Letter to the Editor

Gas micronuclei that underlie decompression bubbles and decompression sickness have not been identified

Gas micronuclei are gas-filled voids in liquids from which bubbles can form at low gas supersaturation. If water is depleted of gas micronuclei, high gas supersaturation is required for bubble formation. This high gas supersaturation is required in part to overcome the Laplace pressure at the point of transition from dissolved gas to a bubble of perhaps nanometer-scale radius. The sum of gas and vapour partial pressures inside a spherical bubble (P_{bub}) of radius r exceeds the ambient barometric pressure (P_{amb}) and is given by the Young-LaPlace equation:

$$P_{bub} = P_{amb} + \frac{2\gamma}{r} \quad (1)$$

for a bubble not in contact with a solid surface. The second term on the right-hand side is the Laplace pressure across the gas-liquid interface due to surface tension (γ). For instance, for a surface tension characteristic of blood of 0.056 $N \cdot m^{-1}$, *de novo* formation of a bubble of r = 10 nm requires gas supersaturation exceeding $2\gamma/r$ = 11.2 MPa.[1]

However, in humans, detectable venous gas bubbles follow decompression to sea level from as shallow as 138 kPa air saturation, implying gas supersaturation of only a few kPa are required for decompression bubble formation.[2] It is widely accepted that bubbles that form at such low gas supersaturation grow from pre-existing, micron-scale gas micronuclei. For such gas micronuclei to already exist prior to gas supersaturation they cannot simply be small bubbles because positive feedback of Laplace pressure causes a micron radius bubble to dissolve in a fraction of a second.[3] Theoretical candidates for gas micronuclei are bubbles coated in surfactants that counteract the Laplace pressure or crevices where gas voids assumes shapes that negate the Laplace pressure. However, to date, the nature of gas micronuclei that underly decompression-induced bubbles and decompression sickness have yet to be identified.

Consequently, I was intrigued that in two previous issues of *Diving and Hyperbaric Medicine* (2018 Volume 48, Issue 2, page 114 and Issue 3, page 197), letters from Ran Arieli to the Editor hypothesized a mechanism for decompression bubble formation in blood vessels and in the skin. Both letters stated "*It is known that nanobubbles form spontaneously when a smooth hydrophobic surface is submerged in water containing dissolved gas. We have shown that nanobubbles are the gas micronuclei underlying decompression bubbles and decompression sickness*". Surface nanobubbles have been extensively described in the physical chemistry literature, but the second sentence is supported by citation of an hypothesis article.[4] The latter is based on experimental work (referenced therein) in which sections of large blood vessels from sheep were incubated in saline and compressed to 1.013 MPa for 18 hours then rapidly decompressed to the surface, whereupon macroscopic bubbles were photographed forming on the luminal surface of the vessels. The authors speculate that the bubbles were forming from surface nanobubbles on the vessel lumen, but no experimental or analytical evidence was presented that surface nanobubbles were present on the vessel lumen or were the precursors of the observed macroscopic bubbles.

Surface nanobubbles form on atomically smooth, hard surfaces in gas supersaturated liquids and, imaged with atomic force microscopy, appear as spherical caps of gas. As far as I can determine, surface nanobubbles have not been reported on biological tissue surfaces. Surface nanobubbles typically have diameters less than 100 nanometers but have lifetimes that are orders of magnitude longer than would a bubble of similar dimensions. Surface nanobubbles do not grow into macroscopic bubbles when exposed to pressure waves sufficient to cause bubble formation from adventitious gas micronuclei elsewhere in the apparatus.[5,6] This is surely not the last word in this new and active field of research into nanoscopic gas species; however, based on current evidence one must treat with skepticism speculation that unobserved surface nanobubbles are the gas micronuclei from which bubbles form in humans with low gas supersaturation and which underlie decompression sickness.

References

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doi: 10.28920/dhm49.1.64. PMID: 30856670.

Key words
Letters (to the Editor); All other relevant keywords are in the title