Experiences with Air Embolism

W. J. KOLFF, M.D., Ph.D.

Most Common Cause

Most commonly, air emboli occur because there is a need for rapid transfusion of blood or infusion of solutions. The need is most likely to occur during operations and quite often, air is pumped into the transfusion or infusion bottles to accelerate the flow. If the attention of the physician or nurse in charge of this bottle is diverted, as is likely when the patient is in trouble, a large amount of air may enter the patient’s vascular system.

Initially the blood level in the bottle falls very slowly. It goes much faster when it begins to descend in the tube. The largest acceleration takes place when the air passes through the narrowest part of the line which may be a screw clamp or the needle in the vein. The narrow point offers a certain resistance to blood, but the resistance to air is very much less and therefore the air rushes in at a greatly accelerated speed.

Many deaths have occurred all over the country as a result of the practice of pumping compressed air in a blood or infusion bottle. The Department of Anesthesia in the hospital where I worked had a float in the drip chamber. Air would cause the float to close off the outflow. It was not always effective.

During regional heparinization, one infuses heparin into the arterial line and protamine sulphate in the venous line of an artificial kidney. The pressure on the arterial inflow line may be considerable, and it becomes impractical to give a continuous drip of heparin into the arterial line when this is propelled by gravity only. Many years ago, we hooked up bottles in tandem and we applied gas pressure to the first bottle only. The rule was that the second bottle should always be filled.

To further decrease the danger, we used compressed CO₂ rather than air because CO₂, in case of an embolism, can be absorbed much more rapidly. One night, the resident on call, realizing that heparin was expensive, thought that this extra bottle was a waste of money and eliminated it. During the small hours of the morning, the heparin bottle ran out and the CO₂ under pressure rushed up, partly toward the artificial kidney, but much more seriously, it ran up against the stream into the patient’s artery.

What happened was described as a convulsion and the patient died instantly. I arrived 20 minutes later, and it was not hard to reconstruct what had happened. The right arm was practically bloodless., the blood having been replaced by the CO₂. From that date on, we made a rule that under no condition were we to allow gas under pressure to be pumped in a bottle that is connected to the vascular system of the patient.

Plastic Bags

In our dialysis patients, we go through the trouble of transferring infusion fluids into plastic bags. These plastic bags can then be compressed by air on the outside. Since there is no air in the plastic bag, air embolism cannot occur. I have been told that in Canada, one can buy IV solutions in plastic bags. Is it the glass lobby that made their sale illegal in the United States? If so, we need an anti-lobby.

Air emboli of a different nature can come from bubble oxygenators. These
emboli are so small that they can usually not be seen and most surgeons get away with the use of bubble oxygenators without much trouble. However, it is not certain that the patients always get away with them. We are all familiar with the mental changes that sometime occur in patients after open-heart surgery. Loss of memory may be transient, but not always. I know of a case where a patient's memory was wiped out forever.

Most enlightening, but also most disturbing is the study performed by Dr. Simmons presented at the meeting of the AAMI and at the American Society for Extracorporeal Technology in 1970. He first opened the skull of dogs and then treated them with conventional pump oxygenators. During the run, air could quite clearly be recognized in the small vessels of the brain.

Air At Autopsy

One might ask why air in the brain has so rarely been recognized at autopsy. The answer is that its presence is very difficult to prove. When the skull is opened and the skull cap is removed, suction nearly always occurs and air will then enter through the cuts in the vessels of the cadaver. Therefore, air in the blood vessels in the brain is a common finding at autopsy, but it is an artifact. Even when the skull is opened under saline, the fact that the air or gas was there when the patient was alive is hard to prove.

Pump oxygenators are of course not the only source of air emboli during open-heart surgery. Many times air is trapped in the heart cavity. I believe that it is wise to flush the open chest with CO₂ during the time the heart is open. Any gas entrapped would be, at least to a certain extent, CO₂.

If anybody doubts the possibility of keeping CO₂ in an open well, place a burning candle in the bottom of a pail, with a tube releasing CO₂ at the rim of the pail. The CO₂ being heavier than air, will sink to the bottom of the pail and extinguish the candle. To convince our surgical friends that it would be worthwhile to flush the chest cavity with CO₂, we actually carried the burning candle in the pail into their office and convinced them with the experiment. However, after a while, they became annoyed with the extra tube on the chest wall and abandoned the practice.

Fortunately, most air can be removed from the heart cavity and from the aorta by puncturing at the highest point. Air is quite often seen in the coronary arteries during open heart surgery. I believe that the best thing to do then is to continue perfusion with sufficient pressure head. The air will finally migrate through the coronary arteries and no lasting damage is done.

Whenever a pump is used in a system, there is a possibility that the pump created sub-atmospheric pressure and that air enters the system through a small needle hole or junction. If the vacuum is low enough, degassing of the blood will take place which will create enough gas to cause embolism.

Air Emboli During Hemodialysis

During treatment with the artificial kidney, air emboli can originate from:
1. IV bottles, either on the arterial or the venous side.
2. Heparin or protamine sulphate administration.
3. It can be sucked into a system whenever a pump is used.
4. Air can lodge inside an artificial kidney when it is not properly flushed.
5. During removal of blood from either a Kil or a coil kidney, some people use air to displace the blood. It is dangerous, particularly when that air is pumped in.

Notwithstanding these possibilities, air emboli were relatively rare until recently. AV fistulas increased the risk of air embolism.

AV fistulas are a great improvement for many patients. A blood pump is usually needed. And to get enough flow, the blood pump must actually suck. If the blood flow through the needle or cannula suddenly stops, a fairly high vacuum can be created, which may aspirate air. This air can be pumped all the way through the kidney until it fills the bubble trap and if it is not detected, it will continue its way through the venous return line to the patient. The flow is slow until the last obstruction narrow spot in the line is reached and then the air rushes in.

Without sending out questionnaires, or talking to a large number of our colleagues, we have heard of five fatal air emboli and quite a few near misses. The air may either enter in small quantities mixed with blood over some time or it may rush in in a large volume all at once. When that happens, it is likely that the patient experiences acute distress. He may become blue, have air hunger, cough, vomit, have severe pain in his head and back or chest or he may convulse.

The picture may be most alarming, which indeed it is. The family in attendance may rush to the aid of the patient, one holding his head, somebody rubbing his back, or rushing for a basin so he won't vomit all over the bed. In the meantime, chances are that air goes undetected and continues to be pumped into the patient.

We use many fistulas and hope to continue to use them, but we insist that our patients be protected by an air bubble detector in the blood flow line from the kidney to the patient. When an air bubble is detected, the venous return line is immediately clamped, the blood pump is stopped, a light blinks and an alarm sounds.