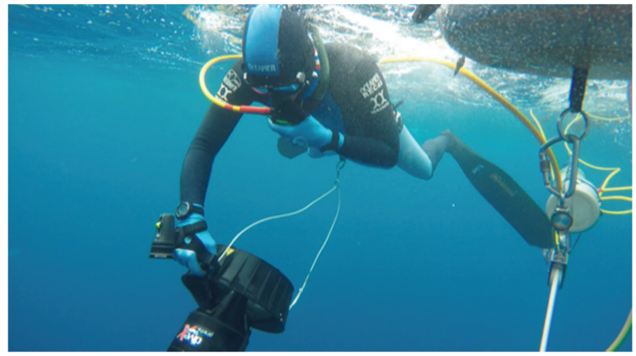

Figure 2. A technical freediver utilizing enriched air nitrox (EANx) on the surface in between dives. [Photo credit: Bill Coltart]

scuba cylinder underwater, a diver can effectively accomplish "lung packing," or glossopharyngeal insufflation (GI). Considering the diver is breathing from a second-stage regulator, which provides gas at ambient pressure, a technical freediver may inhale a substantially larger volume of gas compared to that achieved by GI at the surface. For instance, it is estimated that traditional lung packing on the surface can provide up to 4.16 L of additional intrathoracic gas volume (Loring et al., 2007). A technical freediver at 6 msw could theoretically achieve an additional volume of over 6.7 L. It should be noted that this gas must be exhaled before surfacing to prevent barotraumatic lung injury and arterial gas embolism (AGE), since the diver has effectively increased the total lung capacity above what could normally be inhaled at the surface. A safety diver is utilized to signal to the ascending freediver the need to exhale at the appropriate depth. Since this particular aspect of technical freediving involves taking a breath underwater, one could argue that it is no longer freediving—rather scuba diving. However, K.K. argues that this single underwater breath is quite distinct from sustained breathing underwater, which is the essence of scuba diving. Furthermore, technical freedivers may choose not to employ this particular aspect of technical freediving in their diving.

Upon surfacing, inhaling oxygen-enriched gases or 100% oxygen quickly corrects a relative or near-critical hypoxic state and creates a diffusion gradient for rapid off-gassing of nitrogen. As a result, the freediver can recover quickly from the metabolic demands of the dive and decrease the likelihood of DCS. Part of this recovery and the preparation for a subsequent dive may be conducted a few meters below the surface in order to further improve off-gassing of nitrogen and to decrease the large relative change in ambient pressure experienced during the ascent. Underwater recovery and preparation should only be practiced after a diver has safely returned to the surface and has demonstrated no signs of distress for at least 30 seconds.

The use of oxygen-enriched air or pure oxygen may also be complemented by an external means of propulsion, such as that offered by a diver propulsion vehicle (DPV). DPVs or scooters are propeller-driven, torpedo-shaped machines

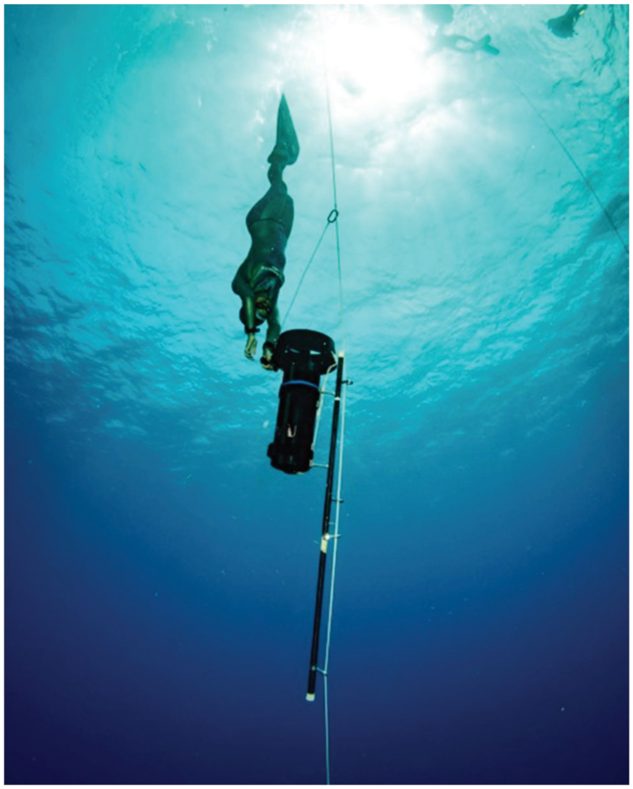

Figure 3. A freediver utilizing a DPV to aid in the descent. [Photo credit: Eiko Jones]

with large-capacity, rechargeable batteries (see Figure 3). DPVs nearly eliminate physical exertion during a freedive. As a result, the metabolic demands are drastically reduced, descent and ascent speeds are drastically increased, and greater depths can be achieved. Nonetheless, these increased speeds and depths also engender additional risk.

