Complications of Cardiac Catheterization of Neonates, Infants, and Children
A Three-Year Study

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SUMMARY
In order to assess the influence of recent modifications in cardiac catheterization technique and patient management, a prospective study of all complications in a series of 1160 cardiac catheterizations of neonates, infants, and children was performed. Thirty-four major and 136 minor complications were recorded. Fatal complications were rare in all age groups (0.26%); however, postcatheterization deaths not attributable to the procedure were common in critically ill neonates with nonremediable lesions.

Arrhythmias and arterial complications accounted for 78% of all complications. Although the incidence of arrhythmias was high (8.3% of all cases), particularly in infants, almost all responded to simple therapeutic measures. Five arrhythmias resulted in clinical deterioration and two contributed to death.

The incidence of arterial complications varied considerably with the method of arterial entry. Percutaneous catheterization by the sheath method was associated with fewer complications than with the Seldinger technique, arteriotomy, or insertion of a teflon cannula into an exposed artery. Complications were particularly common after brachial arteriotomy in patients with coarctation of the aorta (16.1%).

Complications of contrast media and perforation of the heart were infrequent, each occurring once.

Although the total number of major complications was only moderately less frequent than in patients of comparable age in the Cooperative Study on Cardiac Catheterization,1 there was a considerable reduction in the most severe complications and deaths. The changes in catheterization technique and patient management that contributed to decreased mortality and morbidity are discussed.

Additional Indexing Words:
Arteriotomies Complications Contrast medium
Arrhythmias Hypoxic spells

In 1968 THE COOPERATIVE STUDY on Cardiac Catheterization reported the major complications of cardiac catheterizations performed in 16 participating laboratories between November 1, 1963, and October 31, 1965.1 The study included complications in infants and children as well as adults. Since that study, and in part as a result of it, improvements in catheterization techniques as well as in management of acutely ill children during the procedure have made catheterization safer. The present study presents our recent experience with major and minor complications of cardiac catheterization of neonates, infants and children at the University of California Medical Center, San Francisco. We have described changes in technique and in the procedure which we feel have contributed to reduced risks.

Material
The population includes 1160 neonates, infants, and children who underwent cardiac catheterization at the University of California Medical Center, San Francisco, between January 1, 1970, and December 31, 1972. During that period prospective records were kept of all major and minor complications. In addition, each of the catheterization records was reviewed in order to insure complete reporting. It is likely, however, that there was underreporting of certain minor complications. A superficial wound infection that occurred after leaving the hospital might well have been cared for by the patient’s primary physician without our being notified; it is unlikely that a more serious infection would not have been brought to our attention. Minor arrhythmias such as mild first degree atrioventricular block may not have been recognized during oscillographic monitoring, particularly if there was considerable variation in the patient’s heart rate. Consequently, we have designated as...
"minimum" the incidence of those complications that were particularly subject to underreporting.

The great majority of patients had the usual spectrum of congenital cardiac disease although a few had acquired cardiac disease (3%), no cardiac disease (2%), or pulmonary disease (1%).

The age distribution of the patients is shown in figure 1. The large number of neonates under four weeks and infants four weeks to one year is apparent. Very few infants and children who were catheterized were classified as severely ill. Most were in the clinically well, mildly ill, or moderately ill categories. The moderately ill included patients with marked hypoxemia or refractory congestive heart failure. In contrast, most of the neonates were moderately or severely ill at the time of catheterization; many were in extremis and included desperately ill babies who required assisted ventilation and other life-supportive measures.

In order to facilitate comparison we have used the definitions of major complications that were used in the Cooperative Study. These are summarized in table 1A. We have supplemented this with a tabulation of minor complications not associated with any prolonged or serious clinical disturbance and these are listed in table 1B. The number of major and minor complications in each group is included.

Deaths

With two exceptions, all deaths during or within 24 hours after catheterization occurred in neonates, i.e., under four weeks of age. Consequently, our experience with neonates deserves special attention.

Invariably, emergency catheterization was performed in neonates because they were extremely sick or it was anticipated that they might undergo rapid deterioration. This latter group included cyanotic neonates who were dependent on a patent ductus arteriosus for survival. The severity of illness varied considerably and we have classified them as:

a) Mildly ill — Nondistressed, nonacidotic, but hypoxemic babies with a Po2 greater than 25 mm Hg, or those in controlled congestive failure.

b) Moderately ill
   i) intensely hypoxemic babies with a Po2 of less than 25 mm Hg, but without metabolic acidosis, or
   ii) infants in severe congestive failure, poorly controlled with digitalis and diuretics.

c) Critically ill — Neonates with one or more of the following:
   i) requiring ventilatory assistance
   ii) profound hypoxemia with acidemia
   iii) poor peripheral perfusion resulting in a shocklike picture or marked acidemia (pH < 7.1, base excess > -12)

A tabulation of the severity of the illness and the immediate outcome of 218 neonates undergoing cardiac catheterization is given in table 2.

Mildly ill neonates

There were 82 patients in this group, with one death. This occurred in a three-week-old patient with Down's Syndrome, endocardial cushion defect, and mild congestive failure. The patient had recovered from a recent episode of diarrhea and had mild metabolic acidosis at the time of catheterization. This acidosis was corrected with intravenous sodium bicarbonate, and the catheterization was uneventful but 24 hours after catheterization, the patient was found dead in her crib. Autopsy demonstrated no cause for death. Although no relationship to catheterization could be established, it is possible that the patient had a fatal arrhythmia.

