An expanding role for cardiopulmonary bypass in trauma

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Objectives: To analyze experience at the McGill University Health Centre with cardiopulmonary bypass (CPB) in trauma, complemented by a review of the literature to define its role globally and outline indications for its expanded use in trauma management. **Data sources:** All available published English-language articles from peer reviewed journals, located using the MEDLINE database. Chapters from relevant, current textbooks were also utilized. **Study selection:** Nine relevant case reports, original articles or reviews pertaining to the use of CPB in trauma. **Data extraction:** Original data as well as authors' opinions pertinent to the application of CPB to trauma were extracted, incorporated and appropriately referenced in our review. **Data synthesis:** Overall mortality in the selected series of CPB used in the trauma setting was 44.4%. Four of 5 survivors had CPB instituted early (first procedure in operative management) whereas 3 of 4 deaths involved late institution of CPB. **Conclusions:** Although CPB has traditionally been used in the setting of cardiac trauma alone, a better understanding of its potential benefit in noncardiac injuries will likely make for improved outcomes in the increasingly diverse number of severely injured patients seen in trauma centres today. Further studies by other trauma centres will allow for standardized indications for the use of CPB in trauma.

Objectifs : Analyser l'expérience du pontage aortocoronarien (PAC) en traumatologie au Centre de santé de l'Université McGill et la compléter par une recension documentaire afin d'en définir le rôle en général et de présenter un aperçu d'indications pour son utilisation accrue dans la prise en charge de traumatismes. **Sources de données :** Tous les articles disponibles publiés en anglais provenant de journaux critiqués par des pairs, trouvés au moyen de la base de données MEDLINE. On a utilisé aussi des chapitres tirés de manuels courants pertinents. **Sélection d'études :** Neuf rapports de cas pertinents, articles originaux ou critiques portant sur l'utilisation du PAC en traumatologie. **Extraction de données :** Des données originales, ainsi que des opinions d'auteurs pertinentes à l'utilisation du PAC en traumatologie, ont été extraites, intégrées et mentionnées comme il se doit en référence dans notre recension. **Synthèse de données :** Le taux global de mortalité dans la série choisie de PAC utilisés en traumatologie s'est établi à 44,4 %. Chez quatre des cinq patients qui ont survécu, on a entrepris rapidement le PAC (première intervention dans la prise en charge opératoire), tandis que dans trois des quatre cas de décès, on l'a fait plus tardivement. **Conclusions :** Même si l'on a toujours utilisé le PAC en traumatologie cardiaque seulement, une meilleure compréhension des avantages qu'il peut offrir dans des cas de traumatismes non cardiaques permettra probablement d'améliorer les résultats chez les patients gravement blessés et de plus en plus diversifiés que les centres de traumatologie accueillent maintenant. D'autres études réalisées par d'autres centres de traumatologie permettront de normaliser les indications portant sur l'utilisation du PAC en traumatologie.

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The concept of cardiopulmonary bypass (CPB) was introduced by Gibbon in 1937 and has since been applied to a growing number of surgical and nonsurgical procedures. Gibbon eventually reported its use in the surgical treatment of acute, massive pulmonary embolism.[1] In 1967, Davies and associates[2] adapted CPB for the treatment of hypothermia, and in the 1970s, Mattox and Beale described standard CPB for injury to the cardiac and thoracic aorta.[3] Subsequently, improvements in CPB extended its usefulness to include noncardiac indications. More recent technical advances in percutaneous access[4] and heparin-bonded circuitry[5] have further enabled the use of CPB in other areas of trauma.

We present our experience with 9 patients admitted with traumatic injury to a level 1 trauma centre between 1992 and 1998 in whom CPB was used as part of their management (Table 1). Complementing our own experience with a literature review, we aim to outline the indications for the use of CPB globally in the trauma setting.

Cardiac trauma

Penetrating injury

Penetrating cardiac injuries are most commonly sustained secondary to stab wounds, missile injuries or, rarely, a fractured sternum or ribs.[6] Less than 10% of patients sustaining penetrating cardiac injury reach hospital alive; the remainder die of exsanguination or tamponade.[7] The frequency of injury with respect to the anatomic area injured depends on the degree of anterior exposure.[6] Thus, the most commonly injured chambers are the right ventricle (45%), followed by the left ventricle (35%), right atrium (5%) and left atrium (5%). The intrapericardial great vessels are injured in less than 5% of cases, and the coronary vasculature is rarely damaged.

