DO ARTERIALIZED VENOUS GAS EMBOLI (VGE) INITIATE CEREBRAL OR SPINAL DECOMPRESSION SICKNESS (DCS)?

Richard D. Vann RD[1,2], Laurens E. Howle[3], Neal W. Pollock[2,3], Richard E. Moon[1]
[1]Hyperbaric Center and Department of Anesthesiology, Duke University Medical Center; [2]Divers Alert Network;
[3]Mechanical Engineering and Materials Science Department, Duke University, Durham, NC, USA

BACKGROUND

- DCS includes a wide range of signs and symptoms, some of the most serious of which are associated with helium-oxygen (He-O_2) or gas switching. We hypothesize that VGE can pass through the lungs into the arterial circulation from where they may initiate bubble formation and DCS in tissues that are otherwise bubble-free, e.g., brain or spinal cord.

EVIDENCE FOR VGE ARTERIALIZATION THROUGH THE LUNGS

- Conventional wisdom holds that arterial blood is bubble-free in the absence of right-to-left shunt (e.g., patent foramen ovale [PFO]) as VGE are filtered by the lungs.[1-5] However, small bubble contrast agents (e.g., 1-3 µm Optison™ and Definity™) easily pass through the lungs, and large bubbles cross during exercise.[6] Advances in ultrasound technology have confirmed that AGE are relatively common after diving even without PFO.[7,8]

EVIDENCE FOR DCS-LIKE MANIFESTATIONS INITIATED BY AGE

- AGE are implicated in cerebral and spinal manifestations by association with PFO that allows VGE to bypass the pulmonary filter and enter the arterial circulation.[9,10] AGE-initiated cerebral DCS is suggested since divers breathing He-O_2 only have more VGE and more cerebral DCS than divers breathing N_2-O_2 only,[11] compatible with the hypotheses that VGE may be more numerous and, perhaps, smaller with He than N_2.

EFFECTS OF INERT GAS SWITCHING

- Increased VGE have been observed following some inert gas switches suggesting a greater likelihood of arterialization. Some gas switches accelerate inert gas washout beneficially (e.g., He→N_2),[12] but others generate VGE by cutaneous or deep-tissue counterdiffusion (e.g., respired H_2→He[13] or respired N_2→He[14]; cutaneous He exposure with respired Ne or N_2[15]). Vestibular DCS is associated with PFO (implicating AGE initiation[16]) and respired He→N_2 deeper than about 100 fsw (30 msw), possibly due to counter-diffusion from perilymph and endolymph compartments in the inner ear.[17]

INTERVENTIONS TO REDUCE VGE AND AGE

- Nitroglycerine[18] and exercise during decompression[19] appear to reduce VGE formation, possibly by affecting blood flow and/or endothelial nitric oxide synthase. Thus, interventions to decrease VGE might also reduce the risk of AGE-initiated DCS from arterialized VGE.

CONCLUSIONS

- Serious DCS (cerebral and spinal) continues to bedevil operational diving safety. This problem might be mitigated by: (a) interventions to reduce VGE and the likelihood of their arterialization; and (b) decompression algorithms[20] that assign independent probabilities to mild and serious DCS.

ACKNOWLEDGMENT

Supported by NAVSEA Contract #N61331-06-C-0014.

REFERENCES

1. Hills, B. & B. Butler (1981) Size distribution of intravascular air emboli produced by decompression. *Undersea Biomed Res,* 8, 163-70.
2. Butler, B. D. & B. A. Hills (1985) Transpulmonary passage of venous air emboli. *J Appl Physiol,* 59, 543-7.
3. Vik, A., A. O. Brubakk, T. R. Hennessy, B. M. Jenssen, M. Ekker & S. A. Slordahl (1990) Venous air embolism in swine: transport of gas bubbles through the pulmonary circulation. *J Appl Physiol,* 69, 237-44.
4. Vik, A., B. M. Jenssen & A. O. Brubakk (1991) Effect of aminophylline on transpulmonary passage of venous air emboli in pigs. *J Appl Physiol,* 71, 1780-6.
5. Powell, M., M. Spencer & O. von Ramm. 1982. Ultrasonic surveillance of decompression. In *The physiology of diving and compressed air work*, 404-434. London: Bailliere Tindall.
6. Eldridge, M. W., J. A. Dempsey, H. C. Haverkamp, A. T. Lovering & J. S. Hokanson (2004) Exercise-induced intrapulmonary arteriovenous shunting in healthy humans. *J Appl Physiol,* 97, 797-805.
7. Ljubkovic, M., Z. Dujic, A. Mollerlokken, D. Bakovic, A. Obad, T. Breskovic & A. O. Brubakk (2011) Venous and arterial bubbles at rest after no-decompression air dives. *Med Sci Sports Exerc,* 43, 990-5.
8. Pollock, NW. Personal communication.
9. Wilmshurst, P. T., J. C. Byrne & M. M. Webb-Peploe (1989) Relation between interatrial shunts and decompression sickness in divers. *Lancet,* 2, 1302-6.
10. Wilmshurst, P. & P. Bryson (2000) Relationship between the clinical features of neurological decompression illness and its causes. *Clin Sci (Lond),* 99, 65-75.
11. Shannon, J. 2003. The relationship of inert gas and venous gas emboli to decompression sickness. MS Thesis. *Mechanical Engineering and Materials Science*. Durham, NC: Duke University.
12. Keller, H. & A. Buhlmann (1965) Deep diving and short decompression by breathing mixed gases. *J Appl Physiol,* 20, 1267-70.
13. Gardette, B., M. Comet, C. Gortan, J. Imbert, X. Fructus & H. Delauze. 1988. Life in a hyperbaric environment. A new O2-H2 breathing mixture for industrial diving. In *Colloquium on Space & Sea*, 31-40. Marseille, France: European Space Association.
14. Hamilton, R., Jr, G. Adams, C. Harvey & D. Knight. 1982. SHAD-NISAT: a composite study of shallow saturation diving. New London, CT: Naval Submarine Medical Research Laboratory.
15. Lambertsen, C. J. & J. Idicula (1975) A new gas lesion in man, induced by "isobaric gas counterdiffusion". *J Appl Physiol,* 39, 434-443.
16. Mitchell, S. J. & D. J. Doolette (2009) Selective vulnerability of the inner ear to decompression sickness in divers with right-to-left shunt: the role of tissue gas supersaturation. *J Appl Physiol,* 106, 298-301.
17. Doolette, D. J. & S. J. Mitchell (2003) Biophysical basis for inner ear decompression sickness. *J Appl Physiol,* 94, 2145-50.
18. Wisloff, U., R. S. Richardson & A. O. Brubakk (2003) NOS inhibition increases bubble formation and reduces survival in sedentary but not exercised rats. *J Physiol,* 546, 577-82.
19. Dujic, Z., I. Palada, A. Obad, D. Duplancic, D. Bakovic & Z. Valic (2005) Exercise during a 3-min decompression stop reduces postdive venous gas bubbles. *Med Sci Sports Exerc,* 37, 1319-23.
20. Vann, R., L. Howle (2012) UHMS Meeting, Poster F127. Describing decompression sickness (DCS) of the brain, spine, and joints by multinomial probability.