THE ABILITY to resuscitate a patient in cardiac standstill or ventricular fibrillation without opening the chest constitutes a major advance in the treatment of acute cardiac emergencies. In 1957, Rainer and Bulough reported successful treatment of presumptive cardiac arrest during operation in children by flexing the legs and thighs against the closed chest. Kouwenhoven and co-workers in 1960 clearly demonstrated the effectiveness of closed-chest massage and defibrillation in man with reports of cases. Since then, there have been numerous reports of successful closed-chest resuscitation both in the hospital and outside. Gurewich and co-workers have reported aortic pressures recorded during an unsuccessful attempt at closed-chest massage directly following coronary angiography.

We here report six acute cardiac emergencies occurring during cardiac catheterization and angiocardiography. All patients were resuscitated without thoracotomy.

**Laboratory Procedure**

Four hundred and ninety-two patients were studied during the first 18 months of operation of a new cardiac-catheterization laboratory (table 1). Ninety-six were less than 2 years of age and 31 were adults. Seventy per cent of the patients had angiocardiography in the course of the procedure. Five acute cardiac emergencies occurred (table 2, cases 1 to 5), an incidence of 1.0 per cent.

All diagnostic procedures were under the direction of a physician experienced in the problems of cardiac catheterization. A nurse anesthetist was continuously present, with an anesthesiologist either present or available in the adjacent operating suite.

Patients were sedated with a meperidine-promethazine-chlorpromazine mixture supplemented with oxygen and nitrous oxide or halothane as described by Moffitt and colleagues. Complete anesthetic equipment was in the laboratory ready for immediate use.

The electrocardiogram (lead II) and the femoral arterial blood pressure were among the variables continuously monitored by a trained technician and also displayed on a cathode-ray oscilloscope in the catheterization room.

**Methods of Resuscitation**

External cardiac massage was applied on adults in the manner described by Kouwenhoven and co-workers. In infants and small children, however, this method was modified by one of us (H.J.C.S.). The operator stood at the right of the patient (the usual position during catheterization). The left hand was so placed (fig. 1a) as to elevate, extend, and support the posterolateral aspect of the left thoracic cage. The "heel" of the right hand was placed over the sternum immediately above the xiphisternum. Rhythmic compression of the sternum and rib cage was obtained with flexion and extension of the right hand at the wrist (fig. 1b) at a rate of 60 to 100 per minute. The required force of compression was gauged by the systemic arterial pressure attained. Every 30 seconds, massage was discontinued for 5 seconds to assess the cardiac status.

A Morris external pacemaker-defibrillator EDP-1*, which delivers a current of 5 am-
Table 1
Principal Diagnosis in 492 Patients Undergoing Catheterization

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transposition of the great arteries (complete, or associated with complex anomalies such as common ventricle or tricuspid atresia)</td>
<td>94</td>
</tr>
<tr>
<td>Ventricular septal defect:</td>
<td></td>
</tr>
<tr>
<td>Without pulmonary vascular disease</td>
<td>54</td>
</tr>
<tr>
<td>With severe pulmonary vascular disease</td>
<td>42</td>
</tr>
<tr>
<td>With atrial septal defect</td>
<td>8</td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>41</td>
</tr>
<tr>
<td>Pulmonary stenosis or atresia</td>
<td>38</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>26</td>
</tr>
<tr>
<td>Atrial septal defect plus pulmonary stenosis</td>
<td>6</td>
</tr>
<tr>
<td>Aortic-valve anomalies</td>
<td>30</td>
</tr>
<tr>
<td>Normal hemodynamics</td>
<td>21</td>
</tr>
<tr>
<td>Postoperative investigations</td>
<td>21</td>
</tr>
<tr>
<td>Atrioventricular canal</td>
<td>18</td>
</tr>
<tr>
<td>Truncus arteriosus</td>
<td>16</td>
</tr>
<tr>
<td>Anomalous pulmonary venous connection</td>
<td>15</td>
</tr>
<tr>
<td>Mitrval-valve anomalies</td>
<td>13</td>
</tr>
<tr>
<td>Tricuspid-valve anomalies</td>
<td>10</td>
</tr>
<tr>
<td>Patent ductus arteriosus or coarctation</td>
<td>12</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>6</td>
</tr>
<tr>
<td>Endocardial fibroelastosis</td>
<td>5</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>16</td>
</tr>
</tbody>
</table>

peres for 0.25 second, was at all times ready for use. Electrical potential varies from 400 to 900 volts according to the resistance of the thoracic tissues. For defibrillation, the contact paddles were covered with a Raytex sponge soaked in normal saline and positioned respectively on the front and back of the chest (fig. 2).