Traditionally, CPB has been used primarily in the setting of coronary artery grafting[8] and has seen little use in cardiac trauma. This is partly related to the fear of using systemic heparinization when there are associated or suspected injuries.[9] However, multiple case reports have documented the safe and effective use of systemic anticoagulation with CPB-assisted injury repair in polytrauma patients. Buchman and associates[7] reported the successful repair of 2 separate combined cardiac and hepatic vascular lacerations using CPB, and Karmy-Jones and colleagues[8] detailed the complete repair of multiple left ventricular lacerations using CPB in a hypothermic patient. We treated a patient with a left ventricular laceration that required 2 attempts at repair, the second using CPB.

Case 1

A 51-year-old man was stabbed in the posterior left chest and presented in tamponade. Sternotomy revealed a left ventricular laceration, which was repaired, and a laceration of the obtuse marginal artery (OMA), which was ligated. Three hours postoperatively, the patient had mediastinal hemorrhage and was returned to the operating room. The repaired left ventricular injury was found to be bleeding. Definitive repair was achieved with the use of CPB. Subsequently, in the intensive care unit, the patient suffered an infarction in the ligated OMA territory causing

Table 1

Summary of Nine Patients Treated for Trauma With the Use of Cardiopulmonary Bypass (CPB)

Case no.	Injury	Bypass type	Early CPB	Outcome	Role or benefit of CPB
1	Ventricle, OMA	RA–aorta	No	Reoperation, MI, death	Would have allowed bypass of injured coronary artery.
2	Ascending aorta	RA–aorta	Yes	DIC. death	Necessary for repair secondary to site
3	Descending aorta, pulmonary contusion	Femoral artery–aorta	Yes	Alive	Overcame inability to ventilate and maintained spinal perfusion.
4	Intrapericardial IVC, right auricle	SVC–aorta	Yes	Alive	Overcame persistent bleeding and permitted intracardiac inspection.
5	Right innominate vessels	RA–aorta	No	Exsanguination, death	Would have allowed controlled repair of complex injuries.
6	Retrohepatic IVC, liver	RA–aorta, circulatory arrest	Yes	Alive	Allowed rapid repair (12 min) in a bloodless field.
7	Retrohepatic IVC, liver	RA–aorta, circulatory arrest	No	Alive	Overcame persistent bleeding and permitted rapid repair (8 min).
8	Hypothermia (26°C)	Femoral–femoral	No	Cardiac arrest, death	Would have allowed rapid rewarming and resuscitation.
9	Hypothermia (28°C)	Femoral–femoral	Yes	Alive	Allowed rapid rewarming and successful defibrillation.

OMA = obtuse marginal artery, IVC = inferior vena cava, RA = right atrium, SVC = superior vena cava, MI = myocardial infarction, DIC = disseminated intravascular coagulation.

malignant arrhythmias and cardiac arrest. Although resuscitated, he eventually died 2 months later of septic complications.

Comment

Coronary artery injuries represent less than 5% of penetrating heart injuries, with the left anterior descending artery being most commonly involved.[8] In the prebypass era, treatment consisted of proximal and distal ligation of the lacerated artery or an attempt at primary repair in a beating heart. With the advent of CPB, the options of saphenous vein patch grafting or a proximal ligation with distal aortocoronary bypass became available.[10] The added advantage of the CPB-based repair was, of course, the quiet, bloodless operative field, permitting definitive repair of the damage. CPB is also the favoured approach for repair of high, proximal coronary vessel injury, decreasing the risk of extensive infarction.[10] Reissman and colleagues[10] reviewed the literature with respect to penetrating coronary artery injuries managed with or without CPB. The results showed that although there is no difference in mortality, there was a significant difference in morbidity, with patients having CPB for repair suffering fewer ischemic complications. In the case presented here, the early implementation of CPB and repair of the injured OMA would likely have obviated the need for reoperation and avoided the eventually fatal ischemic-related postoperative complications.

