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The Sights and Sounds of Air

"Believing that it is good practice to prepare for war in time of peace, I intend on this occasion to call your attention to one of the most dreaded and, I may add, one of the most uncontrollable causes of death; I allude to air-embolism" (Senn N: An Experimental and Clinical Study of Air-Embolism. Annals of Surgery, 1885)

A SENSE OF HISTORICAL PERSPECTIVE is important in retaining our ability to measure developments and progress in science, with medicine being no exception. It is beneficial to understand the origins of methods and techniques; meaningful to document the early beginnings of scientific hypothesis; and both exciting and humbling to realize that epistemological considerations of specific biologic criteria occurred in many areas, even centuries before the advent of twentieth century medicine.

Before celebrating the important technological developments described by Martin and Colley[1] and Furuya and co-workers[2] in this issue of ANESTHESIOLOGY, it might be useful to place some of the problems associated with venous air embolism (VAE) in some type of historical perspective. Throughout the history of science, important landmark findings have often been ignored, obscured, and brought to light only as an afterthought or in the context as an unimportant medical curiosity. Two towering magnum opuses on air embolism appeared in the nineteenth century, the first a book by Amussat[3] (225 pages) published in 1839, and the second a long dissertation by Senn[4] (115 pages) that was printed in 1885. Between the two of them, Amussat and Senn collected, reviewed, and described more than 250 clinical cases and case reports of VAE and many hundreds of experiments using a variety of animal species. It is to be remembered that VAE was a much feared complication during the nineteenth century in the spontaneously ventilating (anesthetized or non-anesthetized) patient, with many surgical procedures carried out in the sitting or semisitting position. In fact, more than 150 articles, reviews, and books were published on air embolism during the 1800s.

Amussat's[3] and Senn's[4] descriptions and speculations about the physiopathology of air embolism (both venous and arterial) are extraordinarily modern in context. They noted the heart tone changes that we have labeled "millwheel," the gasping respiration, cyanosis, and cardiovascular collapse. They spoke about mechanical overdistension of the right side of the heart due to air bubble accumulation, asphyxia from obstruction to the pulmonary circulation often producing acute "anemia of the brain" and causing "acute cerebral ischemia." They also were familiar with the different responses to venous air and arterial air embolism and experimentally described and clinically documented that the development of gradients between the right heart and incisional area was critical in promoting the movement of air ("The force of gravitation"[4]). Amussat and Senn identified VAE in cases involving internal, external, facial, axillary, anterior thoracic, superficial cervical, femoral, internal saphenous, uterine, pulmonary, and diploic veins as well as the superior longitudinal and uterine sinuses. They also advocated the prophylactic approach of painstaking hemostasis by compression, flooding the operative field, and vein ligation. In a number of elegant experimental studies, they demonstrated that air in the right side of the heart could be removed by needle aspiration or by the introduction of a cannula or catheter via the jugular vein into the atrium and subsequent aspiration.

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The work of Michenfelder *et al.*[5] concerning the use of the right atrial catheter for VAE aspiration, the employment of the ultrasonic Doppler for air bubble detection as pioneered by Maroon *et al.*,[6] and our knowledge of the gas solubility factors enhancing bubble size that was contributed by Munson and Merrick,[7] are all modern extensions of the nineteenth century work on air embolism highlighted by Amussat and Senn.

Unfortunately, and in spite of our more sophisticated diagnostic and therapeutic approaches, VAE still carries with it a propensity for severe morbidity and mortality that has been pinpointed in the neurosurgical patient, but probably also occurs in other surgical specialties and in trauma.[8] Recognition of the risk of VAE is important also because of the dangers involved in the development of paradoxical air emboli[9] via a probe-patent foramen ovale or across the pulmonary capillary bed.

In our search for improving methods of air bubble detection, the two papers in this issue of ANESTHESIOLOGY have given us the potentiality of being able to detect the "sights and sounds of air" on the left side as well as the right side of the heart. The clinical implications in the use of this type of technology are indeed important when one remembers that the sequelae of embolization of air into brain can be treated successfully by hyperbaric oxygenation if therapy can be instituted early. The early detection of air entering the left side of the heart would alert us to the occurrence of a paradoxical embolus and possible embolization to the brain.

By using a transesophageal Doppler transducer, Martin and Colley are able to avoid chest configuration problems found with the precordial Doppler. Their 360° Doppler probe has a good sensitivity and the ultrasonic output is in the range that is safe for biologic tissues.[10] By placing another probe at the appropriate anatomic level, it also might be possible to monitor right and left heart simultaneously using a unit that would be relatively inexpensive.

Echocardiography has proven to be a very valuable non-invasive technique for the diagnosis and evaluation of cardiac disease. It can dynamically image and trace cardiac structures and changes on a beat-to-beat basis, and is reliable and reproducible. By going the transesophagel route, Furuya and co-workers have obviated the difficulties of using the precordial echocardiograph in the obese patient or one who has a chest deformity. Their unit has the capability of imaging occult air on both left and right sides of the heart simultaneously, and they have noted good sensitivity and reliability. Perhaps this device might be limited somewhat for clinical use because of its present cost, and because of the fact that one must continuously scan the paper visually for evidence of air passing the transducer.

In terms of making surgical procedures safer for the patient, it is exciting to realize that these devices are available now (or will be shortly), and in the historical perspective, represent another quantum of the beneficent aura cast by Amussat and Senn.

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