Cardiopulmonary Bypass in 2009: Achieving and Circulating Best Practices

As an intern at the Massachusetts General Hospital in 1932, Dr. John H. Gibbon Jr lamented the loss of one of his charges, a gravida who succumbed to an amniotic fluid embolus. He wrote, “During that long night’s vigil, the idea occurred to me that the patient’s life might have been saved if some of her cardiorespiratory function might be temporarily taken over by an extracorporeal blood circuit.” So began his more than 20-yr quest to develop an extracorporeal support device that would eventually permit open-heart surgery. In May 1953, at Jefferson College Hospital he culminated this effort with the successful repair of an atrial septal defect in an 18-yr-old woman using what is now known as cardiopulmonary bypass (CPB). This seminal event broke a long-standing barrier, operating on the heart, and initiated the era of modern cardiac surgery. Physicians treating patients suffering previously untreatable cardiac pathology (congenital lesions, valve malformations, coronary artery, and thoracic aortic disease) now had therapeutic options. Today, more than one million cardiac procedures that depend upon CPB are performed annually worldwide.

Although the past 50 yr have brought improvements in extracorporeal technology, including improved gas exchange devices, venous reservoir construction, and heparin-coated circuits, the modern extracorporeal circuit is still remarkably similar to that developed a half century ago. However, over the last decade, a large body of research has substantially improved our understanding of the pathophysiology induced by CPB. Although we have learned much, the substantial morbidity still suffered by patients managed with CPB, amply demonstrates that we have more to learn than we have mastered. Adverse outcomes associated with bypass (Type I central nervous system events, 3%–6%; long-term cognitive dysfunction, 15%; renal dysfunction, 7%–9%; hemodialysis, 1%–2%) are substantial. Despite the advances, definitive answers and consensus on optimal practices are unrealized. Fundamental questions remain regarding the management of CPB; for example, what pump flow, arterial blood pressure, temperature, acid-base strategy, hematocrit, or glucose level should be targeted during bypass. This difficulty, in part, reflects the enormity of the task at hand: creation of a mechanical model for the complex and dynamic human circulatory system.

This month’s journal features a comprehensive review by Murphy et al.1 that is substantial and timely. Their effort summarizes the evidence supporting or refuting the use of specific physiological goals during CPB, with particular consideration given to the components of the bypass circuit. The authors characterize the physiological parameters (mean arterial blood pressure, pump flow rate, hematocrit, temperature) and technologies (heparinized versus nonheparinized circuits, arterial line filters, pulsatile versus nonpulsatile pumps, centrifuge versus roller pumps) that may allow for “optimal perfusion.” Their article adds to the ongoing trend in medicine to standardize practices based on the best evidence available. Currently, the management of patients during CPB varies substantially by institution and even by practitioner (including the surgeon, anesthesiologist, or perfusionist involved).
Several groups have made efforts to address the dearth of perfusion best practice guidelines. But, to date, standardized recommendations have not been widely adapted. DiOrio et al., working on behalf of the New England Consortium of Cardiac Surgery, found that <25% of their members followed the practice paradigms developed by their own group. To address these issues, the Society of Cardiovascular Anesthesiologists, represented by Mike D’Ambra and the Allied Health Committee, has convened a task force that includes representatives of the Society of Thoracic Surgeons and the American Society of Extracorporeal Technology. This group is tasked with identifying and promulgating best practice perfusion guidelines to health care professionals caring for patients managed with CPB.

The use of α- versus pH-stat acid-base management during hypothermic CPB has long been a topic of controversy. In this issue of the journal, Hoover et al. compare the use of the two strategies in patients with impaired cerebral blood flow (CBF) autoregulation randomizing 40 coronary artery bypass graft patients with clinical factors associated with impaired cerebral autoregulation (age >70 yr, a history of hypertension, diabetes, and/or stroke) to either strategy. The purported advantages of pH-stat management are the sequelae of increased CBF, enhanced cerebral protection by more homogeneous brain cooling and superior maintenance of enzymatic function. Although pH-stat strategies appear to be associated with improved neurological outcomes in pediatric patients, the potential benefit of an increase in CBF seems to be lost in populations in which intraoperative cerebral embolic phenomenon are more prevalent. Alpha-stat management preserves cerebral autoregulation, thus preventing brain hyperperfusion and the attendant increase in cerebral emboli.

The Hoover et al. study presents another permutation in this debate. The increase in CBF seen with pH-stat management has generally been regarded as “luxury” flow. Measuring jugular venous oxygenation, the investigators identified periods of desaturation (percent oxygen saturation of jugular venous blood hemoglobin [SjvO2] <50%) and reduced blood oxygen content (partial pressure of oxygen in jugular vein plasma [pO2] <30 mm Hg) during rewarming in the α-stat managed but not the pH-stat patients. The investigators point out that cerebral desaturation has been associated with poor neurological outcome and suggests that pH-stat management appeared to prevent such desaturations. The conclusions, however, that pH-stat management offers a significant advantage over α-stat management in this high-risk population is premature. The study was neither designed to look at adverse cerebral events nor did they monitor for subtle cognitive dysfunction. However, it is noteworthy that cerebral injury occurred more frequently in the pH-stat group. This raises the question of whether these periods of venous oxygen desaturation are clinically important.

Hoover et al. also highlight the limitations of our current cerebral monitoring technologies. The use of jugular venous bulb probes in all patients is impractical and possibly hazardous and thus, noninvasive cerebral oximetry serves as an alternative to monitor global brain venous blood oxygen saturation. However, because the vast majority of cerebral injury in adults is a consequence of embolic phenomenon, increasing CBF (and thus, improving global venous oxygen saturation) will not reduce but may, in fact, increase the risk of embolic ischemic injury. At Stanford, we currently limit the use of cerebral oximetry to patients at increased risk for reductions in CBF (ascending and/or aortic arch surgery, carotid procedures). However, perhaps we should consider applying this technology to patients at risk for impaired cerebral autoregulation. But, even if venous desaturations represent periods of real and potentially serious cerebral injury, is pH-stat management (essentially increasing the partial pressure of CO2) the best means to address this apparent problem? Could other maneuvers, such as increasing pump flows or pressures, a reduction in the rate of rewarming, and/or administering drugs to decrease cerebral metabolic rate, achieve the same effects without increasing the risk of embolic injury associated with pH-stat management?

The publications in this month’s journal illustrate that we have a long way to go before we can claim to have fully realized the landmark innovation that Dr. Gibbon first implemented in 1953. In a sense, we have only begun this process, but our predecessors and our current colleagues have added and continue to add critical information to our understanding of the benefits and limitations of CPB. As we continue this journey, an alliance of the professionals responsible for the care of patients during CPB “best practices” is based on the data currently available. Perhaps another 50 yr of research will culminate in a system that exactly replicates outside of the body “optimal” cardiorespiratory function: stem cells to replicate a compatible heart and lungs for short-term use? The suffering of Gibbon’s patients and families inspired his impassioned search for a method to provide extracorporeal circulation. We are similarly challenged by the individuals that we care for everyday. It is our privilege to follow Gibbon’s lead and continue the search for methods to provide “risk-free” CPB and improve our patients’ lives.

REFERENCES