Blunt injury

Blunt cardiac trauma is most frequently sustained during high-speed motor vehicle collisions.[6] Such injury to the heart is secondary to massive compression and involves the right atrium (50%), the right ventricle or left atrium (25%), and the left ventricle (13%). More than one cardiac chamber is injured about 8% of the time, with valve rupture and coronary artery tears being rare but reported injuries in blunt cardiac trauma.[11] Few patients survive cardiac chamber rupture.[12] Atrial tears, on the other hand, can usually be managed with the use of partial occlusion clamps, without the assistance of CPB.[12] In such instances, however, CPB is helpful because it facilitates exploration, thereby avoiding sudden bleeding during exposure and promoting easy repair, as well as allowing repair of any associated injuries.[12] For example, Hendel and Grant[12] reported the successful repair of a simultaneous rupture of the right atrium and left ventricle using CPB, and DiMarco and associates[13] used CPB to repair a simultaneous rupture of the right atrium and pulmonary vein. The potential uses of CPB are not limited to cardiac chamber injury. CPB has also been used in repair of traumatic rupture of the papillary muscles causing mitral insufficiency, with or without concomitant cardiac injuries.[10]

Noncardiac trauma

Great vessel injury

Injury to the great vessels is found in one-third of patients who undergo thoracotomy for chest trauma. The aorta is injured most often (37%), followed by the pulmonary artery (28%); the intrathoracic vena cava, innominate vessels and pulmonary vein are affected in 19%, 16% and 16% of cases respectively.[14]

Blunt rupture of the ascending aorta or aortic arch, or both, routinely requires CPB for adequate repair. Although anterior penetrating injuries may be repaired without CPB, posterior lesions usually benefit from the use of CPB. The benefit of hypothermic circulatory arrest in addition to CPB in these cases has also been reported.[14] We report a case of ascending aortic compromise with associated atrial damage, repaired on CPB.

Case 2: Combined ascending aortic and left atrial injury

A 79-year-old driver who was wearing his seat belt was involved in a motor vehicle collision. He suffered blunt head, chest and abdominal trauma. Laparotomy revealed an isolated splenic injury treated by splenectomy. However, he remained hypotensive, so a subdiaphragmatic pericardiotomy was performed, which indicated bleeding. A sternotomy demonstrated a 4-mm tear on the ascending aorta. The injury was repaired with the use of CPB (bypass time 150 min, cross-clamp time 50 min). Postoperatively, the patient bled intracranially suffering irreversible neurologic damage. He died 6 weeks after initial presentation.

Comment

Although CPB was necessary to facilitate repair of both the ascending aorta and atrium, this case demonstrates one of the recognized complications of systemic heparinization involved in the implementation of CPB; that is, bleeding from an associated injury, which in this case was intracranial.

The benefits of CPB in the management of descending thoracic aortic rupture are, however, not as definitive. Standard repair using aortic cross-clamping only, with direct reconstruction, has the advantage of requiring no systemic heparinization, but has been associated with a 25% overall incidence of paraplegia.[15] CPB may be safer because it decreases the strain on the left ventricle from the cross-clamp and increases perfusion to the spinal cord and kidneys.[11] The latter fact, however, may outweigh the risk of bleeding from systemic anticoagulation and the need and cost of specialized CPB equipment and teams. An example of early implementation of CPB in a case of descending aortic rupture follows.

Case 3: Descending aortic rupture with associated pulmonary contusion

A 30-year-old man, a driver involved in a high-speed motor vehicle collision, was referred to our centre for a possible traumatic rupture of the descending aorta. On arrival, despite maximal ventilatory support, he was suffering from severe impairment of gas exchange secondary to severe bilateral pulmonary contusions (more severe on the right side). Aortography revealed rupture of the descending aorta approximately 2 cm distal to the origin of the left subclavian artery, necessitating operation. During attempts to repair the aorta, the patient had severe hypoxemia refractory to all therapy. Because it was evident that the right lung would not be sufficiently functional to support gas exchange with the left lung deflated, CPB was instituted, facilitating repair of the ruptured segment of aorta. He was discharged 3 weeks postoperatively.

Comment

The benefit of early CPB implementation in this case was to provide adequate tissue oxygenation and perfusion in the face of severe pulmonary contusion and an inability to ventilate the patient effectively.