Endotracheal intubation was performed after diagnosis of the acute cardiac emergency. Positive-pressure ventilation with 100 per cent oxygen was manually performed until adequate spontaneous respirations returned.

Report of Cases

Case 1

A deeply cyanosed white boy (arterial oxygen saturation of 50 per cent), aged 2 months and weighing 4.3 Kg., had a provisional diagnosis of transposition of the great arteries with ventricular septal defect. Medication consisted of intramuscular administration of promethazine, 7.5 mg.

The procedure was uneventful for 1 hour, until the catheter was introduced into the left ventricle through a patent foramen ovale. Left ventricular pressure was 80/0 mm. of mercury when the electrocardiogram revealed the onset of ventricular tachycardia. This quickly changed into ventricular fibrillation, and respiration ceased. The catheter tip was withdrawn from the left ventricle. The child was intubated and ventilated with oxygen. External defibrillation was carried out within 60 seconds; the first shock restored an effective beat for a few seconds but ventricular fibrillation recurred. A second shock again restored normal sinus rhythm with a slow rate which gradually increased to 140 per minute. Femoral arterial blood pressure then was recorded at 100/60.

After observation for several minutes, the child's condition warranted further effort to make the diagnosis. An angiogram was then obtained after injection of 6 ml. of sodium diprotrozoate and diatrizoate (Ditrikon) into the right ven-
## Table 2

### Summary of Data on Six Patients Who Underwent Closed-Chest Cardiac Resuscitation

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Acute cardiac emergency</th>
<th>Probable precipitating cause</th>
<th>Resuscitation</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>2 mo.</td>
<td>Transposition and ventricular septal defect</td>
<td>Ventricular fibrillation</td>
<td>Manipulation of catheter in L. ventricle</td>
<td>External defibrillation, artificial ventilation</td>
<td>Resuscitated within 60 sec, procedure continued and diagnosis made. Subsequent successful repair</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>1 mo.</td>
<td>Total anomalous pulmonary venous drainage to portal vein</td>
<td>Ventricular fibrillation</td>
<td>Injection of contrast medium at angiography</td>
<td>External massage, artificial ventilation</td>
<td>Normal sinus rhythm after 3½ min, procedure terminated. Died 7 days later— inoperable</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>2 yr.</td>
<td>Supravalvular aortic stenosis</td>
<td>Ventricular fibrillation</td>
<td>Manipulation of catheter in ascending aorta</td>
<td>External defibrillation, artificial ventilation</td>
<td>Normal sinus rhythm in 50 sec. Subsequent successful corrective repair</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>4 yr.</td>
<td>Severe tetralogy of Fallot, large patent ductus arteriosus</td>
<td>Severe hypotension and bradycardia. Clinically indistinguishable from cardiac arrest</td>
<td>Injection of meperidine, promethazine and chlorpromazine into catheter placed in R. ventricle</td>
<td>External massage, artificial ventilation</td>
<td>Resuscitated in 2 min., procedure continued and diagnosis completed</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>35 yr.</td>
<td>L. atrial myxoma</td>
<td>Ventricular fibrillation</td>
<td>Injection of contrast medium at angiography</td>
<td>External massage, artificial ventilation</td>
<td>Resuscitated in 4½ min., succumbed to ventricular fibrillation 4 hr. later</td>
</tr>
</tbody>
</table>
tricle. This produced a few ventricular extrasystoles. The diagnosis of transposition of the great arteries and ventricular septal defect was established. Ten days later, the child successfully underwent a corrective open-heart operation.

Case 2

A cyanotic girl (arterial oxygen saturation of 46 per cent), 4 weeks old and weighing 3.5 Kg., was catheterized under medication with meperidine, 12.5 mg., promethazine, 3.75 mg., and chlorpromazine, 3.75 mg.

