Use of Cardiopulmonary Bypass to Salvage Patients With Multiple-Chamber Heart Wounds

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**Background:** The need for cardiopulmonary bypass in the treatment of penetrating heart injuries is debated.

**Objectives:** To review our experience with penetrating heart injuries and determine the indications and outcome for cardiopulmonary bypass.

**Design:** Retrospective review.

**Setting:** A university-based, level I trauma center.

**Patients:** All victims of penetrating heart injury presenting between July 1, 1989, and December 31, 1995.

**Methods:** Medical records were reviewed for demographic and physiological data, operative findings, and outcome.

**Results:** Overall survival for 106 patients with penetrating heart injury was 55%. In an effort to resuscitate the heart, 4 patients with unresponsive cardiogenic shock were placed on cardiopulmonary bypass; none survived. Of 30 patients with multiple-chamber injuries, 11 presented with signs of life and 7 survived. Cardiopulmonary bypass was essential to repair complex injuries in 2 of the 7 survivors.

**Conclusion:** Cardiopulmonary bypass was ineffective in salvaging patients with cardiogenic shock but was essential in some patients with complex multiple-chamber cardiac injuries that could not be exposed and repaired by other means.

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The specific indications for cardiopulmonary bypass (CPB) in patients with penetrating cardiac trauma are not clearly defined. Some reports indicate that penetrating heart injuries can be managed without the emergency availability of CPB; other authors believe that access to emergency CPB is essential to the survival of some patients. In previous studies, trauma surgeons managed 98% to 100% of penetrating heart injuries without the use of CPB. Proposed indications for CPB in patients with penetrating heart injuries include supporting a patient during physiological collapse and assisting with the repair of injuries not amenable to simple repair because of anatomical inaccessibility. Physiological reasons for using CPB have been proposed because patients with penetrating heart injuries and advanced hemorrhagic or cardiogenic shock frequently die of hypovolemia, hypothermia, and hypoxemia after their injuries are repaired. Emergency CPB can be used to perfuse and oxygenate the tissues and rewarm patients, thus allowing their heart time to rest and recover. Anatomical reasons for using CPB in the treatment of patients with penetrating heart injury include posterior (dorsal) cardiac injuries, multiple-chamber cardiac injuries, valve injuries, and coronary artery injuries.

In this study, we reviewed our experience with penetrating heart injuries to determine the indications for and outcome of using CPB in their management.

**RESULTS**

One hundred eight victims of penetrating cardiac injuries were treated between July 1989 and December 1995; 106 medical records were available for review. Demographic data for survivors and nonsurvivors are shown in Table 1. Overall survival was 55%. Survivors were younger and more likely to be stabbing victims. The physiological status of sur-

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PATIENTS AND METHODS

All patients with penetrating cardiac injuries presenting to the University of California, Davis, Medical Center, a level I trauma center, from July 1, 1989, to December 31, 1995, were included in the study. This group of patients included those who arrived at the emergency department (ED) with cardiopulmonary resuscitation (CPR) in progress.

The data collected for each patient included the mechanism of injury (gunshot wound or stab wound), age, sex, vital signs on presentation, length of time under CPR, and initial cardiac rhythm.

Operating room (OR) records were reviewed for the location and type of cardiac injury and associated noncardiac injuries. Intraoperative cardiothoracic surgical consultation was documented, and for those patients placed on CPB, we recorded the reason for using CPB and the interval between presentation and the initiation of CPB. Injuries were classified as “multiple-chamber injuries” when more than 1 of the 4 cardiac chambers was injured; injuries to the great vessels, even when confined to the intrapericardial portion of the vessels, were not considered a chamber injury.

Postoperative complications and outcomes were recorded. The coroner’s reports were reviewed for autopsy findings and for pathological details of cardiac and associated injuries in patients who died.

All penetrating cardiac trauma was managed by trauma (general) surgeons. In accordance with our institution’s protocol, all victims of penetrating trauma to the torso who presented to our ED with no signs of life or in extremis were managed with an immediate resuscitative ED thoracotomy. Intraoperative cardiac surgical consultation was obtained in patients who were felt to be candidates for CPB. The type of bypass used and the amount of heparin sodium used varied depending on the indication for CPB and the anatomical nature of the injury.