Survival of traumatic rupture of the aorta is also dependent on prompt and accurate diagnosis, facilitating rapid surgical repair. Although aortography was used in the previous case and is currently the standard for diagnosing aortic injury, other methods including computed tomography, magnetic resonance imaging and transesophageal echocardiography (TEE) are useful. Over recent years, TEE has proven both accurate and safe in critically injured patients, and comparable to aortography for detecting aortic rupture.[16] Smith and colleagues,[16] demonstrated 100% sensitivity and 98% specificity for detecting aortic damage in 101 patients by TEE. Owing to suboptimal visualization of the innominate, left carotid and subclavian arteries, aortography is still a superior modality when injury to these structures is suspected.

The role of CPB in aortic isthmus repair has also been explored. Pate and colleagues[15] examined the incidence of paraplegia in such cases of injury and repair, as well as the risks of systemic heparinization. The study consisted of 80 patients with acute isthmic rupture repaired on femoral–femoral CPB. None of these 80 patients suffered paraplegia or experienced increased intra-abdominal bleeding secondary to anticoagulation. Three patients did, however, have worsening intracranial injury. In their report, they also reviewed data from other series of patients with repairs using different methods. This review showed a 21% and 9% rate of ischemic myelopathy with the use of "clamp and sew" and passive shunt techniques respectively. This was in contrast to a 0% and 2% incidence of paraplegia when left heart bypass and partial CPB, respectively, were used.[15]

Rupture of the aorta in multiple locations occurs in 10% of cases and usually involves the isthmus and an additional lesion in the ascending aorta.[17] Del Rossi and associates[18] documented 3 such cases; in 2 the aorta was repaired without the use of CPB, and these were complicated by paraplegia; the third case was repaired on CPB and without paraplegia. They concluded that implementation of CPB is recommended in the repair of multiple-loci traumatic rupture of the aorta, whose repair increases cross-clamp time and requires increased surgical exposure.[18]

Traumatic injury to the posterior aspect of the pulmonary artery also benefits from repair on CPB, whereas anteriorly located lesions can be managed with direct arteriorrhaphy.[14] Injuries to the pulmonary vein are usually associated with cardiac chamber or pulmonary artery injury, and thus usually require CPB for repair.[14]

The intrathoracic inferior vena cava is also difficult to repair because of exposure unless total CPB is used. The superior vena cava can usually be repaired with a venorrhaphy, with or without the use of an intracaval shunt.[14] Here we document a case of intrapericardial repair of the inferior vena cava with the use of CPB.

Case 4: Intrapericardial inferior vena caval and right auricular injury

A 40-year-old HIV- and hepatitis C-positive man was shot in the right posterior lower thorax and presented in tamponade. Sternotomy revealed a left-sided intrapericardial inferior vena caval tear at the entrance to the right atrium, as well as a tear of the right auricle. Despite repair there was persistent bleeding from the vena caval tear, necessitating superior vena caval–aortic CPB for definitive repair. A right atriotomy confirmed an intact tricuspid valve and atrial septum. The patient had an uncomplicated postoperative course.

Comment

Early initiation of CPB allowed for rapid, definitive repair of inferior vena caval and auricular damage in this case. Damage to other vessels, including the innominate artery and vein, have also been repaired on CPB. Whereas uncomplicated injury to the innominate vessels can successfully be treated off-pump, as demonstrated in 42 cases of blunt and penetrating innominate vessel injuries by the group at Ben Taub Hospital in Houston,[19] severe or complicated injuries frequently require CPB. Faro and associates[20] required the use of CPB to repair a severe avulsion of the innominate artery from the aortic arch. Another such case, described by Fulton and Brink,[21] in which the patient suffered simultaneous right innominate artery and vein, common carotid artery and subclavian artery injuries, also necessitated CPB for successful repair. Here, we document a complex case of multivessel injury treated at our trauma centre with the use of CPB.

Case 5: Combined injury of the innominate, common carotid and subclavian vessels

A 32-year-old man was shot in the right side of the neck. On admission, he was hemodynamically unstable and had a right hemothorax. During exploration through an incision over the right sternocleidomastoid muscle, the patient deteriorated (including cardiac arrest requiring resuscitation) necessitating a median sternotomy. A large through-and-through laceration of the innominate artery, and transection of the proximal common carotid and subclavian arteries were identified. Repair was performed using synthetic grafts. Following reperfusion, the patient again became unstable and his heart arrested. CPB was instituted to facilitate resuscitation. The patient now had disseminated intravascular coagulation, having received massive transfusions. Although he was weaned off bypass, he suffered a cardiac arrest during closure and died on the operating table.

