Cardiac causes of shock early after open heart surgery: etiologic classification by radionuclide ventriculography

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ABSTRACT Early after open heart surgery, cardiac shock due to tamponade is easily misdiagnosed as ventricular dysfunction. The distinction is critical to successful therapy. We assessed the utility of $^{99m}$Tc–red blood cell, gated equilibrium radionuclide ventriculography in 50 patients with early postoperative cardiac shock after historical, clinical, and invasive hemodynamic evaluation failed to identify either tamponade or ventricular dysfunction as the specific cause of their shock. The cause was established by radionuclide ventriculography in 45 of 50 patients and led to a change in therapy in 21 patients. A single cause was found in 35 patients: 13 had severe global dysfunction of the left ventricle (three patients), right ventricle (seven patients), or both ventricles (three patients); three had severe segmental left ventricular dysfunction; and 19 had an exaggerated region of photon deficiency (nine patients) or an abnormal and accumulating blood pool (10 patients) surrounding small hyperdynamic ventricles. Sixteen of these 19 patients with scintigraphic evidence of tamponade underwent aspiration with a pericardial needle or reoperation early after radionuclide ventriculography, resulting in confirmation of scintigraphic findings and improved hemodynamics. Ten additional patients had combined ventricular dysfunction and a pericardial abnormality, and five of these underwent reoperation resulting in improved hemodynamics. Radionuclide ventriculography provided no explanation for the cause of cardiac shock in five patients. Thus, the various causes of cardiac shock early after open heart surgery can be distinguished by $^{99m}$Tc–red blood cell, gated equilibrium radionuclide ventriculography, eliminating diagnostic uncertainty that can occur with traditional evaluation. Circulation 71, No. 6, 1153–1161, 1985.

CARDIAC SHOCK complicating open heart surgery is well known in the setting of poor preoperative left ventricular function and when excessive postoperative bleeding leads to tamponade. When it occurs under less well-defined circumstances, differentiation of ventricular dysfunction from tamponade can be difficult by clinical examination, chest x-ray, electrocardiography, and hemodynamic monitoring. Therapy, depending on the cause of shock, may include operative exploration to relieve tamponade or administration of vasoactive drugs with or without intra-aortic balloon counterpulsation to improve ventricular function.

In the early postoperative patient, $^{99m}$Tc gated equilibrium cardiac blood pool scintigraphy has been used primarily for determining the time course of postoperative ventricular recovery. Theoretically, it could be a valuable clinical tool in patients who develop cardiac shock after open heart surgery. We therefore designed this study to determine the utility of portable cardiac blood pool scintigraphy in patients with cardiac shock of uncertain cause early after open heart surgery.

Methods

Patient population. Eighteen hundred and thirty-five adult patients underwent open heart surgical procedures at Cedars-Sinai Medical Center between November 1981 and July 1984. Of these, 319 had postoperative courses complicated by development of cardiac shock and 50 of these were entered into this study when the cause of shock could not be definitely determined by historical, clinical, and hemodynamic parameters. Patients in whom there was an apparent cause of cardiac shock were not included in the present analysis. In all cases, $^{99m}$Tc-labeled red blood cell radionuclide ventriculography was requested for clinical reasons, to help with diagnostic and hence therapeutic decision making.
Of the 50 patients meeting these criteria, 28 had undergone coronary artery bypass graft surgery, 17 had had mitral or aortic valve replacements with or without concomitant revascularization, and five had miscellaneous operative cardiac procedures. In 45 patients, time from surgery until scintigraphic study was less than 96 hr. Five additional patients underwent scintigraphy between 4 and 13 days after surgery. They were included in this analysis because they met the criteria for study and because the etiologic spectra did not differ from those found immediately after surgery. Radionuclide ventriculography was performed in all patients within 12 hr after development of cardiac shock and subsequent to finding that its cause was uncertain.

