HOW DO MICRONUCLEI GENERATE BUBBLES?

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1. WHAT TRIGGERS the formation of DCS bubbles?

We present a plausible description of micronuclei and how they may behave.

We assume that body fluids may contain semi-permanent spherical gas-filled aggregates of surfactant molecules that resist the collapsing force of surface tension (Fig. 1).

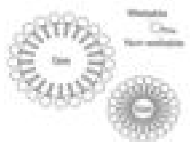


Figure 1. Cartoon of micronuclei, the lower one is at its minimum size.

We presume that gases can diffuse in and out of the micronuclei.

According to fundamentals of surfactant chemistry, forces exerted on the micronuclei are (in order in Eq. 1)

- Expanding pressure due to the surfactant molecules (C = a constant that depends on the number of molecules)
- Collapsing pressure due to surface tension (γ = surface tension, R = radius)
- Pz = collapsing pressures external to the micronucleus (atmospheric pressure, blood pressure, etc)

$$\frac{C}{R^3} = \frac{2\gamma}{R} + Pz \qquad \text{Eq. 1}$$

2. STABILITY. The forces balance, allowing a "stress-strain" diagram.

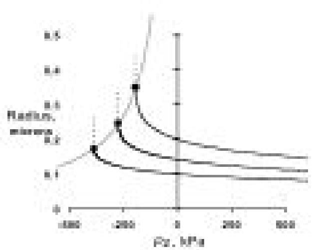


Figure 2. Graphs of Eq. 1 for three different micronuclei composed of different numbers of surfactant molecules.

About Fig. 2:

- The micronuclei are unstressed at zero Pz.
- Micronuclei can move to the right by compression (Boyle's law) or diffusion out of gas.
- They can move to the left by decompression or diffusion in of gas.
- If they get so big that the curve is vertical, stability is lost (black points) – they "nucleate" and release a bubble that grows rapidly due to unhindered diffusion from the surroundings (vertical dashed lines).
- The gray curve in Fig. 2 shows the nucleation radius for any micronucleus.
- Note that there is a threshold for nucleation (see the horizontal distance between the gray curve and the zero vertical axis in Fig. 2.)
- Does a micronucleus reconstitute itself around a small amount of gas after nucleation or is its structure destroyed?

3. FOUR PHASES DURING A SIMPLE DIVE.

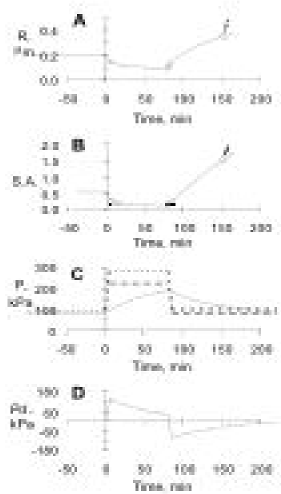


Figure 3. Expected changes during a moderately risky dive. A. radius of a micronucleus. B. accompanying changes in micronucleus surface area. C. tissue nitrogen tension. D. gradient for diffusion between the micronucleus and its surroundings.

- In Fig. 3A, compression decreases the micronucleus radius rapidly (first node).
- At depth, outward diffusion to the as-yet unequilibrated tissue or blood decreases the size a little more (second node).
- On decompression, the radius increases a little (third node) and then grows due to diffusion in from the now-supersaturated tissue or blood.
- When the micronucleus passes its critical nucleation radius, it releases a potentially damaging bubble (fourth node).
- Panel B shows the large surface area after decompression, it aids inward diffusion.
- Panel C shows the pressure changes and the tissue washin and washout of N_2.
- Panel D shows the diffusion gradient for shrinkage during the dive and growth after decompression.

4. BACK TO THE FIG. 2 DIAGRAM (R vs. Pz)

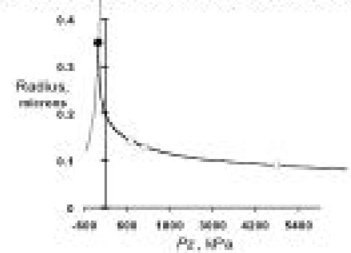


Figure 4. Location of the nodes from Fig. 3 on a copy of Fig. 2.

- In Figure 4, the micronucleus that was depicted in Figure 2 starts unstressed with zero Pz at 0.2 micrometer radius.
- Then it moves down the curve to the first node during physical compression.
- Then it goes all the way down to the third node during the diffusion phase at depth.
- Then it returns up to the second node during decompression.
- Finally it grows by inward diffusion until it nucleates (black point at the left).

5. CRUSHING

Experiments have suggested that bubble formation can be prevented by a short exposure at high pressure.

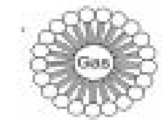
We envision two possible reasons why a micronucleus would not form a bubble after a dive.

First, it may have become so small during the dive that it cannot reach its nucleation radius after the dive.

According to this, exposure at high pressure may not actually destroy or "crush" micronuclei.

Second, a reasonable case can be made that surfactant-stabilized spherical bubbles can be destroyed or "crushed":

If the molecules are compressed together maximally, more compression would rupture the structure. If so, increasing positive Pz causes radius to decline moderately until it reaches a "critical crushing radius."



6. DISTRIBUTIONS OF MICRONUCLEI

We presume that the population of micronuclei can be characterized as a frequency distribution.

- Some micronuclei are probably bigger than others.
- If one assumes a distribution of sizes, one can characterize the distribution of critical nucleation pressures from information in Eq. 1 and a relatively simple calculus calculation.

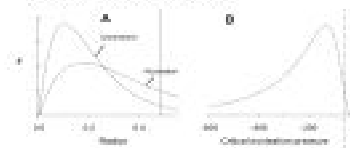


Figure 5. A. assumed distribution of sizes of unstressed micronuclei and sizes at the critical nucleation radius. B. calculated distribution of critical nucleation pressures for the panel A distribution.

- Panel A shows micronuclei at critical nucleation radius larger than unstressed micronuclei, as expected.
- Panel B shows the distribution of critical nucleation pressures. Note the threshold.

7. CONCLUSIONS

We have assembled this scheme from several noncontroversial ideas (Boyle's law expansion of gas, diffusion of gas, etc), and a few assumptions that are the most reasonable we can imagine.

Our theoretical scheme will have merit if it inspires experimental work to support or refute it.

Reference. Van Liew HD, Raychaudhuri S. "Stabilized bubbles in the body: pressure-radius relationships and the limits to stabilization." J Appl Physiol. 1997, 82:2045-2053.