Pathophysiology and Risks

The tremendous physiological demands imparted on the human body by traditional breath-hold diving are well described and include effects on the cardiovascular, pulmonary, neurological, and renal systems (Dujicv & Breskovic, 2012; Gren et al., 2016; Marabotti et al., 2013; Mijacika & Dujic, 2016; Pendergast & Lundgren, 2009; Tetzlaff, Schöppenthau, & Schipke, 2017). In addition to these physiological challenges, technical divers may be at an increased risk for DCS, Taravana syndrome, AGE, central nervous system (CNS) oxygen toxicity, and barotraumatic injuries of the middle ear, eyes, and sinuses.

As technical freedivers expose themselves to more aggressive diving profiles, which include deeper depths, longer bottom times, more frequent dives, and an overall greater number of dives during a diving session, they also expose themselves to an increased inert gas loading, which may increase the risk of DCS. One study estimates that the risk of DCS is negligible for a single dive to depths of less than 100 meters, but then increases to 7% with dives deeper than 100 meters (Fitz-Clarke, 2009). In addition to extreme depths, those performing repetitive dives to more shallow depths may also develop DCS due to the accumulation of residual inert gases from previous dives (Lemaître, Fahlman, Gardette, & Kohshi, 2009; Schipke, Gams, & Kallweit, 2006). Nonetheless, to date, there are no scientific studies exploring these risks in a technical freediver population.

Taravana syndrome, most likely a type of neurologic DCS, exemplifies the dangers of repetitive, deep breath-hold diving. First described in 1965 in the pearl divers from the Tuamoto Archipelago in the South Pacific, Taravana syndrome includes a constellation of neurological findings, such as dizziness, vertigo, numbness, nausea, euphoria, dysarthria, and altered mental status, and can result in death (Cross, 1965; Lemaître et al., 2009). The symptoms are usually present within two hours following a dive. However, Taravana syndrome has been recognized in divers as late as 21 hours after a dive (Cortegiani et al., 2013). As technical freediving practices become more common, it is foreseeable that this condition will become more prevalent but, hopefully, better understood.

In addition to DCS, AGEs also occur in breath-hold divers (Kohshi, Katoh, Abe, & Okudera, 2000; Moon & Gray, 2010). In fact, AGEs have even been reported in a breath-hold dive that was only 1.2 meters deep as well as dives just beneath the surface of the water (Harmsen, Schramm, Karenfort, & Christaras, 2015; Newton, 2001). For those performing GI before dives, they may further predispose themselves to gas trapping, lung barotrauma, and AGEs (Linér & Andersson, 2010). If divers breathe from submerged scuba cylinders (as described above) in place of GI, they must be certain to exhale during ascent to prevent lung overexpansion injuries. Meanwhile, DPVs can achieve velocities of 100 meters per minute and significantly increase diver descent and ascent rates (SUEX, 2017). Consequently, freedivers utilizing DPVs may be at further risk of lung barotrauma and AGEs due to rapid changes in ambient pressure and air space volumes. These risks are similar to those practicing no-limit freediving, where a ballast weight aids descent and a balloon or diving suits aid with ascent.

The risk of oxygen toxicity is also increased in technical freedivers compared to traditional breath-hold divers. Upon pre-breathing an oxygen-enriched gas, a technical diver increases his or her PO2 even before leaving the surface. As the diver descends in the water column, they will metabolize some of the pre-breathed oxygen, but will also be subjected to the increasing surrounding pressure, which further increases the tissue PO2. Rapid descents to significant depths may lead to a sharp rise in tissue PO2 and trigger CNS oxygen toxicity, which may induce a seizure and subsequent death. In an effort to avoid this potentially fatal complication, one of the authors mandates that divers switch from surface oxygen to a breathing gas with a lower fraction of oxygen or simply to air for five minutes before initiating a subsequent dive.

Finally, breath-hold divers may also be afflicted by middle-ear barotrauma, sinus barotrauma, and subconjunctival hemorrhages secondary to mask squeeze. Technical freedivers using DPVs may compound this risk, since equalization of air spaces must occur more rapidly in order to keep pace with the quickly increasing or decreasing ambient pressure.

Future Directions

As the techniques of technical freediving are being invented, practiced, and disseminated through the diving community, the opportunities for studying the limits of human physiology will continue to expand. Although technical freediving likely poses additional risk to its practitioners, the magnitude of this ancillary risk is unknown. Future research should aim to quantify the risks of DCS, AGE, and CNS oxygen toxicity within technical freedivers. Additionally, the acute hemodynamic and respiratory effects of these extended-range freedives should also be investigated, allowing medical personnel to better risk-stratify potential technical freedivers or those recovering from a diving-related injury.

Acknowledgment

The authors are grateful to Marc Kaiser for his comments, which greatly improved the manuscript.

References

Cortegiani, A., Foresta, G., Strano, M. T., Montalto, F., Garbo, D., & Raineri, S. M. (2013). An atypical case of Taravana syndrome in a breath-hold underwater fishing champion: A case report. *Case Reports in Medicine*, *2013*, 939704. https://doi.org/10.1155/2013/939704

Cross, E. (1965). Taravana-diving syndrome in the Tuamotu diver. *Physiology of Breath-Hold Diving and the Ama of Japan*, *1341*, 205–219.