**Clinical and hemodynamic assessment.** All 50 patients had arterial lines and pulmonary arterial balloon flotation catheters in place, were being continuously monitored electrocardiographically, and had complete physical, portable anteroposterior chest x-ray, and 12-lead electrocardiographic examinations in close proximity to the time of the radionuclide ventriculographic examination. Cardiac shock was defined as systemic hypoperfusion (cardiac index < 2.0 liters/min/m², systolic blood pressure < 90 mm Hg, and compatible clinical signs) plus elevated pulmonary capillary wedge and right atrial pressures (≥ 12 mm Hg). The cause was defined as uncertain when there was no historical (preoperative or intraoperative) evidence of severe ventricular dysfunction, no clinical evidence of excessive intrathoracic bleeding with obstructed egress, and no characteristic physical, hemodynamic, chest x-ray, or electrocardiographic findings to specifically suggest a diagnosis of ventricular dysfunction or tamponade.

All patients included in this study were in advanced degrees of cardiac shock. Every patient had received plasma volume expanders as well as various combinations of intravenous pharmacologic support (inotropes, five patients; pressors, seven patients; inotropes and pressors and/or vasodilators, 38 patients). Seventeen patients also had intra-aortic balloon pumps.

**Scintigraphic studies.** For the performance of radionuclide ventriculographic studies, red blood cells from each patient were labeled in vitro with 25 mCi of 99mTc. After 15 min of incubation, the labeled red blood cells were reinfused into the patient, and mobile gated blood pool scintigraphy (Anger camera; 1/4 inch sodium iodide crystal; high-resolution collimator) was performed at the bedside in the cardiac surgical intensive care unit. With the patient in the supine position, the heart was imaged sequentially in the 45-degree left anterior oblique and anterior views. In each view, 250,000 counts in each of 16 frames per cardiac cycle were collected over approximately 10 min.

To improve the detection of pericardial bleeding, we made two additions to our standard imaging protocol. Images were acquired first in a zoomed and subsequently in a nonzoomed mode. That is, the initial image focused directly on the cardiac chambers, and a second image was acquired that enabled visualization of the entire thorax. Second, unless an abnormal pericardial blood pool indicating active bleeding with obstructed egress was diagnosed at initial imaging, at least one set of delayed images was acquired subsequent to initial imaging, the timing dependent on clinical stability. The first set of delayed images was acquired immediately after initial imaging.

**Image processing.** Raw scintigraphic images were spatially and temporally smoothed by a portable bedside computer. Images of the cardiac cycle were displayed in a continuous endless-loop flicker-free movie format. The computer system (MDS-A3) allowed simultaneous display of both views and of initial and delayed images.

**Scintigraphic interpretation.** Scintigraphic studies, initially assessed at the time of acquisition by a cardiologist experienced in nuclear imaging techniques and interpretation, were analyzed for this study by consensus of two experienced observers who were unaware of the clinical details on any of the patients being imaged. Global systolic function of the left and right ventricles, segmental function of both ventricles, qualitative assessment of size of all four cardiac chambers, and the appearance of the space surrounding the heart were recorded, and right and left ventricular ejection fractions were determined by computer-assisted definition of region of interest.

The following scintigraphic definitions were used: (1) Biventricular global dysfunction: diffuse severe hypokinesis of both ventricles with depressed left ventricular and right ventricular ejection fractions. (2) Isolated left ventricular global dysfunction: depressed left ventricular ejection fraction with diffuse severe hypokinesis and a normally contracting right ventricle. (3) Isolated right ventricular global dysfunction: depressed right ventricular ejection fraction with diffuse severe hypokinesis and normal left ventricular contraction. (4) New segmental dysfunction of the left ventricle: the development of akinesis or dyskinesis of the inferior, posterolateral, or anterolateral regions of the left ventricle when corresponding regions of the preoperative angiographic ventriculogram were known to be normal. (5) Pericardial effusion or blood clots: the presence of a photon-deficient region surrounding the cardiac chambers at least twice the thickness of the interventricular septum as visualized in the 45-degree left anterior oblique view. (6) Active pericardial bleeding: the presence of abnormal blood pool radioactivity in the pericardial space, as previously described.