After 90 minutes in the laboratory, angiography was done with injection of 5 ml. of sodium diprotirizato and diatrizoate into the left ventricular outflow tract. As the dye was injected, the electrocardiogram showed the onset of ventricular fibrillation. The arterial blood pressure decreased and respiration ceased (fig. 3a). External massage and ventilation with oxygen were begun without delay. Compression of the intact chest wall at an approximate rate of 100 per minute produced a femoral arterial systolic blood pressure of 75 to 80 mm. of mercury (fig. 3b). Pupils remained small. After 3½ minutes, normal sinus rhythm returned, followed shortly by spontaneous respiration (fig. 3c). The procedure was terminated and the child returned to her room in good condition.

Angio cardiograms showed that the catheter tip had passed through the aortic valve into the base of the aorta. The coronary vessels were well delineated with dye (fig. 4).

The condition of the infant slowly deteriorated and she died 7 days later. The diagnosis at necropsy was total anomalous pulmonary venous drainage into a portal vein with a closed ductus venosus. There was also a ventricular septal defect.

Case 3

A 2-year-old boy, weighing 10.2 Kg., had a clinical diagnosis of aortic stenosis. Within the previous month, he had had two episodes of sudden loss of consciousness.

Retrograde aortography was planned, with a catheter introduced through the right brachial artery. Meperidine, 20 mg., was given intramuscularly and the child was anesthetized with equal volumes of nitrous oxide, oxygen, and 0.75 per cent halothane.

Thirty minutes later, the catheter was advanced from the aortic arch to the ascending aorta and aortic root. The pressures recorded in these two sites were 120/67 and 160/68 respectively, indicating the presence of supravalvular narrowing of the aorta. Within 1 minute, there was tran-

sient acute bradycardia with a fall in pressure in the aortic root from 180/75 to 40/0. The electrocardiogram then revealed a ventricular tachycardia which passed into ventricular fibrillation. The catheter was immediately withdrawn to the aortic arch, as it was thought to be obstructing the narrowed segment of the aorta. Endotracheal intubation preceded manual ventilation with 100 per cent oxygen. After 50 seconds of no effective cardiac action, the heart was defibrillated through the chest wall with a single shock. The subclavian arterial pressure rose gradually to a maximal value of 160/80. Since the diagnosis of supravalvular aortic stenosis had been made, the child was returned to his room awake, crying, and in good condition.

Two weeks later, this patient underwent open repair of his cardiac lesion. His recovery was uneventful and he was dismissed 14 days postoperatively.

Case 4

A 4-year-old boy, weighing 15 Kg., had a clinical diagnosis of severe tetralogy of Fallot with a large pulmonary blood flow principally through a patent ductus arteriosus.

Medication with meperidine, 50 mg., chlorpromazine, 12.5 mg., and promethazine, 12.5 mg., was insufficient and was supplemented with nitrous oxide and oxygen. Ninety minutes later, sedation was inadequate; so meperidine, 25 mg., chlorpromazine, 6.5 mg., and promethazine, 6.5 mg., were given through the catheter directly into the right ventricle. The arterial systolic blood pressure fell to 50 mm. of mercury and the heart rate to 60 beats per minute. The electrocardiogram showed a sudden change to atrial flutter with a 2:1 block. The ventricular rate slowed to 20 beats per minute and the patient’s condition became clinically indistinguishable from that of cardiac arrest. Closed-
chest massage was commenced, endotracheal intubation and manual ventilation were performed, and the catheter was withdrawn to the superior vena cava. After 2 minutes, normal sinus rhythm was restored and the femoral arterial blood pressure was recorded at 100/60.

As his condition remained satisfactory, the procedure was continued. An angiocardiogram was obtained after injection of 19 ml. of sodium diatrizoate and diatrizoate into midright ventricle. This produced three ventricular extrasystoles.

The patient was returned to his room in good condition with the preoperative diagnosis established.

Case 5

A white woman, aged 35 years and weighing 60 Kg., had a 1-year history of cardiac irregularity, congestive heart failure of increasing severity, confusion, disorientation, and seizures. As her condition was rapidly deteriorating and the possible diagnosis of left atrial tumor was entertained, she was accepted for study in spite of the extreme risk involved.