Data are presented as mean ± SD. We compared characteristics for survivors and nonsurvivors using the χ² or Fisher exact test to analyze dichotomous variables and the Student t test to compare continuous variables.

Survivors and nonsurvivors was markedly different. Only 2 patients whose initial cardiac rhythm in the ED was agonal (nonsinus) survived. Of 67 patients presenting to the ED with a sinus rhythm, however, 56 survived.

Only 4 of 40 patients who required CPR before arriving at our facility survived despite aggressive attempts to resuscitate all patients. The mean duration of CPR in the field was 17 ± 7 minutes. No patient requiring CPR longer than 15 minutes survived. Three survivors who received CPR longer than 5 minutes before their arrival had severe anoxic brain injury requiring continuous nursing care on discharge from the hospital. One patient who had prehospital CPR of 5 minutes survived and made an excellent recovery; he had a sinus rhythm at presentation. The overall survival rate for patients requiring CPR before arriving at our hospital was 10% (4/40); in contrast, survival for patients having cardiac arrest in the ED or the OR was 58% (11/19).

The cardiac chamber most frequently injured was the right ventricle (68 patients), followed by the left ventricle (36 patients), right atrium (17 patients), and left atrium (8 patients). Isolated right ventricular injury occurred in 42 (40%) patients and was associated with a 67% (28/42) overall survival rate and a rate of 93% (27/29) for those patients who did not require CPR before arriving at the hospital.

Thirty patients had multiple-chamber injuries (Table 2). Overall survival in this group was 23% (7/30). Of the 30 patients with multiple-chamber injuries, 21 (70%) required CPR before arriving at the hospital; all but 1 of these 21 patients died. Signs of life on presentation (at least a sinus rhythm) were noted in 11 patients, and 7 of these patients survived (64%). Two patients required urgent CPB to repair complex cardiac...
injuries (Table 3). One of these patients had a large 3-cm defect in the posterior left atrium that was not accessible without CPB. The second patient had a defect to the apices of both the right and left ventricles that required a patch to repair. Both of these patients survived and had complete recoveries.

Cardiopulmonary bypass was used not only to assist with repair of the injuries described above (anatomical), but also in an effort to reestablish normal cardiovascular function in patients with irreversible shock by resting and supporting the heart (physiological) during the correction of hypothermia, coagulopathy, hypovolemia, and acidosis. Four patients with intractable shock were placed on CPB in an attempt to restore cardiovascular function in patients with irreversible shock by resting and supporting the heart (physiological) during the correction of hypothermia, coagulopathy, hypovolemia, and acidosis. Four patients with intractable shock were placed on CPB in an attempt to restore cardiovascular function (Table 3); all 4 of these patients died. Review of their anesthetic records revealed that all 4 were in profound shock on arrival in the OR. Two died in the OR when their blood pressure could not be reestablished after a 63-minute and a 180-minute bypass support, respectively. A third patient, who was unable to be weaned from femoral-femoral bypass, died in the intensive care unit of massive disseminated intravascular coagulation within 24 hours. The fourth patient died on the second postoperative day of severe anoxic brain injury.

The 2 patients who required CPB for anatomical reasons were placed on full bypass using aortic and right atrial cannulas. One of the patients placed on CPB for physiological reasons was also placed on full CPB using aortic and right atrial cannulas. The other 3 patients were placed on femoral-femoral bypass; 2 were placed on partial bypass (1 was later converted to full CPB), and another was placed on full CPB. Heparin sodium (10,000-40,000 U) was used in all but 1 of the 6 patients placed on bypass. The average time elapsed between the cardiac injury and beginning CPB was 76 ± 30 minutes (range, 30-120 minutes).

A cardiac surgical consultation was obtained for 20 (19%) patients with penetrating heart injuries. Six of these patients were placed on CPB as described above. Eleven of the remaining 14 patients who were evaluated by a cardiothoracic surgeon survived. The 3 deaths occurred in 1 patient who died of sepsis and multiorgan dysfunction on postoperative day 5 and in 2 patients who died in the OR; 1 had 6 gunshot wounds with multiple injuries and the other died of irreversible cardiogenic shock despite having his injury repaired.