**Results**

**Hemodynamic, electrocardiographic, and roentgenographic assessment.** For the entire group, mean pulmonary capillary wedge pressure was 18 ± 4 mm Hg and mean right atrial pressure was 17 ± 5 mm Hg. The mean pulmonary capillary wedge/right atrial pressure ratio was 1.2 ± 0.3. Low electrocardiographic voltage (less than 30 mm of summed R and S amplitude in limb leads I, II, and III) was present in 98% of these patients. None had electrical alternans. There were no significant differences in hemodynamic or electrocardiographic findings in patients with a subsequent scintigraphic diagnosis of tamponade or ventricular dysfunction (table I). Furthermore, blinded retrospective review of the chest x-ray findings revealed that these were neither sensitive nor specific for the presence of tamponade or ventricular dysfunction.

On the average, patients with scintigraphically identified tamponade bled more heavily after surgery (total cumulative chest tube blood loss 1690 vs 820 ml; hourly drainage immediately before development of cardiac shock 107 vs 32 ml) than did patients with a scintigraphic diagnosis of ventricular dysfunction. However, in no case was reoperation planned for bleeding alone, and in no case did the bleeding pattern suggest that there was obstruction to drainage and hence a high likelihood of tamponade as the cause of cardiac shock.

**Scintigraphic findings.** Mean time to completion of scintigraphic studies after injection of 99mTc-labeled...
TABLE 1
Comparison of hemodynamic, electrocardiographic, and roentgenographic findings in patients with scintigraphic tamponade or ventricular dysfunction

<table>
<thead>
<tr>
<th>Scintigraphic diagnosis</th>
<th>Electrocardiographic findings</th>
<th>Suggestive x-ray findings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCWP/RAP ratio</td>
<td>PCWP = pulmonary capillary wedge pressure; RAP = right atrial pressure.</td>
</tr>
<tr>
<td>Tamponade (n = 19)</td>
<td>1.1 ± 0.3</td>
<td>19 ± 9</td>
</tr>
<tr>
<td>Ventricular dys-</td>
<td>1.2 ± 0.3</td>
<td>13 ± 6</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

Two-view initial imaging, unless a significant accumulation of pericardial blood was seen on the immediate postinjection images. Repeat delayed imaging was performed in 13 patients up to 10 hr after initial imaging. In three patients (one at immediate postinitial imaging; two at late delayed imaging) the diagnosis was changed because of results of delayed imaging.

Table 2 lists the radionuclide ventriculographic findings in these 50 patients. Twenty-six patients had severe ventricular dysfunction: five had global biventricular dysfunction, eight had severe global left ventricular dysfunction with normal right ventricular function, 10 had severe global right ventricular dysfunction with normal left ventricular function, and three had developed new severe segmental wall motion abnormalities in the absence of global dysfunction. Ten of these 26 patients also had an exaggerated region of photon deficiency surrounding the cardiac chambers or an abnormal accumulation of blood pool radioactivity localized within or completely occupying the pericardial space or expanding inside the thorax.

Of the remaining 24 patients, 19 had evidence of pericardial tamponade, since left and right ventricular function was normal or hypercontractile while the chambers were surrounded by photon-deficient or photon-positive haloes. The other five patients had normal or near-normal biventricular function with unremarkable pericardial spaces.

Impact of scintigraphy on treatment. Thirty-five of the 50 patients were categorized by radionuclide ventriculography as having a singular cause of cardiac shock: 16 had ventricular dysfunction only and 19 had pericardial tamponade only. In these 35 patients, further therapy was directly influenced by the scintigraphic findings (table 3).

The 16 patients in whom severe ventricular dysfunction was found by scintigraphy to be the only cause of

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TABLE 2
Radionuclide ventriculographic findings in 50 patients with etiologically unclear cardiac shock early after open heart surgery