CPB in this case was only implemented late in the procedure for resuscitative purposes. Early initiation of CPB would have allowed more rapid and definitive repair of the multiple, complex vessel injuries, and potentially could have minimized blood loss that eventually caused this patient's death.

Tracheobronchial rupture

Rupture of the major airways is relatively rare, occurring in less than 0.5% of patients with severe trauma.[22] Although every segment of the trachea is susceptible to rupture, more than 80% of such injuries occur within 2.5 cm of the carina.[23] Seventy-four percent of tracheal ruptures are isolated and transverse, 18% are longitudinal within the membranous trachea and 8% are complex, involving a combination of the above or multiple lacerations.[23] Intraoperative bronchoscopy is the standard to diagnose injury, and successful management relies on maintaining effective ventilation during repair.[23]

Orotracheal intubation is usually possible with a bronchoscope, with the endotracheal tube passed distal to the tracheal rupture site, or by selective intubation of the uninjured main bronchus, or both. CPB may be required for repair if the endotracheal tube cannot be passed because of a complex airway injury or if there is associated great vessel injury. While CPB is being established, bronchoscopic or jet ventilation can be performed. After repair and before coming off-pump, an endotracheal tube is inserted with the tip just above the suture line.[23]

Symbas and colleagues[23] documented the management of 6 patients with complex airway injuries. They were able to repair 5 of the 6 injuries without CPB, using only single-lung ventilation. The sixth case, involving a central posterior longitudinal tear of the distal trachea extending to the carina and rupture of both mainstem bronchi, required the use of CPB for repair. Similarly, Hirsh and associates[24] experienced a case with extensive tracheal disruption involving the right mainstem bronchus, in which they were unable to selectively ventilate the left side; CPB was required for successful repair. Although we have managed several cases of tracheobronchial rupture at our centre, we have not yet required CPB to facilitate repair, as we were able to successfully treat the injuries with selective intubation and direct repair.

Retrohepatic vein injury

Bleeding from injury to the supra- and infrahepatic vena cava can frequently be controlled and repaired directly. Alternatively, retrohepatic vein injury (consisting of the thin-walled retrohepatic vena cava and the hepatic veins) usually poses a greater challenge for exposure and control. In achieving anterior exposure of the injury, liver dissection and rotation are often necessary. Such injuries are associated with a high mortality (50%–100%).[25]

Traditionally, retrohepatic vein injury has been managed with total vascular occlusion using multiple occlusion clamps on the aorta, porta hepatis and vena cava. This method frequently results in inability to maintain adequate blood pressure due to arrested inferior vena caval flow.[25] The use of an atriocaval shunt was proposed by Schrock and colleagues in 1968[26] in order to avoid total occlusion of the inferior vena cava. Buechter and associates[25] demonstrated that this technique in fact increased mortality (90% v. only 50% with direct repair alone) because of a delay in exposure and definitive control of bleeding.[25] We describe 2 cases retrohepatic inferior vena caval injury.

Case 6: Retrohepatic inferior vena caval and hepatic injuries

A 17-year-old boy was injured when a tractor ran over his abdomen. He underwent laparotomy with resection of segments 2 and 3 of his liver at a peripheral hospital. Packing was applied and he was transferred to our trauma centre. He became unstable, with a drop in hemoglobin level to 40 g/L; his abdomen was thus re-explored. A 2-cm laceration of the retrohepatic inferior vena cava at its junction with the left hepatic vein was identified. An attempt was made to repair the injury using an atriocaval shunt, but the bleeding continued profusely, prompting the decision to put the patient on CPB with deep hypothermic arrest. The injury was repaired in 8 minutes and the patient discharged from hospital 2 weeks later in good condition.

Comment

Our experience with the preceding case influenced the subsequent management of a similar case, in which CPB was again used to repair a retrohepatic inferior vena caval injury. In this instance, the decision was made to institute CPB immediately without the insertion of an atriocaval shunt in an effort to expedite repair and the return the patient to normal circulatory status.

Case 7: Retrohepatic inferior vena caval injury and laceration of the left hepatic lobe

A 21-year-old man was shot in the right upper quadrant at close range. Laparotomy revealed a through-and-through laceration of the left lobe of the liver. After oversewing the laceration, there was persistent hemorrhage, which originated from a large hole in the anterior inferior vena cava at the level of the diaphragm. The decision was made to immediately place the patient on CPB with circulatory arrest to expedite the repair (done in 12 min). The patient was discharged from hospital 2 weeks later.