Most (n = 31) of the 48 deaths occurred in the OR, and most (n = 24) of these deaths occurred in patients who required CPR before arriving at the hospital. Seven patients who did not require CPR before arrival at the hospital died in the OR. Of these 7 patients, 3 had injuries that were difficult to repair, and the remaining 4 patients had devastating associated injuries (Table 4).

### Table 3. Demographic, Physiological, Bypass, and Outcome Data for 30 Patients With Penetrating Heart Injuries Treated With Cardiopulmonary Bypass (CPB)*

<table>
<thead>
<tr>
<th>Reason for CPB</th>
<th>Age of Patient, y</th>
<th>Mechanism of Injury</th>
<th>Location of Cardiac Arrest</th>
<th>Arrival to Bypass, min</th>
<th>Associated Injuries</th>
<th>Complications</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomical (in 2 patients)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large LV and RV injury</td>
<td>37</td>
<td>GSW</td>
<td>OR</td>
<td>77</td>
<td>GSW lung</td>
<td>ARDS</td>
<td>Home POD 30</td>
</tr>
<tr>
<td>Posterior LA injury</td>
<td>37</td>
<td>GSW</td>
<td>OR</td>
<td>60</td>
<td>GSW esophagus</td>
<td>ARDS, ATN</td>
<td>Home POD 68</td>
</tr>
<tr>
<td>Physiological (in 4 patients)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor LV function</td>
<td>20</td>
<td>GSW</td>
<td>Field CPR for 30 minutes</td>
<td>90</td>
<td>None</td>
<td>None</td>
<td>Died in OR</td>
</tr>
<tr>
<td>Poor LV function</td>
<td>55</td>
<td>GSW</td>
<td>OR</td>
<td>80</td>
<td>GSW IVC and liver</td>
<td>DIC</td>
<td>Died in OR</td>
</tr>
<tr>
<td>Cardiovascular collapse</td>
<td>41</td>
<td>SW</td>
<td>ED</td>
<td>30</td>
<td>None</td>
<td>DIC</td>
<td>Died POD 0</td>
</tr>
<tr>
<td>Cardiovascular collapse</td>
<td>41</td>
<td>SW</td>
<td>OR</td>
<td>120</td>
<td>SW lung</td>
<td>Anoxic brain injury</td>
<td>Died POD 2</td>
</tr>
</tbody>
</table>

* LV indicates left ventricle; RV, right ventricle; GSW, gunshot wound; OR, operating room; ARDS, acute respiratory distress syndrome; POD, postoperative day; LA, left atrium; ATN, acute tubular necrosis; CPR, cardiopulmonary resuscitation; IVC, inferior vena cava; DIC, disseminated intravascular coagulation; SW, stab wound; and ED, emergency department. All presented to the ED with a sinus rhythm.

### Table 4. Demographic, Physiological, and Injury Data for Patients With Penetrating Cardiac Injuries Who Did Not Require Cardiopulmonary Resuscitation (CPR) in the Field and Died in the Operating Room* *

<table>
<thead>
<tr>
<th>Patient</th>
<th>Cardiac Injury</th>
<th>Age, y</th>
<th>Mechanism of Injury</th>
<th>Systolic Blood Pressure on Presentation, mm Hg</th>
<th>Associated Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>1†</td>
<td>RA, RV</td>
<td>55</td>
<td>GSW</td>
<td>80</td>
<td>GSW IVC and liver</td>
</tr>
<tr>
<td>2</td>
<td>LV, RV</td>
<td>39</td>
<td>SW</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>RA, RV</td>
<td>54</td>
<td>GSW</td>
<td>60</td>
<td>GSW lung, abdomen</td>
</tr>
<tr>
<td>4</td>
<td>RA</td>
<td>21</td>
<td>GSW</td>
<td>70</td>
<td>Spinal cord</td>
</tr>
<tr>
<td>5</td>
<td>Large defect, RV</td>
<td>39</td>
<td>SW</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>RV</td>
<td>50</td>
<td>GSW</td>
<td>60</td>
<td>GSW liver</td>
</tr>
<tr>
<td>7</td>
<td>Partial thickness</td>
<td>55</td>
<td>GSW</td>
<td>70</td>
<td>GSW aorta</td>
</tr>
</tbody>
</table>

* RA indicates right atrium; RV, right ventricle; GSW, gunshot wound; IVC, inferior vena cava; LV, left ventricle; and SW, stab wound. All presented to the emergency department with a sinus rhythm.