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>Findings on radionuclide ventriculography</th>
<th>LVEF (%)</th>
<th>RVEF (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>3</td>
<td>Global LV and RV dysfunction</td>
<td>18 ± 9</td>
<td>11-28</td>
</tr>
<tr>
<td>2</td>
<td>Global LV and RV dysfunc.; pericardial bleeding</td>
<td>22 ± 11</td>
<td>14-29</td>
</tr>
<tr>
<td>3</td>
<td>Global LV dysfunction</td>
<td>19 ± 9</td>
<td>9-26</td>
</tr>
<tr>
<td>4</td>
<td>Global LV dysfunction; pericardial bleeding</td>
<td>26 ± 6</td>
<td>19-31</td>
</tr>
<tr>
<td>1</td>
<td>Global LV dysfunction; pericardial effusion</td>
<td>—</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Segmental LV dysfunction</td>
<td>37 ± 4</td>
<td>33-40</td>
</tr>
<tr>
<td>7</td>
<td>Global RV dysfunction</td>
<td>58 ± 11</td>
<td>48-76</td>
</tr>
<tr>
<td>1</td>
<td>Global RV dysfunction; mediastinal bleeding</td>
<td>—</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>Global RV dysfunction; pericardial effusion</td>
<td>64</td>
<td>64-64</td>
</tr>
<tr>
<td>9</td>
<td>Pericardial effusion</td>
<td>55 ± 13</td>
<td>36-81</td>
</tr>
<tr>
<td>10</td>
<td>Pericardial bleeding</td>
<td>64 ± 13</td>
<td>43-81</td>
</tr>
<tr>
<td>5</td>
<td>No evident abnormality</td>
<td>57 ± 13</td>
<td>43-77</td>
</tr>
</tbody>
</table>

LV = left ventricular; RV = right ventricular; EF = ejection fraction.
cardiac shock were all treated with aggressive medical therapy. The mortality in this group was 38% (six of 16).

Sixteen of the 19 patients with a scintigraphic diagnosis of tamponade underwent reoperation. This took place an average of 3.6 hr from completion of radionuclide ventriculographic testing, and in 12 patients was performed less than 2 hr after scintigraphic imaging. Of the nine patients in whom a large pericardial region of photon deficiency was the only abnormal scintigraphic finding, seven were treated with either needle aspiration (one patient) or operative drainage. In patients undergoing reoperation, large pericardial effusions were present, no evidence of active bleeding was seen, and ventricular function was normal visually, thus confirming the scintigraphic findings. Although all seven patients demonstrated hemodynamic improvement after relief of tamponade, two subsequently died, one of complications of reoperation and one secondary to fluid reaccumulation despite repeated aspiration.

Ten patients had scintigraphic evidence of active pericardial bleeding without other abnormalities. Although the bleeding was occult clinically, ventricular function was normal and tamponade was therefore diagnosed. Nine underwent reoperation and demonstrated hemodynamic improvement, but three died of shock-related complications early after repeat surgery.

In 10 patients combined scintigraphic causes were found for their cardiac shock. Seven had active bleeding in addition to ventricular dysfunction. Three underwent reoperation, two died before the reoperation, and two were treated medically. Three had large areas of photon deficiency surrounding hypocontractile right or left ventricles; one underwent reoperation and one pericardial needle aspiration.

The five patients with no severe systolic dysfunction of either the right or left ventricle and no abnormal blood pool or photon deficiency surrounding the cardiac chambers were all managed medically, and no deaths ensued.

**Description of scintigraphic findings**

**Global biventricular dysfunction.** In the three patients in whom scintigraphy demonstrated biventricular dysfunction (figure 1), mean left ventricular ejection fraction was 18% (range 11% to 28%) and mean right ventricular ejection fraction was 27% (range 22% to 29%). Pulmonary capillary wedge/right atrial pressure ratio was 1.1 ± 0.4. After scintigraphic assessment, all continued to receive aggressive medical management. Two of the three patients survived.

![FIGURE 1. Severe biventricular dysfunction. *Left,* End-diastole; *right,* end-systole, 45 degree left anterior oblique view. Note the lack of significant photon deficiency or abnormal accumulations of radionuclide activity outside the cardiac chambers.](http://circ.ahajournals.org/lookup/suppl/doi:10.1161/01.CIR.83.4.1156/-/DC1/figure1.jpg)
FIGURE 1. Isolated global left ventricular dysfunction. Left, End-diatole; right, end-systole, 45 degree left anterior oblique view. The normal contraction of the right ventricle contrasts with the severe global dysfunction of the left ventricle.

Global left ventricular dysfunction. Figure 2 illustrates the end-diastolic and end-systolic images in the 45 degree left anterior oblique view in one of the three patients with isolated severe global left ventricular dysfunction and normal right ventricular function. Mean left ventricular ejection fraction was 19 ± 9%, while mean right ventricular ejection fraction was 43 ± 4%. Pulmonary capillary wedge/right atrial pressure ratio was 1.3 ± 0.1. Two of these three patients died while on medical therapy.