Dujic, Z., & Breskovic, T. (2012). Impact of breath holding on cardiovascular respiratory and cerebrovascular health. *Research in Sports Medicine*, *42*(6), 459–472. https://doi.org/10.2165/11599260-000000000-00000

Fitz-Clarke, J. R. (2009). Risk of decompression sickness in extreme human breath-hold diving. *Undersea Hyperbaric Medicine*, *36*(2), 83–91. Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=2ahUKEwj8g9ien9XhAhVJ-qwKHXrZAOUQFjADegQIBRAC&url=https%3A%2F%2Fpdfs.semanticscholar.org%2F25a0%2F6e5dda25737881efc0131c0230cd48077415.pdf&usg=AOvVaw2_VJz8YJ1pzbwhTAFGR2lZ

Gren, M., Shahim, P., Lautner, R., Wilson, D. H., Andreasson, U., Norgen, N.,… Zetterberg, H. (2016). Blood biomarkers indicate mild neuroaxonal injury and increased amyloid β production after transient hypoxia during breath-hold diving. *Brain Injury*, *30*(10), 1226–1230. https://doi.org/10.1080/02699052.2016.1179792

Harmsen, S., Schramm, D., Karenfort, M., & Christaras, A. (2015). Presumed arterial gas embolism after breath-hold diving in shallow water. *Pediatrics*, *136*(3), e687–e690. https://doi.org/10.1542/peds.2014-4095

Kohshi, K., Katoh, T., Abe, H., & Okudera, T. (2000). Neurological diving accidents in Japanese breath-hold divers: A preliminary report. *Journal of Occupational Health*, *43*, 56–60. https://doi.org/10.1539/joh.43.56

Lemaître, F., Fahlman, A., Gardette, B., & Kohshi, K. (2009). Decompression sickness in breath-hold divers: A review. *Journal of Sports Science*, *27*(14), 1519–1534. https://doi.org/10.1080/02640410903121351

Linér, M. H., & Andersson, J. P. (2010). Suspected arterial gas embolism after glossopharyngeal insufflation in a breath-hold diver. *Aviation, Space, and Environmental Medicine*, *81*(1), 74–76. Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwiblIjErdXhAhUO7qwKHRNMDQ4QFjAAegQIABAC&url=https%3A%2F%2Fuhms.org%2Fimages%2FDCS-and-AGE-Journal-Watch%2Fliner_suspected_age_aviat_sp.pdf&usg=AOvVaw2q-V5yjclAQdLYxFfWxuLv

Loring, S. H., O'Donnell, C. R., Butler, J. P., Lindholm, P., Jacobson, F., & Ferrigno, M. (2007). Transpulmonary pressures and lung mechanics with glossopharyngeal insufflation and exsufflation beyond normal volumes in competitive breath-hold divers. *Journal of Applied Physiology*, *102*(3), 841–846. https://doi.org/10.1152/japplphysiol.00749.2006

Marabotti, C., Scalzini, A., Menicucci, D., Passera, M., Bedini, R., & L'Abbate, A. (2013). Cardiovascular changes during SCUBA diving: An underwater Doppler echocardiographic study. *Acta Physiologica (Oxford)*, *209*(1), 62–80. https://doi.org/10.1111/apha.12112

Mijacika, T., & Dujic, Z. (2016). Sports-related lung injury during breath-hold diving. *European Respiratory Review*, *25*(142), 506–512. https://doi.org/10.1183/16000617.0052-2016

Moon, R. E., & Gray, L. L. (2010). Breath-hold diving and cerebral decompression illness. *Undersea Hyperbaric Medicine*, *37*(1), 1–5. Retrieved from http://archive.rubicon-foundation.org/xmlui/bitstream/handle/123456789/9297/20369647.pdf?sequence=1

Newton, H. B. (2001). Neurologic complications of scuba diving. *American Family Physician*, *63*(11), 2211–2218. Retrieved from https://www.aafp.org/afp/2001/0601/p2211.pdf

Pendergast, D. R., & Lundgren, C. E. (2009).The underwater environment: Cardiopulmonary, thermal, and energetic demands. *Journal of Applied Physiology*, *106*(1), 276–283. https://doi.org/10.1152/japplphysiol.90984.2008

Schipke, J. D., Gams, E., & Kallweit, O. (2006). Decompression sickness following breath-hold diving. *Research in Sports Medicine*, *14*(3), 163–178. https://doi.org/10.1080/15438620600854710

SUEX. (2017). XJ37 diving vehicle instruction manual and warnings for use. Rome, Italy: Submarine Exploration Company. Retrieved from https://www.suex.it/documenti/manuali/70970_M_W.pdf

Tetzlaff, K., Schöppenthau, H., & Schipke, J. D. (2017). Risk of neurological insult in competitive deep breath-hold diving. *International Journal of Sports Physiological Performance*, *12*(2), 268–271. https://doi.org/10.1123/ijspp.2016-0042