† Patient 1 was placed on cardiopulmonary bypass during his operation for physiological support.
We undertook this study to review our experience with urgent CPB in the treatment of penetrating heart injuries. Previous reports\textsuperscript{1,2} have suggested that the use of CPB is not justified in the management of penetrating heart injuries because of the time it takes to place the patient on CPB and the heparinization required. Several authors,\textsuperscript{3,4} however, have felt that emergency CPB is necessary for the survival of a small percentage of patients with penetrating heart injuries. Urgent CPB has been used for both anatomical and physiological difficulties encountered in patients with penetrating heart injuries. Anatomical reasons included injuries that cannot be adequately exposed and repaired without CPB. Physiological reasons included resting the heart in patients with intractable cardiogenic shock while hypothermia, hypovolemia, and hypoxemia are corrected.

Although some investigators\textsuperscript{5,6} reported that urgent CPB improved survival in victims of cardiac injury who had cardiovascular collapse, our experience was similar to that of other investigators who found no benefit in using CPB to resuscitate the heart.\textsuperscript{7,8} Our poor results with using bypass to restore cardiovascular homeostasis may be due to the length of time between presentation and the initiation of CPB (\textgt; 1 hour). Another reason that CPB may not have been helpful in these patients is that their hearts may not have been normal before the injury; 1 of the 4 patients was 55 years old, and 2 were 41 years old. Unfortunately, the number of cardiac patients requiring bypass in our series and others is too small to draw a definitive conclusion about the role CPB may play in patients with cardiovascular collapse.

Cardiopulmonary bypass was useful in treating 2 patients with multiple-chamber injuries that could not have been repaired without the benefit of emergency CPB. Both of these patients survived without major complications related to the CPB.

Thirty patients in our study had multiple-chamber injuries. Our overall survival rate of 23\% (7 patients) in this subgroup of patients compares favorably with previously reported rates.\textsuperscript{13,14} In this group of patients, CPB was of benefit to 2 patients (Table 3).

In examining the characteristics of patients who had favorable ED presentations (no CPB before arriving at the hospital) and who died in the OR, we found 3 more patients who might have benefited from CPB. Two patients had multiple-chamber injuries, and 1 had a large defect in his right ventricle. None of these patients received CPR before presentation, and all had a sinus rhythm on arrival at the hospital. Based on the high overall survival rate for patients with similar physiological characteristics, these patients might have survived if CPB had been used to facilitate treatment of their complex injuries.

There is a small subgroup of patients with large myocardial injuries not amenable to simple repair and with inaccessible posterior heart wounds whose survival can be improved with the use of CPB. Although we think CPB is necessary to treat a small number of patients with complex cardiac injuries, its effectiveness in salvaging patients with intractable cardiogenic shock is not promising.

Based on our findings, we propose the following approach to manage patients with penetrating torso injury. Because patients who arrived at the hospital under CPR for longer than 5 minutes had such a poor outcome, and because the absence of sinus rhythm was associated with a grim prognosis, we propose that patients with CPR for 5 minutes or less be treated with immediate resuscitative thoracotomy. Patients with CPR for longer than 5 minutes should have their cardiac rhythm evaluated. If in sinus rhythm, the patient should be treated as above; if the rhythm is agonal or asystolic, the patient should be pronounced dead. If a cardiac injury is identified during the resuscitative thoracotomy, it should be assessed, and if it involves the posterior aspect of the heart or if the injury is large, the CPB team should be summoned immediately. The injury should then be controlled manually and resuscitation continued until the patient is placed on CPB, at which time the definitive repair can be performed.