Global right ventricular dysfunction. Figure 3 depicts images from one of the patients with severe global right ventricular dysfunction. The left ventricle is small and markedly hypercontractile. In these patients, mean right ventricular ejection fraction was 29 ± 4% (range 21% to 34%) and mean left ventricular ejection fraction was 58 ± 11% (range 48% to 76%). Mean pulmonary capillary wedge/right atrial pressure ratio was 1.2 ± 0.3. All were treated medically, and two of seven died.

Segmental left ventricular dysfunction. Scintigraphy demonstrated new severe segmental ventricular dysfunction in three patients, all of whom were later confirmed to have sustained a perioperative myocardial infarction on the basis of enzyme (creatine kinase-MB) changes. These patients were managed medically, and two of three (67%) survived. Figure 4 shows the postoperative scintigraphic images, in the anterior view, from a patient who had normal global and segmental function before surgery. The early postoperative electrocardiogram was equivocal. Gated equilibrium radionuclide ventriculography showed a large area of left ventricular dyskinesis involving the anterolateral wall, the apex, and the distal inferior wall. In addition, there was right ventricular apical dyskinesis.

Active pericardial bleeding. In 17 patients, abnormal accumulations of radioactivity were noted outside the cardiac chambers (figure 5). Fourteen of these instances were discovered at initial imaging (within 30 to 40 min from time of radionuclide injection), while in three patients active bleeding was not evident at initial imaging but was noted on delayed images only, presumably because the rate of bleeding was slower.

In five of these 17 patients the abnormal radioactivity was evenly distributed around the entire heart, while in 12 it was localized to specific pericardial regions. Single-chamber tamponade, an entity relatively specific to the early postoperative period, oc-
cur on two of these latter patients. The addition of nonzoomed images resulted in discovery of one patient in whom the standard zoomed image failed to detect right hemithorax bleeding. 10

Of the 17 patients discovered to have occult active pericardial bleeding, 12 underwent reoperation. In all, definitive relief of the tamponade and control of bleeding sites were the only operative procedures. No patient required revision of the bypass grafts or valvular procedures. Two patients died before reoperation, and in three other patients bleeding was seen in the setting of ventricular dysfunction, which was thought to be the predominant hemodynamic problem, and medical therapy only was successfully undertaken.

Pericardial effusions. Twelve patients each had a large area of photon deficiency surrounding the cardiac chambers without abnormal radioactivity in the pericardial space (figure 6). Nine had normal ventricular function, hence establishing the cause of cardiac shock to be pericardial tamponade, while three patients had depressed ventricular function. Seven of the 12 underwent reoperation and two underwent pericardiocentesis, at which time active bleeding was not witnessed, the pericardial contents being serosanguinous fluid. All improved hemodynamically after intervention.

Patients with no scintigraphic abnormalities. Qualitative and quantitative assessment of left and right ventricular systolic function and evaluation of the pericardial space revealed no abnormalities accounting for cardiac shock in five patients. Pulmonary capillary wedge (19 ± 3 mm Hg)/right atrial pressure (15 ± 3 mm Hg) ratio (1.3 ± 0.3) was similar to that in patients with tamponade or ventricular dysfunction. Mean electrocardiographic voltage was 13 ± 5 mm.

Discussion

Traditional assessment of postoperative cardiac shock. Because of physiologic changes induced by prolonged hypothermia and cardiopulmonary bypass, distinction between ventricular dysfunction and tamponade can be difficult should cardiac shock develop early after open heart surgery. 11 Although the frequency of this problem will vary according to patient population and clinical diagnostic acumen, there was a need for ancillary diagnostic approaches in 16% of patients in this study. Historical, electrocardiographic, hemodynamic, and chest x-ray findings did not allow a specific etiologic diagnosis in any of our study patients. They had no historical indication of internal bleeding with obstructed egress or poor ventricular function before surgery or at closure of the thoracotomy after open heart surgery. Low electrocardiographic voltage and similar pulmonary capillary wedge and right atrial pressures were common in all groups. The anteroposterior chest x-rays, while showing no diagnostic changes, were suggestive of the correct scintigraphic diagnosis in less than half of our patients.