Comment

Launois and associates[27] also documented the successful use of CPB with hypothermic, circulatory arrest to repair simultaneous laceration of the right hepatic vein and a middle hepatic vein avulsion. They commented on the benefit of a bloodless field in such repair. CPB, therefore, is of benefit in retrohepatic vein injury, creating a virtually bloodless field and allowing more rapid and precise repair.[28] Timely implementation of CPB would greatly improve the outcome of such cases. We discuss later the risks and current thoughts regarding systemic anticoagulation.

Hypothermia

Mild hypothermia, defined as a core temperature between 32°C and 35°C, can often be effectively managed with external rewarming.[29] Core temperatures dipping to between 28°C and 32°C are considered as moderate hypothermia and are associated with an increased risk of cardiac instability. Thus, accelerated core rewarming by pleural and peritoneal irrigation, warm ventilation or gastrointestinal lavage is utilized.[29]

Severe hypothermia (core temperatures < 28°C), is associated with a high risk of cardiac arrest.[29] Rapid internal rewarming by the techniques already described for the treatment of moderate hypothermia has been successful for a number of patients with stable cardiac rhythms.[29–31] Patients in cardiac arrest have also survived after prolonged cardiopulmonary resuscitation and internal rewarming in a select number of cases.[29,32,33] Such therapy may be suboptimal, however, leading to organ ischemia as warming occurs and metabolic demand increases.[29–32] Rapid institution of CPB in such cases of severe hypothermia with malignant arrhthymias could be of great benefit, providing rapid rewarming while maintaining circulatory support.[29–34]

CPB can be instituted by various methods including atrial–aortic and femoral–femoral bypass. The latter technique is simple, readily established without interrupting CPR and maintains acceptable flow rates.[29] Percutaneous technology now available further enhances this application.[29] Standard atrial–aortic bypass, on the other hand, permits open cardiac massage and direct defibrillation of the heart. As well, higher perfusion flow rates are possible, compared with femoral–femoral bypass.[29,30]

Case 8: Submersion hypothermia (26°C)

A 31-year-old woman was submerged for 90 minutes after a suicide attempt. She was asystolic with a core temperature of 26°C (rectal). Attempts at active core rewarming resulted in a 1°C increase in temperature. Arterial blood gas measurement revealed severe acidosis (pH 6.84). The patient was thus transferred to the operating room for rewarming by femoral–femoral bypass. In 2 hours, her temperature rose to 35°C and her heart returned to sinus rhythm. Postoperatively, however, she had a cardiac arrest and attempts to resuscitate her were unsuccessful.

Case 9: Environmental hypothermia (28°C)

A 50-year-old homeless man was brought to the emergency department following an unknown period of exposure to below 0°C temperature. He had a core temperature of 28°C and suffered a cardiac arrest in the emergency department. CPB was immediately instituted for rewarming and resuscitation, and the patient's heart spontaneously returned to sinus rhythm at a temperature of 32.5°C. He made a good recovery and was well at last follow-up.

Comment

In retrospect, earlier implementation of CPB in case 8 could potentially have allowed for recovery as seen in the second case, by minimizing the metabolic derangements that led to refractory cardiac arrest. After reviewing 68 cases of hypothermia (mean temperature of 21°C) in which the patients were resuscitated with the use of CPB, Vretenar and colleagues[35] concluded that CPB was indicated for hypothermic patients in cardiac arrest and for patients with a core temperatures lower that 25°C, regardless of rhythm. Instead, between 25°C and 28°C either CPB or conventional methods were deemed appropriate.[29] From the same series, they reported a 60% overall survival rate, with 80% of survivors resuming their previous level of functioning.

