Blood Shift and Lung Squeeze

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From the time the freediver commences the breath-hold at the surface, peripheral vasoconstriction acts to move blood from the extremities into the organs in the thoracic region, beginning the blood shift. Vasoconstriction is further enhanced when the face is immersed.

As the freediver submerges and depth increases, water pressure also increases, causing the chest and diaphragm to be compressed inward. At some point, the limits of chest compression and diaphragm flexibility are reached. As depth continues to increase, the water pressure on the extremities along with peripheral vasoconstriction cause a higher pressure in the peripheral blood supply than exists inside the chest. This pushes blood from the extremities into the thoracic organs.

Much of this additional blood in the thorax goes into the lungs and into the pulmonary capillaries in the alveoli walls. This causes the capillaries to expand and compress the intra-alveolar gases. Intra-alveolar gas pressure, overall lung gas pressure, and therefore overall pressure inside the chest all increase as a result. The pressure increase inside the chest opposes water pressure on the outside of the chest, and is what prevents the chest from being crushed on deep dives.

It is an oversimplification to talk about the lungs being compressed to the size of apples, or grapes, or whatever, as once the limits of chest compression and diaphragm flexibility are reached during the descent, the lungs do not actually shrink much more. The limits of chest compression and diaphragm flexibility prevent it. Probably if the whole lungs were squashed to the size of apples, blood flow in the lungs would be squashed as well. Contrarily, blood shift relieves some of the pressure on the chest while still allowing adequate blood flow through the lungs and heart.

Blood shift continues with increasing depth, and is what has made it possible for freedivers to achieve such great depths. This process relies ultimately on the elasticity of the capillary walls in the alveoli. The limiting factor ends up not being water pressure pushing on the chest, as this is nicely handled by the blood shift, but rather the pressure difference between the pulmonary capillaries and intra-alveolar gases.

Lung squeeze occurs when at some point the capillary walls are stretched past their elasticity limit and start to burst. Blood enters the air spaces of the lungs - pulmonary edema [1], and we see it when the diver spits up blood at the surface. It is possible that, in addition to the depth itself, irregular motions and turns might precipitate this kind of squeeze. I suspect that along with depth, anything that might introduce unbalanced stresses in the chest and lungs might increase the likelihood of a squeeze.

Movements that reduce intra-alveolar gas pressure might increase the probability of a squeeze as well. Putting the arms overhead or pushing the diaphragm toward the pelvis could do this. These motions perhaps slightly increase lung volume and reduce intra-alveolar gas pressure relative to pulmonary capillary pressure, sending the pulmonary capillaries closer to their bursting point. Reverse packing [2] would have a similar effect. While not increasing lung volume as the other motions above, this practice reduces intra-alveolar gas pressure by forcefully withdrawing air from the lungs.

Anything that increases blood pressure generally or raises pulse rate might also be a factor. Every time the heart beats, it sends a pressure spike downstream through the pulmonary arteries and capillaries.

Lung squeeze is not a trivial matter. In addition to the visible blood, lung squeeze can in serious cases cause difficulty breathing, reduction in arterial oxygen saturation, unconsciousness, and death. [1]

Take a look at Figure 4, page 288 of "The physiology and pathophysiology of human breath-hold diving" [3] for an excellent illustration and explanation of blood shift and lung squeeze.

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References

[1] Wikipedia contributors, Pulmonary edema, *Wikipedia, The Free Encyclopedia*, 18 February 2015.
[2] Walter L Johnson, Packing, *freedivingsolutions.com*, 12 April 2015.
[3] Peter Lindholm and Claes EG Lundgren, The physiology and pathophysiology of human breath-hold diving, Journal of Applied Physiology, vol. 106, no. 1, pp. 284-292, 1 January 2009.