In our experience, low electrocardiographic voltage is a prevalent and nonspecific early postoperative finding, probably reflecting some or all of ventilator-induced increased pulmonary volumes, myocardial edema from prolonged hypothermia, or a reduced voltage from the myocardium itself secondary to the ischemic insult of surgery. Likewise, elevations in right atrial pressure, which alter the normal wedge-to-right atrial pressure ratio, are also common for unknown reasons. Changes in pulmonary blood volume, total lung water, and cardiac size early after open heart surgery diminish the utility of the chest x-ray for diagnosing acute postoperative cardiac pathology. 11

In patients in cardiac shock early after open heart surgery and without findings to specifically suggest tamponade, the initial clinical approach is usually medical. This reflects concern about the morbidity and mortality associated with repeat thoracotomy in a critically ill patient. In our patients, the average blood loss was greater in those subsequently shown to have tamponade, but reoperation was not planned before scintigraphy because tamponade was not evident and because correction of postoperative coagulation abnormalities is often successful at curtailing bleeding.

Specific findings of radionuclide ventriculography. In these 50 patients with postoperative cardiac shock that could not be etiologically classified by traditional means, 99mTc-labeled red blood cell wall motion scintigraphy provided an apparently unequivocal diagnosis in 70%. It established the presence of one of two broad categories of abnormality in 35 of 50 patients: either ventricular dysfunction or tamponade.

Sixteen patients had right, left, or biventricular dys-
function without pericardial abnormalities. These patients had a combined perioperative mortality of 38%, but in no case was reoperation undertaken. In our experience, many patients with severe cardiac shock and equivocal historical, clinical, and hemodynamic findings are eventually reexplored for the purpose of excluding tamponade unless there is some definite evidence that the problem is myocardial and not pericardial. Unfortunately, because none of these 16 patients underwent reoperation and only one underwent echocardiography (confirmatory of the radionuclide ventriculographic findings), our study did not rule out the possibility that scintigraphically undetected pericardial bleeding or effusion contributed to their cardiac shock.

Nineteen patients had scintigraphic findings of tamponade: abnormalities of the pericardial space in the absence of ventricular dysfunction. Sixteen of these returned to the operating room and in these patients the scintigraphic findings were confirmed at reoperation and there was an immediate improvement in hemodynamics. None of the seven of these 16 patients with "negative" haloes of photon deficiency arounding the heart had any active bleeding sites, and all of the patients with abnormal accumulations of radioactivity in the pericardial space had active bleeding confirmed at surgery. Thus, the finding of a pericardial abnormality in association with normal biventricular function in patients with early postoperative cardiac shock should be regarded as an important diagnostic finding and should influence subsequent patient management.

Ten additional patients had scintigraphic findings suggestive of both tamponade and ventricular dysfunction. Reoperation was undertaken in five patients and planned for two others before death occurred.

Nondiagnostic scintigraphic findings. The scintigraphic images of five of these 50 patients revealed normal or near-normal biventricular function without pericardial effusion or bleeding. No independent means of excluding tamponade were employed in this study. It is possible that tamponade was present but was due to smaller volumes of effusion than could be seen scintigraphically. In our view this is unlikely, particularly since all did well with medical management. An alternative explanation is that these five patients had cardiac functional abnormalities, such as diastolic dysfunction, which were not easily assessed by radionuclide ventriculography. A nondiagnostic scintigraphic finding may allow exclusion of the need for reoperation if the images are of high quality with excellent tagging efficiency and low background counts.