Since the patient was incapable of cooperation, a mixture of nitrous oxide, 75 per cent, and oxygen, 25 per cent, was given during the venous cutdown and introduction of the catheter. The femoral arterial oxygen saturation was 100 per cent while she was breathing pure oxygen and the oxygen saturation of pulmonary arterial blood was 34 per cent. Cardiac output was severely reduced (0.9 L/min./M²). Pulmonary arterial wedge pressure was 45/25 and the pulmonary arterial blood pressure 82/46. Femoral arterial blood pressure was 70/50.

Angiocardiography was carried out with injection of 67 ml. of sodium diatrizoate and diatrizoate into the pulmonary artery, without alteration of cardiac rhythm. One minute later, femoral arterial blood pressure was 45/30 and the electrocardiogram revealed ventricular tachycardia, which quickly changed into ventricular fibrillation. External massage produced a femoral arterial blood pressure of 105/30. Six attempts at external defibrillation were unsuccessful. Procaine amide, 300 mg., was given intravenously and massage continued. Shortly afterward, normal sinus rhythm was restored and the femoral arterial blood pressure was recorded at 130/70. A diagnosis of left atrial tumor was made.

On her return to the ward, her condition worsened with the development of pulmonary edema. Four hours later, ventricular tachycardia and fibrillation recurred. Prolonged attempts at cardiac and respiratory resuscitation failed to revive her.

Case 6

The heart of another patient, not included in the present series, was successfully defibrillated through the closed chest by one of us (H.J.C.S.) on July 15, 1959, in another laboratory. The patient was a white woman, aged 39 years and weighing 109 pounds, who had a clinical diagnosis of rheumatoid aortitis with severe aortic insufficiency. A catheter introduced through the brachial artery was passed through the aortic valve into the left ventricle. The femoral arterial blood pressure dropped suddenly to 30 mm. of mercury and then to 0 as the electrocardiogram revealed the onset of ventricular fibrillation. The catheter was immediately withdrawn from the left ventricle. Electrical defibrillation through the closed chest was accomplished within 40 seconds with a single countershock. The patient immediately regained consciousness. A brief period of complete atrioventricular dissociation preceded the return to normal sinus rhythm. The procedure was terminated and the patient returned to her room awake and in good condition. She succumbed 1 month later from progressive cardiac failure.

Discussion

The 1 per cent incidence of acute cardiac emergencies requiring resuscitation through the closed chest is probably related to complexity of the lesion and type of procedure. The patients studied were highly selected. As an index of this, 94 of the first 492 patients had transposition of the great arteries or complex anomalies with associated transposition such as tricuspid atresia or common

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Figure 3

Case 2. Records obtained during closed-chest cardiac massage. a. Onset of ventricular fibrillation with injection of contrast medium into left ventricular outflow tract. b. Femoral arterial and right atrial blood pressures obtained during closed-chest cardiac massage. c. Reappearance of normal sinus rhythm, with sustained femoral arterial blood pressure but marked fall in right atrial blood pressure. Record is initially at a slower speed than in a and b but is switched to fast speed to display electrocardiogram and pressure curves more clearly.
ventricle (table 1). Follow-up studies on all 492 patients show that 83 (16.9 per cent) have since died with or without surgical treatment. This indicates the risk involved in the management of these patients.

Cardiac massage and defibrillation through

Circulation, Volume XXV, June 1962

Figure 4
Case 2. Angiocardiograms taken at an exposure rate of 5 per second. a and b represent anteroposterior and lateral exposures no. 3, and c and d anteroposterior and lateral exposures no. 15, in the angiocardiographic series. Comparison of early and late exposures shows cardiac dilatation, aortic collapse, and cessation of cardiac output during ventricular fibrillation. Note that contrast medium is present in both ventricles and both atria in exposure no. 15. A ventricular septal defect is evident.
RESUSCITATION IN CATHETERIZATION LABORATORY

the closed chest have been simple and effective procedures. They must be considered the methods of choice for the resuscitation in acute cardiac emergencies in a cardiac catheterization laboratory because (1) routine monitoring of the electrocardiogram permits an immediate diagnosis, (2) routine monitoring of the arterial blood pressure allows evaluation of the effectiveness of massage, (3) patients with severe cardiac disease subjected to thoracotomy experience a considerable mortality unless the intracardiac defect is effectively repaired, (4) open-chest resuscitation may complicate subsequent operation on the heart, and (5) closed-chest resuscitation may enable the cardiac catheterization to continue to a definitive diagnosis and assessment of operability.

