The Engineering of Cardiopulmonary Bypass

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SUMMARY

Cardiopulmonary bypass (CPB) has reached “gold standard” status in cardiovascular surgery for obvious reasons. In the same breath speaking of respect for its capability, there are often cries for its elimination. The absence of controlled clinical studies significantly powered to demonstrate or refute improvements in the CPB systems in use today has left perfusion practice fragmented. Recently, there has been a heightened interest in minicircuits that eliminate the conventional venous reservoir. There are glimpses of what mini-CPB systems could provide in terms of benefit, but the current systems, assembled largely from components designed a decade ago, are far from optimized. Six degrees of engineering separation are presented, which separate what CPB “is” today with what CPB “should be.” With these improvements, CPB can once again be an enabling technology, this time for the next generation of minimally invasive surgical, as well as nonsurgical, procedures.

Key Words: CPB; extracorporeal circulation; minicircuits; micro-air; membrane oxygenator.
INTRODUCTION

With apologies to Daniel Handler (1), if you were expecting a technical review of all the engineering accomplishments and historical improvements in the tools that have enabled cardiopulmonary bypass (CPB) from the days of Dr. Gibbon (2), leading to a placating thesis of how the engineering of CPB has a rosy future in the capable hands of the current product suppliers, then you have come to the wrong place. If that is your interest, you would be well advised to pick up something else (3) to occupy your intellect, or at the very minimum skip this chapter altogether.

At the time of the preparation of this manuscript, there were 1767 published US patent applications containing the words cardiopulmonary bypass (4). For every application aimed at engineering an improvement, there were at least 10 applications aimed at engineering its elimination. This is not entirely new, as the conduct of CPB, at least for coronary artery bypass graft (CABG) surgery, has been under an engineering and marketing attack for more than a decade with the development of “off pump” revascularization platforms (5–7). Even from within the walls of the surgical suite, the vast extracorporeal circuit assembly and equipment used to assume the function of the patient’s heart and lungs has been an easy mark (8–10). The perfusionist has often been assumed guilty by association (11). Today, this attack continues to fuel alternatives to CPB for coronary revascularization, and has aggressively expanded with companies racing to develop platforms for percutaneous repair and replacement of heart valves (12–14). It is not worth debating what the ultimate fate of traditional CPB will be, but it is safe to assume that funding will continue to stimulate innovation aimed at engineering its elimination. As bleak as the future sounds, thankfully (for the patient), there is enough evidence in the scientific literature that CPB “best practices” should be sufficient to stave off these alternatives (15). With some fundamental reengineering and extension of these practices, the conduct of CPB could become an enabling technology once again in the development of surgical (and nonsurgical) approaches that are truly minimally invasive. Exploration of this path is the primary intent of this chapter.

CARDIOPULMONARY BYPASS TODAY

Historical Perspective

The strengths of traditional CPB require little explanation. Nearly 50 years of continuous use has demonstrated the ability of CPB to enable the practice of cardiac surgery. There have been significant efficiency