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REFERENCES

DISCUSSION

Gail T. Tominaga, MD, Honolulu, Hawaii: The current study is a retrospective analysis of 106 penetrating cardiac injuries seen at 1 institution during 6 1/2 years. The mechanism was gunshot wound in 58% and stab wound in 43%, with an overall survival rate of 55%. The survival rate decreased to 10% in patients having prehospital CPR. There were no survivors in patients undergoing more than 15 minutes of prehospital CPR. The article describes a liberal use of ED thoracotomy, with 91 (86%) of 106 patients surviving to have treatment in the OR. These are impressive numbers when compared with previous reports. Were any patients excluded from analysis? When were patients declared “dead on arrival,” and were these patients included in your analysis? How many patients had ED thoracotomy? How many patients who had ED thoracotomy survived?

The current series includes 30 patients with multiple-chamber injuries with 7 survivors (23%). Two of these patients had CPB to assist in the repair of injuries, and they survived. The survival rate for multiple-chamber injuries is markedly better than the 2% to 3% reported previously by the East Bay–Oakland, Calif, group (1994) and the Los Angeles County–University of Southern California group (1997). Both of these groups reported unselected series with 61% to 63% gunshot wounds, and they did not use CPB. How do you account for your high survival rate compared with previous reports in the literature? Are the weapons used in Sacramento, Calif, different from those in Oakland or Los Angeles? Do you think the 2 patients who had CPB would have survived without the use of CPB? These 2 patients seemed to be preselected to have a better outcome because they survived the 60 and 77 minutes that elapsed from arrival to placement on CPB.

The current study found no survivors in patients placed on CPB for intractable shock. This is in accordance with previous reports in the literature. One of the cited problems with CPB is the time delay. In this study, the average time to CPB was 76 ± 30 minutes. Do you think these patients may have survived if they were placed on CPB sooner? Many patients with intractable shock develop coagulopathy, which may contribute to death. In those patients who had CPB, did you see any bleeding problems with the use of heparin, in particular in the patients with associated injuries?

Juan A. Asensio, MD, Los Angeles, Calif: The authors reported a 55% survival rate, and that is definitely impressive. I wonder, however, if this is indeed a preselected group, for several reasons. Checking rhythms in the trauma room is not necessarily accurate. Many times we have proceeded with ED thoracotomy at Los Angeles County Medical Center in the absence of rhythms, only to find that even people who did not have rhythms with the “look-see” obtained with defibrillator paddles actually had tamponades and injuries that could be repaired.

I wonder if this is a preselected group because transport times obviously are not cited in this retrospective study. Consequently, many patients will be excluded from surgical intervention if they arrive without vital signs or dead on arrival. This is the case with many of the patients in large series reported from Cali and Medellin, Colombia, where most patients arrive after surviving prolonged transport times and the Darwinian challenge. How many of these patients with penetrating chest injuries were thus excluded from ED thoracotomy?

Most of the series in the literature are retrospective and have serious problems. These problems stem from the many layers of cases that have been piled on during prolonged peri-

ods and operated on by many surgeons without good prospective physiological scoring of these patients. You have reported a liberal use of ED thoracotomy, and you state that 91 of 106 patients were able to reach the OR alive. To me, that means that a lot of them presented with good physiological status. By “physiological status,” I mean that many had blood pressures, pupillary reactions, sinus rhythms, movement of extremities, etc. Although this is a retrospective study, did you consider assessing their physiological status with the cardiovascular respiratory score component of the trauma score, as we have done prospectively?

With regard to the Injury Severity Score of the patients, they are certainly elevated, but you reported this as the SD. This means of reporting may confuse people because the ranges appear to be 40 to 88. The same problem also occurs with the Injury Severity Score reporting of nonsurvivors. This needs to be corrected.

With regard to the vital signs, you reported mean systolic blood pressures in nonsurvivors of 11 ± 27 mm Hg. These ranges also need to be corrected. It is difficult to measure systolic blood pressures that are this low.

You have listed 30 of 106 patients with multiple-chamber injuries with a survival rate of 23%. Of the nonsurvivors, 7 presented with sinus rhythm. This finding validates that the presence of a sinus rhythm is an excellent predictor of outcome. In the survivors, what kind of admission systolic blood pressures and rhythms did they present with?