Diverse causes of early postoperative cardiac shock. This study demonstrates diverse causes of cardiac shock early after open heart surgery. Tamponade due to occult pericardial bleeding or to postcardiotomy-related effusions and new segmental left ventricular dysfunction due to intraoperative infarction were expected causes.12-14 Transient global deterioration of left and right ventricular systolic function for 48 to 72 hr after surgery has been demonstrated by Gray et al.1,15 and hypothesized to be due to inadequacies of intraoperative myocardial preservation. This study shows that the degree of global ventricular dysfunction may in some cases be extreme, and indeed may involve both ventricles or predominantly or exclusively the left or the right ventricle. Presumably, factors such as the thickness of the myocardium, the location and severity of coronary obstructive lesions, the degree to which various regions of cardiac muscle are metabolically quiescent during surgery, and the rate at which hypothermia develops and reverses may be pertinent aspects of myocardial preservation as this relates to the development of subsequent selective chamber dysfunction. Moreover, ventricular performance visually assessed at the time of termination of cardiopulmonary bypass and closure of the thorax may be satisfactory, and yet deteriorate to a severe degree over the ensuing hours, possibly reflecting development of myocardial edema and/or changes in afterload.

Radionuclide ventriculography vs alternative diagnostic approaches. Radionuclide ventriculography is a theoretically attractive method for differentiating the causes of early postoperative cardiac shock because it is widely available and can be performed at the bedside in the intensive care unit. Extensive validation exists as to its utility in assessing systolic function of both ventricles,5,6,16 in detecting the presence of active pericardial bleeding,7-10 and in detecting pericardial effusions,17-19

Echocardiography is also widely available and provides a potential diagnostic alternative to radionuclide ventriculography. However, while echocardiography may be able to distinguish mature pericardial hematoma from serous effusion,20,21 it does not allow reliable differentiation between pericardial fluid and active pericardial bleeding. Loculated pericardial hematoma resulting in myocardial compression is common in this setting, and limits the usefulness of M mode echocardiography.20 Moreover, the major limitation of echocardiography under these circumstances is technical. The configuration of the early postoperative chest wall, the relative immobility of early postoperative patients, the location of drainage tubes, the presence of hyperinflated lungs, air in the mediastinum, and the placement of bandages cause a high incidence of tech-
technically inadequate echocardiographic evaluations. For example, 13 of our 50 patients underwent both echocardiographic and radionuclide ventriculographic examinations. In this setting, four (31%) echocardiographic studies were technically inadequate and provided no useful diagnostic information, while none of the 50 patients who underwent radionuclide ventriculography had technically inadequate studies.

If a technically adequate two-dimensional echocardiographic study is obtained, the information content for differentiating ventricular dysfunction from tamponade should be similar to that obtained by radionuclide ventriculography. Possible advantages to echocardiography are a greater sensitivity for detecting small pericardial effusions22 and provision of specific rather than inferential data about the presence of tamponade.23, 24 Speed of data acquisition and relative cost are other important considerations. The design of this study did not allow a direct comparison of the two techniques in this setting, and no other such studies exist. Of the nine patients who had technically adequate echocardiograms and radionuclide ventriculograms, the clinical diagnosis was concordant in eight (tamponade in six patients, ventricular dysfunction in one patient, and tamponade as well as ventricular dysfunction in one patient). In one patient who improved with medical therapy, echocardiography diagnosed a pericardial effusion without tamponade or ventricular dysfunction while radionuclide ventriculography revealed no abnormalities of the pericardial space or in ventricular function.

We have previously surmised that it may be important that red blood cells be labeled in vitro2 with $^{99m}$Tc, or by a modified in vivo method,25 when radionuclide ventriculography is employed in this patient population.10 Labeling of red blood cells or albumin with $^{99m}$Tc in vivo results in a reduced percentage of bound radioactivity over time, potentially leading to distribution of $^{99m}$Tc to various extravascular sites, including the pericardial space.19, 26-28 In such cases, the presence of an abnormal blood pool surrounding the cardiac chambers may not be specific for active pericardial bleeding.

In conclusion, this study demonstrates an important clinical role for bedside $^{99m}$Tc–red blood cell radionuclide ventriculography in patients with cardiac shock early after open heart surgery. When etiologic uncertainty remains after traditional evaluation, radionuclide ventriculography frequently determines the cause of shock and influences subsequent therapy.

Our results also reveal that the differential diagnosis of postoperative cardiac shock includes global right, left, or biventricular systolic dysfunction; tamponade that can be due to active but occult bleeding as well as fluid and/or old blood clots; mixed tamponade and ventricular dysfunction; and sometimes factors other than systolic ventricular dysfunction or scintigraphically evident tamponade.

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