The method of closed-chest cardiac massage described by Kouwenhoven and co-workers proved extremely effective in the one adult in our series. Our modification of this method for infants and small children appears to offer an advantage. Elevation and support of the chest with the left hand (fig. 1a) may provide more stability for compression of the ventricles. The resilience of the rib cage in the infant permitted adequate arterial blood pressure to be obtained with relatively gentle manual compression.

There was no clinical, radiologic, or necropsy evidence of tissue injury in the three patients who had closed-chest cardiac massage. Baringer and associates have reported fractured ribs, hemothorax, hemopericardium, injuries of the liver, and narrow emboli. Rupture of the liver has been reported by Morgan. The ability to gauge the force of manual compression by the resulting femoral arterial blood pressure should protect against complications from unnecessarily zealous attempts at resuscitation.

Ventricular fibrillation was the most frequent emergency encountered, occurring in five of the six patients. The precipitating factor in three patients was the manipulation of the catheter either in the left ventricle or in the ascending aorta. The hearts of all three were defibrillated within 60 seconds of the onset of fibrillation, without prior cardiac massage. Kouwenhoven and co-workers indicated that spontaneous heart action may return if the countershock is applied within 3 minutes of the onset of fibrillation. We believe that ventricular fibrillation of less than 60 seconds' duration may be treated by defibrillation alone. However, a period of closed-chest cardiac massage must be employed if two countershocks are unsuccessful or if the duration of fibrillation is longer than 60 seconds. In two patients, ventricular fibrillation was related to the injection of contrast medium, sodium dioptrizoate, and diatrizoate, at angiography. In one of these, a satisfactory arterial blood pressure was maintained for 3½ minutes with closed-chest massage, and normal sinus rhythm returned spontaneously (fig. 4c). In the other, 4½ minutes of closed-chest cardiac massage effectively maintained a higher arterial blood pressure than that recorded before injection of contrast medium. Six electrical countershocks were unsuccessful but normal sinus rhythm returned after intravenous injection of procaine amide, 300 mg., and continued closed-chest cardiac massage.

Extreme hypotension and bradycardia followed the injection of meperidine, promethazine, and chlorpromazine into the right ventricular chamber of a severely cyanotic 4-year-old patient who had suddenly become restless and unmanageable—this practice is no longer followed; 2 minutes of closed-chest massage restored normal sinus rhythm and good cardiac output. Support of the circulation by closed-chest massage should be considered in any situation characterized by a rapidly failing cardiac output. In this way, cardiac asystole or fibrillation may be averted.

Thoracotomy would be performed in our laboratory only after failure to maintain an adequate artificial circulation by external massage or after repeated failure to defibrillate.

The effect of closed-chest massage on the pressures within all chambers of the heart is
indicated in figure 3b. Compression of the chest wall produced a femoral arterial systolic blood pressure of 75 to 80 mm. of mercury. The right atrial pressure rose to 30/10 and returned to 14/8 after restoration of normal sinus rhythm and cessation of massage (fig. 3c).

The angiocardiograms in figure 4 show cardiac dilatation, aortic collapse, and cessation of cardiac output during ventricular fibrillation. Contrast medium fills both ventricles and enters both atria, probably owing to temporary incompetence of all valves.

Summary

Closed-chest massage and defibrillation were used successfully in the management of six acute cardiac emergencies occurring in a cardiac catheterization laboratory. A modification of the Kouwenhoven method of closed-chest massage was used in infants and small children. It is concluded that open-chest resuscitation is usually unnecessary during cardiac catheterization.

References


Heredity and Environment

An account of formative influences which have affected a career should quite properly start with inheritance. It may not be possible to trace the appearance of many traits from generation to generation through a considerable past—the combinations of determinative factors become too complicated as the numbers in the ancestry multiply. Sometimes, however, the transmission of the infinitesimal hereditary packets in germ cells is demonstrated by peculiar features clearly distinguishable in a long family line. The famous Hapsburg lip is an eminent example. Such evidence justifies looking backward for the appearance of characteristics in some of the forebears, especially in recent history. Besides biological inheritance there is tradition to be recognized as a potent agency in affecting behavior.—Walter B. Cannon, M.D. The Way of An Investigator. New York, W. W. Norton & Company, Inc., 1945, p. 11.
Closed-Chest Resuscitation in a Cardiac Catheterization Laboratory
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