



Guest Editor

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A Retrospective On Extracorporeal Circulation

It may sometimes be useful, it certainly is common, for older people to tell “how it was.” The steps in between “what it was like then” and the always wonderfully modern “now” help to identify the steps in knowledge which actually led to making something work. This is not going to be a historical review. I dare not name the pioneers who did the work lest I inadvertently omit one. I will try instead to give some feeling for the ebb and flow of the technology of perfusion as it started from almost nothing and added small bits of new knowledge. Finally, as this is an editorial rather than a scientific paper, I will claim the right to merge and mingle my own impressions of what is true with what has been demonstrated as true by rigorous experiment.

In 1940, extracorporeal circulation (whole-body perfusion) was generally known to be impractical and probably impossible (except in the mind of John Gibbon and a very few others). This “knowledge” was based on a common experience: it had been tried many times, and by and large, it did not work. There seemed to be something magically toxic about taking blood out of the body and returning it. The experimental animals always died.

There were many apparently insoluble problems. An early one is that blood is extremely foamy. Before the advent of the defoaming silicone oils, it was very difficult to take blood from the body, spread it into a film thin enough for oxygenation, and return it to the arterial system. The blood foamed while being oxygenated. It foamed like the legendary magic porridge pot. It foamed ankle-deep over the laboratory floor. John Gibbon, working in limited facilities with Mrs. Gibbon’s help, solved the foaming problem by using the centrifugal force inside a spinning cylinder, an ingenious technique which became unnecessary after silicones arrived. Others developed a wide

variety of filming systems which minimized foaming. Many were variations of the spinning disc dipping into a pool of blood. There were screen wire discs, plastic discs, large and small discs, and inside-out ones. Some systems, such as Gibbon's later "stationary screens" maintained a continuous flow over the filming surface so that there was no place for foam to start forming. Many of these systems worked well.

But solving the mechanics of a workable heart-lung machine did not solve the problem. Perfusion remained a highly lethal procedure both in experimental animals and in patients. The reasons for this seemed entirely incomprehensible at the time. Yet by hindsight, they were largely simple. In medical school I had a Professor of Surgery who kept emphasizing that many of the important factors in surgery were so simple and obvious that "any streetcar conductor" would know them, and yet highly educated physicians constantly forgot them. He was right. I keep seeing this ghostly, mythical streetcar conductor running (or should we say clanging) his way through the history of perfusion.

I am going to chronicle some of these simple things which looked so difficult, and which "we should have seen." Each of these was an important step in the development of the technology, though some of them seem commonplace now.

1. The recognition that blood must be handled gently. In the early 1950's, the experimental animals of most research workers were dying some hours after the perfusion, but those of John Gibbon were not (this was hard to believe at the time). The only reasonable explanation to us then (and I believe the true one) was that he handled the blood more gently, he avoided turbulence, and he passed it over meticulously cleaned surfaces.

2. The advent of Silicone-oil defoaming which allowed oxygenation by bubbling oxygen through blood. This enormously simplified the mechanics of extracorporeal blood oxygenation, but it carried its own hazard in the form of silicone emboli if the defoaming material was improperly prepared.

3. The design of the first bubble oxygenators made of totally disposable tubing. These worked much better than previous "bubblers," but it was not recognized until some time later how much of that advantage was because they used new tubing and other materials each time they were used, so that there was no foreign protein problem (See #6). A later and again largely unrecognized advance was in wrapping the defoaming section in cloth which acted as a partially effective filter (See #7).

4. Adequate flow and pressure. Many early oxygenators could supply only a limited flow of oxygenated blood. For a while this defect was touted as a virtue. "Azygo or perfusion at very low flows became popular largely because there was no alternative. This experience demonstrated that patients could survive rather long periods of controlled. It was some time before it was well recognized (as the capacity of oxygenators improved) that although patients may indeed survive low flow perfusions, they do much better if flow and blood pressure are kept in normal ranges. The streetcar conductor would have known this.