Extended indications

Irreversible shock

Prolonged hypovolemia, among other insults, can lead to irreversible shock secondary to an ill-defined mechanism.[36] Theories proposed have included an excessive decrease in precapillary tone, direct cardiac injury or a circulating myocardial depressant factor.[36] Classically, treatment has involved inotropes and pressors, which help to stabilize hemodynamic status, but at the expense of increased myocardial oxygen demand. In such cases, the early use of extracorporeal cardiopulmonary life support (ECLS) could maintain hemodynamic parameters without increasing myocardial or pulmonary workload.[36,37] Potentially, this alteration could decrease the incidence of irreversible shock and of multisystem organ failure, but further studies are warranted. Perchinsky and colleagues[37] reported a series of 6 severely injured trauma patients who were treated with ECLS. Two patients died before ECLS could be fully instituted and a third could not be weaned from circulatory support. Of the 3 survivors, 2 made a full recovery, and the third suffered moderate neurologic impairment secondary to cardiac arrest and protracted resuscitation efforts at the peripheral community hospital. Although a small series, the group concluded from the results that ECLS is a viable life support option for selected severely injured patients.[37]

Respiratory failure

Multiple trauma is often complicated by respiratory failure, a significant cause of morbidity and mortality in these patients. In addition, conventional ventilatory management can exacerbate the problem, causing iatrogenic barotrauma and pulmonary toxicity.[38] Anderson and colleagues[38] reported a series of 24 polytrauma patients who had respiratory failure or adult respiratory distress syndrome despite maximal ventilatory support (oxygen saturation < 85% on maximal fractional intake of oxygen and positive end-expiratory pressure). These patients were placed on venoarterial or venovenous ECLS with continuous systemic heparin anticoagulation, and the ventilator settings were lowered to "rest" levels. After improvement in lung compliance and partial pressure of oxygen, the patients were weaned off ECLS. Of the 24 patients, 17 recovered lung function; 15 of these made a complete recovery. They further noted that when ECLS was instituted within 5 days there was a 100% survival rate. Thus, the investigators concluded that early intervention with ECLS was beneficial in selected cases of respiratory failure, regardless of the high rate of bleeding (75% of cases) associated with systemic heparinization.[38] With the advent of heparin-bonded circuitry, the hope is that much of the risk of systemic anticoagulation in multiple trauma cases will be avoided.[5,37]

Organ transplantation

Little work has been published with respect to the use of CPB in preserving organs for transplantation in cases of cardiopulmonary resuscitation without neurologic recovery. Lechtman and associates[39] addressed this issue and presented a case of a 3-year-old boy who was immersed in water at 7°C for approximately 30 minutes. At the time of treatment, the patient was in cardiac arrest with a core temperature of 27°C. CPB was established and maintained for 111 minutes. The patient was successfully rewarmed and resuscitated, recovering complete cardiac, respiratory, renal and hepatic function. Neurologic recovery, however, never occurred, and he was declared brain dead. His preserved cardiopulmonary status allowed for successful transplantation of both kidneys that evening and harvesting of the heart, liver, pancreas, eyes and corneas for research and banking. Further investigation will be necessary to provide more information on the viability of organs for transplantation from CPB-preserved, neurologically deplete trauma patients.

Technologic advances

Percutaneous cardiopulmonary bypass

Traditional emergency CPB involves surgical exposure of the femoral artery and vein. Phillips and colleagues[4] extended the use of percutaneous sheaths used for the intra-aortic balloon pump, for rapid institution of percutaneous CPB. They documented a series of 5 patients unable to be resuscitated with CPR, cardiac drugs and intra-aortic balloon pump placement. The patients underwent percutaneous cannulation of the femoral vessels by the Seldinger technique, with 12-French, 4 mm sheaths. A vortex pump and Shiley oxygenator were used, with an initial bolus of heparin and subsequent interval heparinization. All 5 patients were successfully revived with the use of percutaneous CPB.[4]

Laub and associates[40] reported on the successful application of percutaneous CPB in a 36-year-old lady in cardiac arrest from accidental hypothermia (core temperature 26°C). Percutaneous CPB was established in less than 20 minutes, with 30-French venous and 20-French arterial cannulas. Flow rates of 2 to 4 L/min were maintained for 90 minutes, and the patient was successfully defibrillated at 34°C and weaned off bypass. She made a complete recovery.

The initiation of percutaneous bypass requires far less time and effort than standard "cut down" techniques. Average time of instituting CPB, according to a literature search, was 134 minutes, compared with approximately 20 minutes in the presented case.[40] Furthermore, the percutaneous technique may provide further time-sparing in obese patients with difficult surgical vascular access. Based on the ease and efficiency of use and the desirable outcome in this report, percutaneous CPB appears to be a viable option in the resuscitation of hypothermic circulatory collapse.

