EDITORIAL/REVIEW

Pediatric Perfusion: An Evolving Science

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Although the first successful clinical application of extracorporeal circulation for open-cardiac surgery involved a young adult patient, the operation performed was closure of an atrial septal defect which is, of course, a form of pediatric heart disease (1). Since that beginning, the application of cardiopulmonary bypass to younger patients has progressed dramatically and broadened considerably in scope. Today, the practice of pediatric perfusion includes, in addition to bypass for open-heart surgery, long-term extracorporeal membrane oxygenation, application of perfusion technique to facilitate neuro and hepatic surgery, in vitro perfusion of organs for transplantation, and use of various monitoring techniques for the intensive care patient. In this article, we will confine our comments primarily to cardiopulmonary bypass for open-cardiac surgery in the pediatric patient and will discuss past milestones, current controversies, future horizons, and pediatric perfusion as a distinct subspecialty of extracorporeal technology.

Cardiopulmonary bypass for open-heart surgery in children in the late 1950s and early 1960s was merely a scaled down protocol reflecting the adult perfusion methods in use at the time. Since that time, the trend in pediatric cardiac surgery has been towards earlier total repair of more complex congenital heart defects. The development of deep hypothermia and circulatory arrest as a useful technique for open-cardiac surgery in infants and small children in the 1960s (2) was a milestone that clearly separated, for the first time, pediatric perfusion from routine cardiopulmonary bypass. The use of circulatory arrest has always been somewhat controversial, but its use has undeniably greatly facilitated the development of surgery for complex congenital defects in infants. More recently, low flow techniques have been developed and employed in place of circulatory arrest. Some feel low flow techniques have supplanted the need for circulatory arrest almost completely. This debate rages on, but clearly, applications of cardiopulmonary bypass in small infants are here to stay. Membrane oxygenators, improved high-flow cannulae, and potassium cardioplegia solutions have also had tremendous impact on pediatric perfusion. The membrane oxygenator has made prolonged cardiopulmonary bypass for correction of very complex defects safer and has even allowed extended support in the ICU to be accomplished successfully in some instances. The development of improved high-flow cannulae has made the surgeon's job far easier since acceptable external diameter cannulae for insertion now have adequate lumens for ample flow during cardiac procedures. The rediscovery of potassium cardioplegia solutions as a mechanism for myocardial preservation during cardiac surgery has had a tremendous effect on the ability to repair complex defects in older children. The use of these solutions in infants, however, is still controversial and many unanswered questions remain.

The field of pediatric perfusion as it exists today is filled with controversies. There are as many methods and protocols to handle each individual situation as there are perfusion groups or even individual surgeons and perfusionists scattered throughout the country and the world. One of the controversies that was alluded to earlier is the use of potassium cardioplegia solutions in immature myocardium. It has been clearly demonstrated that neonatal myocardium differs from adult myocardium in its ability to maintain adenosine triphosphate precursors during ischemia and immature myocardium also appears to have a much more efficient mechanism for employing anaerobic metabolism as an energy source. These characteristics of immature myocardium make cardioplegia almost superfluous if profound hypothermia is used during cardiac surgery. If circulatory arrest is employed, crystalloid cardioplegia may well be detrimental since the buffering capacity of the bicarbonate solution is so much weaker than that of blood and myocardial acidosis from active anaerobic pathways results when no possibility of washout of the cardioplegia from the capillary bed is present. It could be that blood cardioplegia or other highly buffered solutions could be used in this situation successfully.

Another area of controversy related to profound hypothermia during cardiopulmonary bypass relates to control of pH under these conditions. We know from studies of cold-blooded animals that as the temperature drops the natural physiologic response is progressive alkalosis. This so called alphastat theory is easily employed if blood gas measurements are uncorrected for temperature. One then merely maintains a normal pH at a blood temperature of 37° regardless of the temperature of the patient when the blood sample is obtained (3). The pH stat theory, which is used by some, maintains normal

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pH at the temperature of the patient when the blood was collected. Certainly this circumstance for a lizard represents extreme acidosis and is also likely acidotic in a human infant.

Controversies between circulatory arrest and low-flow cardiopulmonary bypass for correction of defects in small infants centers primarily around potential for neurologic sequelae if circulatory arrest is employed. Previous studies have demonstrated slight decreases in intelligence quotient in patients who have undergone circulatory arrest compared to their siblings and to other children who had undergone cardiac surgery employing cardiopulmonary bypass techniques not involving circulatory arrest (4). Other studies have demonstrated that cerebral blood flow following circulatory arrest may be decreased for up to 24 h (5). Although there is very little question that circulatory arrest if employed inappropriately can do damage, it is very likely that as long as temperatures are low enough, times are short enough, and appropriate pharmacological protection is employed, this technique can be utilized safely. It also should be mentioned that prolonged cardiopulmonary bypass results in metabolic derangements in the small infant which are not inconsequential. Bypass times when circulatory arrest is employed are considerably reduced, and if conditions are properly controlled, metabolic derangements can be minimized.