5. The use of hypothermia. It was recognized early that hypothermia reduced metabolism and hence oxygen uptake. It took longer to recognize that it also reduces damage to the blood enzyme systems, especially to the coagulation cascade system. It supplies a wider margin of safety for major physiological systems when they are being disturbed. But the exploration of the limits of hypothermia carried a high mortality,

because there are limits. All tissues do not cool at the same rate. Major intracellular electrolyte shifts take place. There is a price to pay for the extra time gained.

6. Pyrogens and “pump–lung.” It seems clear now that “pump–lung” (postoperative hemorrhagic atelectasis) was most commonly caused by dirty oxygenators. But it was far from clear then. Yet we should have known. It had been well established a few years earlier that it was essentially impossible to re–use blood transfusion sets without getting severe febrile reactions, no matter how carefully the tubing was cleaned. We then went and built heart–lung machine systems with hundreds of times the surface area of transfusion tubing, cleaned them in a rather desultory way, and were then exceedingly surprised when we got severe reactions. Among the worst of the systemic symptoms was pump–lung. Any streetcar conductor would have told us that if the re–use problem was bad with transfusion sets, it would be much worse with heart–lung machines. I have personally seen several “epidemics” of pump–lung cured (in the days of disc–oxygenators) by persuading the assembly technician to “sniff” the interior of the “lung.” If there was any perceptible organic smell, the machine was sent back for recycling through a chemical cleaning program.

7. Membrane oxygenators and “surface denaturization.” There has been considerable evidence from the earliest days of pump–oxygenators that properly cleaned and assembled membrane oxygenators can be operated for longer safe perfusions than “bubbles” or “discs.” For many years, conventional wisdom said that this was because the presence of the membrane prevented the “surface denaturization” which occurs at any direct interface between a liquid protein solution and a gas. Surface denaturation does take place, and it may well be a factor in the superiority of membrane oxygenators for very long perfusions. But it is my personal opinion, which I admit I cannot prove by direct evidence, that the early superiority of membrane systems over bubblers and discers was because with their multiple thin layers they acted as relatively efficient filters, which led to the next large jump in technology, filtration.

8. Microemboli, filtration, extracardiac suction and postoperative psychosis. One of the most important recent advantages in “pump” technology was the demonstration that a major cause of perfusion toxicity is the presence of cellular micro–aggregates in the perfused blood. Curiously, this finding grew from the work of a neurologist, Swank, rather than from a perfusionist. There is good evidence that blood sucked back from outside the heart by the extracardiac or “coronary” suckers contains a large number of emboli of many sorts, including tissue fragments, clots, and cellular clumps. Although extracardiac “sucked” blood contains the largest and most numerous emboli, even clean blood from the reservoir of the machine contains a reasonably large number. They appear first in the venous blood emanating from the patient, probably resulting from some kind of partial activation of the clotting system by the perfusion. The most common emboli seem to be platelet and white–cell aggregates.

We were slow to recognize their presence though it is obvious enough that the extracardiac blood is necessarily “dirty” blood. I can hear my streetcar conductor saying “of course you ought to filter your blood. Who can tell what lumps and bumps you may get into it when you let it out of the body.” What was remarkable and very satisfying was that a major complication of open heart surgery, post–operative psychosis, diminished sharply when continuous blood filtration was added to perfusion.

I have briefly described what I believe are the major advances which have made whole-body perfusion for open-heart surgery relatively safe and easy. They include recognition that: 1. blood is easily damaged and must be handled gently, 2. adequate flow and blood pressure are preferable to shock, 3. hypothermia increases the safe margin for mistakes, 4. dirty tubing or machines cause severe reactions, 5. the quality of the surface touched by the blood is important for long perfusions, 6. "Dirty" or "activated" blood should be filtered.

This brings us up to date. But the story is by no means over. What are we still doing wrong right now? Things are much better, but they are by no means perfect. What will "any streetcar conductor" be saying ten years from now? Are we causing excessive trauma to blood components by the energy released, as bubbles burst during defoaming, and is this easy to minimize? Are there means to depress and minimize the "activation" of coagulation and proteolytic enzymes by perfusion which are so obvious we are missing them? I don't know, but I am sure that if future knowledge follows the pattern of the past, a certain humility is in order.