Cardiopulmonary bypass without heparinization

The concept of heparin-coating was first introduced by Gott and associates in 1963.[41] von Segesser and Turina[5] have pioneered the extension of its use to the oxygenator and tubing for CPB. His group compared a heparin-coated system without systemic heparinization to the conventional membrane bubble oxygenators using heparinization in an animal experiment.[5] The heparin-coated system demonstrated no difference in flow or oxygenation for 6 hours, and was less traumatic to blood elements as demonstrated by higher hemoglobin levels and platelet indices. There was no macroscopic clotting on pump surfaces nor was there any evidence of heparin washout associated with an increase in the activated clotting time.[5]

In a later publication, von Segesser and colleagues[42] reported successfully applying this technology in a case of traumatic hypothermia. A 13-year-old boy was found 18 hours after being stranded in the woods (core temperature 23°C), having suffered severe cerebral injuries. He was in cardiac arrest and had fixed, dilated pupils. Heparin-bonded CPB was used to perfuse and rewarm the patient by way of atrial–aortic bypass for 139 minutes. He was successfully rewarmed and resuscitated, and after a long hospital stay made a good somatic and neurologic recovery. This case demonstrates that CPB without systemic heparinization is a good treatment option for severe hypothermia, especially when contraindications to anticoagulation exist, such as severe cerebral injuries.

Perchinsky and colleagues[37] reported the use of heparin-bonded circuitry CPB for 6 patients suffering from polytrauma, shock and hypothermia, who were coagulopathic and unable to be ventilated because of pulmonary hemorrhage. ECLS was instituted by use of a centrifugal pump, heat exchanger, membrane oxygenator and percutaneous cannulas, all with heparin-bonded circuitry. There were 3 survivors, 2 of whom lead active productive lives. They suggested that ECLS without heparinization may buy time to evaluate the extent of injury, while providing cardiopulmonary support without an increased risk of bleeding.[37]

Downing and associates[43] recently published a series of 50 patients with aortic traumatic injuries repaired by heparin-bonded percutaneous CPB. They reported a mortality of 10% (with all deaths resulting from concomitant injuries) and no new cases of paraplegia or worsening pulmonary or intracranial injuries.[43] Furthermore, they commented on the advantages of temperature regulation, oxygenation, rapid volume infusion and an unobstructed operative field associated with this setup. They concluded that this technique was beneficial and avoided the risk of anticoagulation.[43]

Predisposition to hemorrhage, either local or systemic, is the most notable relative contraindication to the use of CPB in the trauma setting, particularly in the context of suspected intracerebral or intra-abdominal or pelvic injury. As already discussed, the problem can be partially avoided with the use of heparin-free circuitry. Antifibrinolytic drugs have also been shown to be effective in decreasing operative blood loss during CPB in cardiac surgery in patients prone to excessive bleeding, such as those taking acetylsalicylic acid.[44] These include tranexamic acid, aminocaproic acid, aprotinin and desmopressin. Results of studies involving over 1000 patients who underwent cardiac surgery demonstrated a reduction of blood loss by 30% to 40% with tranexamic acid or aminocaproic acid, as compared with placebo.[45] Although effective, the usefulness and safety of these agents in the trauma setting in conjunction with CPB have not yet been formally evaluated.

Summary and conclusions

Although the initial use of emergency CPB was seen predominantly in cardiac surgery, there has been a progressive extension of its indications to include noncardiac trauma.

In our experience, the overall mortality of the reported cases was 44.4%. Four of the 5 survivors had CPB instituted early (i.e., the first procedure in operative management) whereas 3 of the 4 deaths involved late implementation of CPB. Clearly, the timely use of CPB in selected cases had some benefit in the survival of these patients, but the precise degree of association would require a larger survey with statistical analysis.

CPB allows for improved outcomes in the increasingly diverse number of severely injured patients seen in trauma centres today. Decreased incidence of organ ischemia[10,15,29–32] and more rapid and definitive repair of primary[28] and associated injuries[12] have all contributed to decreased morbidity associated with the use of CPB in selective trauma management.[10] Technologic advances such as portable CPB, percutaneous access and heparin-bonded circuitry have further complemented the application of CPB to trauma-related cases. Further research and safety studies are needed to address issues regarding anticoagulation, however. And although the precise indications of CPB in trauma management require further definition, the existing data provide convincing evidence that CPB is beneficial and mandates its availability in any level 1 trauma centre.

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