Another current controversy in pediatric perfusion involves the use of pulsatile blood flow during cardiopulmonary bypass. Among its many advantages are shortened bypass times for cooling and rewarming, prevention of peripheral vascular shutdown to some extent, and, based on some studies, reduced postoperative time on the ventilator (6). Previously, employment of pulsatile flow required venous as well as arterial pump heads, but the more recent development of noncompliant membrane oxygenators and mini-prime circuits have allowed employment of this technique with a single pump head and very small priming volumes. Although teams who employ pulsatile flow feel there is an advantage, this remains to be scientifically documented.

Recent concerns involving blood transfusion related to transmitted diseases as well as immunologic reactions have recently had a tremendous impact on adult cardiac surgery. A high percentage of adult cardiac operations can be accomplished without homologous blood transfusions. This, however, is not routinely true in the pediatric age group. Development of mini-prime circuits, use of hemoconcentration techniques, and reinfusion of shed blood products as well as the use of autotransfusion has facilitated blood conservation even in the pediatric age group. The question that remains unanswered, however, is how much hemodilution can be tolerated under various circumstances. This question requires an answer which will apply to the intraoperative as well as the postoperative situation.

The use of prolonged extracorporeal support in the pediatric age group has been popularized by its successful application in many cases of neonatal respiratory distress syndrome. Its use in the postoperative cardiac patient, however, remains controversial. Some centers have reported salvage rates from profound cardiogenic shock following repair of complex heart disease of 40%–50% when prolonged ventricular assist was employed (7). Other centers, however, have not been able to duplicate this salvage rate. The employment of prolonged ventricular assist in the pediatric patient could become a serious ethical issue if the indications for its use and the parameters for implementation are not clearly established.

Future horizons in pediatric perfusion will follow advances in pediatric cardiac surgery. The use of cardiac, pulmonary, and cardiopulmonary transplantation in infants and children is already occurring in a few centers. As this practice proliferates, pediatric perfusionists may be called upon to provide extracorporeal circulatory support for donors, certainly for recipients, and in some cases preservation of organs and tissue may involve in vitro preservation circuits similar to those already employed for preservation of kidneys. Because of the relative rarity of pediatric donors and often long distances which exist between the available donor and awaiting recipient, prolonging the safe preservation time of organs and tissues effectively increases the availability of transplant technology to the pediatric population.

Currently, open-heart surgery is relatively routine in newborn infants even during the first hours of extrauterine life. There are simple lesions, however, whose impact on embryonic cardiac development is immense but could be minimized if they were corrected during intrauterine life. Surgery on the fetal heart, although still very experimental, has been accomplished successfully in animal models (8). In humans, fetal surgery for drainage of hydrocephalus and hydroephrosis has been employed. In the future, pediatric perfusionists may well be called upon to provide circulatory support for not only the unborn fetus but also the mother during a procedure to correct a heart lesion in utero.

Perhaps a more practical possibility in the relatively near future for cardiopulmonary bypass in small infants involves a perfusion circuit that could be entirely contained within the operative field and manipulated remotely. The elimination of the extensive tubing required to connect to a pump oxygenator would further reduce priming volumes and allow blood conservation tactics to be more routinely employed in small infants. Small hydraulic pumps and small membrane oxygenators have already been developed and likely will soon be employed in the development of such "microprime" circuits.

It is clear that pediatric perfusion is indeed an evolving science. As with the evolution of any science, the key to continued evolution will be communication. As alluded to earlier, there are many techniques for each individual situation which are employed around the world. Since pediatric perfusion involves many different situations and the number of cases falling into each category may be small, it is imperative that communication and cooperation be maximized so that statistically significant numbers of patients can be studied and valid conclusions drawn as to the effectiveness of various techniques. The institution of a pediatric perfusion newsletter could be the first step in developing an open communication channel. One would hope that eventually the newsletter could develop into an international journal on pediatric perfusion. Communication via the spoken word, employing audiovisual aids, is also essential. A forum on pediatric perfusion designed to facilitate this type of interchange will be necessary for this science to evolve into the future. We all are aware that the future of any science rests with the current trainees who must be specifically exposed to pediatric perfusion through apprenticeships in high volume centers and employing various types of didactic educational modalities. It is conceivable that pediatric perfusion technology may become a subspecialty recognized by perfusion certification organizations, requiring specific certification for perfusionists who deal with infants and small children.

In summary, we have seen from the very beginnings of perfusion technology through the past milestones current controversies leading to the evolution of pediatric perfusion as a science in its own right. For this evolution to proceed at a rapid rate in the appropriate direction, communication, education, and ultimate recognition are essential.

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