Finally, how many coronary artery injuries did you have? That is important. In our series of 105 patients prospectively tracked during 2 years, there were 9; only 1 survived, and that was without bypass.

I agree with your indications for CPB. I suggest another one that I think is important. The use of CPB should be considered when one is forced to ligate the middle third of either the right coronary artery or the left anterior descending artery when one sees the immediate development of a myocardial infarction with or without associated cardiogenic shock.

I congratulate the authors for attempting to define once and for all the indications for CPB in penetrating cardiac injuries.

William P. Schecter, MD, San Francisco, Calif: What time of the day did these patients arrive at the hospital? Did any of them arrive after sunset? Also, was the pump team in the hospital and ready to go, or did they come from somewhere else? How did you stop the bleeding from these complex wounds and control the hemorrhage while you were instituting bypass? I would also like to know about the details of the incisions. I assume that most of the patients had left anterior thoracotomies if they had their chests opened in the ED. When you discovered you had to do a bypass, did you then do a sternal split? Did you divide the sternum transversely, or were you able to institute bypass through an extended left anterior thoracotomy incision?

Clayton H. Shatney, MD, San Jose, Calif: I am wondering if you now practice what you preach. Do you have one of your recommendations as a protocol on line every day, ie, CPR more than 5 minutes in the field, and you declare them dead on arrival, assuming that when they arrive they have no signs of life?

Dr Battistella: This series represents a nonselected group of patients. The study includes all patients arriving at the medical center with a penetrating cardiac injury. Our approach to patients with penetrating torso injuries during this time was aggressive. Of the 106 patients in this series, 49 underwent an ED thoracotomy. Thirty-nine of the 40 patients who had prehospital CPR had a thoracotomy performed in the ED. One patient was taken directly to the OR and had his thoracotomy performed there. The remaining 10 patients who had an ED thoracotomy at Los Angeles County Medical Center in the absence of rhythms did they present with?
rhythm in the ED, many of the rhythms we reported were those of inner-city hospitals, however. With respect to checking the patient's heart rhythm, our transport times are not much longer than those of inner-city hospitals. This is due to the geography of Sacramento. Our transport times tend to be a bit longer than those reported by others because we are in a medically underserved area, and we have a selection bias, but we did not delay therapy. All patients who presented to our ED, regardless of how long they had been under CPR, their rhythm, or the presence or absence of vital signs, had an immediate resuscitative thoracotomy if they had no blood pressure in the ED.

You raised the concern that 93 of our patients reached the OR. Not all patients brought to the OR had signs of life. Many were brought to the OR to continue their resuscitation. Frequently patients were pronounced dead in the OR shortly after their arrival because they could not be resuscitated, again reflecting an aggressive approach to these patients.

Dr Tominaga also asked about transport times. We had 2 patients who were transferred to our facility as secondary transfers from other hospitals. One could argue that these 2 patients represent a selected group. The remaining 104 patients, however, were brought directly to our hospital. Dr Schecter also asked about the surgical approach. Exposure was obtained through an anterolateral thoracotomy in nearly all patients. This was extended across the sternum in patients placed on CPB.

Dr Shatney asked about our current protocol. Do we practice what we preach? I have to be honest and say that at this point we do not. Our current practice is to proceed with aggressive resuscitative efforts if the patient has any signs of life witnessed by any of the medical personnel, including the paramedics who bring in the patient. If any signs of life are documented, we are aggressive. Based on this study, we are going to change our protocol to that recommended here.

One last thing. It is frequently difficult to get reliable time estimates from the paramedics. There is a simplicity to “5 minutes of CPR” as a trigger for a fork in an algorithm. Even if the injury were to occur just outside the ED in the parking lot of your hospital, it is going to take longer than 5 minutes for the paramedics to deliver the patient to your ED. For all practical purposes, that 5 minutes really distills down to whether or not the patient arrives under CPR. If they arrive with CPR in progress, we recommend that you assess the cardiac rhythm and that you proceed only if it is sinus.