Moderately ill neonates

There were seven deaths in this group; five occurred during or soon after emergency cardiovascular surgery. One of the other two deaths occurred in a two-day-old infant with Ebstein's malformation, patent ductus arteriosus, pulmonary insufficiency, tricuspid insufficiency and a right-to-left atrial shunt. There were 13 brief episodes of supraventricular tachycardia during the catheterization but this was not associated with clinical deterioration of the patient. Two hours after completion of the catheterization study, increasing cyanosis, bradycardia, and progressive acidosis suddenly developed. This was not responsive to intensive medical therapy and the patient died. The second patient who died was three-
### Table 1: Complications of Cardiac Catheterization

<table>
<thead>
<tr>
<th>Complication Type</th>
<th>Definitions and Number of Cases</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Death</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Contributed to by catheterization</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>b) Possibly contributed to by catheterization</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>c) Pericatheterization deaths not attributed to catheterization</td>
<td>(32)</td>
<td></td>
</tr>
<tr>
<td><strong>B. Arrhythmias</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Cardiac standstill</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>b) Ventricular fibrillation</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>c) Prolonged ventricular tachycardia</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>d) Other arrhythmias leading to prolonged severe hypotension and/or premature discontinuation of the procedure (or countershock)</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td><strong>C. Profound hypotension</strong></td>
<td>requiring sustained therapy such as pressor agents</td>
<td>0</td>
</tr>
<tr>
<td><strong>D. Arterial</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Loss of limb</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>b) Ischemic symptoms for more than one week</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c) Requiring surgical exploration of vessel</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><strong>E. Perforation of heart or great vessel</strong></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>a) By catheter</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b) By contrast material</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>F. Catheter problems</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Complete breakage of catheter or guide wire</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b) Knotting of catheter</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>G. Infections</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Bacterial endocarditis</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b) Local infections requiring surgical drainage</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>H. Allergic reactions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Contrast</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b) Premedication or anaesthetic</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c) Other drugs</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>d) Transfusion reactions</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>e) Pyrogen reactions; temp 104 (R)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>I. Embolism</strong></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>J. Cardiac</strong></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>a) Myocardial infarction</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b) Acute pulmonary edema</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>c) Severe hypoxemic spells</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>K. Bleeding</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Requiring surgical intervention</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>b) Requiring transfusion</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>L. Pneumothorax</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>M. Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Catheter entrapment in coronary artery</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td></td>
<td>34</td>
</tr>
</tbody>
</table>

*Note: Definitions and number of cases for each complication type are listed.*
days-old and had aortic atresia and a restrictive patent ductus arteriosus. Prior to the catheterization, arterial pulses were weak but peripheral perfusion was adequate. After an uneventful catheterization, the pulses diminished, acidemia developed, and death occurred, probably due to further constriction of the ductus arteriosus with impaired peripheral perfusion.

Critically ill neonates

Of the 47 critically ill neonates, two died during the procedure, 15 after the procedure, and eight died during or soon after emergency cardiovascular surgery. There were 22 survivors.

Of the two infants that died during the procedure, the first was a moribund 12-hour-old infant with severe pulmonary disease, poor cardiac output, and acidosis. He was receiving alkali, isoproterenol, and intermittent cardiac massage prior to and throughout the procedure. Prior to the catheterization, the patient had an episode of ventricular fibrillation and a second episode occurred during the procedure. Both were successfully terminated by DC shock. The patient’s peripheral perfusion decreased throughout the procedure and he died. The second death occurred in a severely ill, two-day-old infant with mitral and aortic atresia. The patient developed 2:1 atrioventricular block during catheter manipulation. The arrhythmia undoubtedly contributed to his deterioration and death.

Of the 15 critically-ill neonates who died within 24 hours after catheterization, most had nonremediable conditions (ten aortic and/or mitral atresia, two asplenia, one tracheal agenesis with total anomalous pulmonary venous connection, one pulmonary disease and one severe cardiomegaly following prolonged hypoxia). In each case, the death was believed to be the result of progressive clinical deterioration related to the disease. In none of these cases was there an arrhythmia or other specific incident likely to have furthered deterioration. In fact, several patients transiently improved during catheterization, probably as a result of receiving bicarbonate therapy or correction of hypoglycemia. In some patients with untreatable lesions, extensive resuscitation was not continued and death occurred within 24 hours after catheterization. In contrast, 21 of the 22 survivors in this critically ill group had pulmonary disease or cardiac problems other than aortic and/or mitral atresia.

Comment

An analysis of deaths in neonates that can be directly attributed to the catheterization procedures is difficult. Many of the studies were performed on critically ill and sometimes moribund patients, some of whom were intubated and ventilated, and in three instances receiving intermittent external cardiac massage. We have therefore recorded all deaths that occurred within 24 hours of the procedure. There were 33 deaths in 218 neonates. Although it is possible that the catheterization procedure may have contributed to the death of some of these infants, in our judgment only one neonate died as a result of the procedure and in another the relationship was not clear. The remaining 31 deaths were attributed to the presence of serious nonremediable lesions or to surgery.

Table 2

<table>
<thead>
<tr>
<th>Severity of Illness</th>
<th>Total no. of cases</th>
<th>Deaths during catheterization</th>
<th>Deaths within 24 hours of catheterization</th>
<th>Deaths during or after surgery</th>
<th>No deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>82</td>
<td>0</td>
<td>1 ECD</td>
<td>0</td>
<td>81</td>
</tr>
<tr>
<td>Moderate</td>
<td>80</td>
<td>0</td>
<td>2 HLH</td>
<td>5 Ao. Stenosis</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Ebstein's, PDA, PI</td>
<td>2 TAPVC</td>
<td></td>
</tr>
<tr>
<td>Critical</td>
<td>47</td>
<td>2</td>
<td>10 HLH</td>
<td>8 TGA</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Pulm. Dis.</td>
<td>1 TAPVC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Asplenia</td>
<td>2 Ao. Stenosis</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 TAPVC</td>
<td>1 VSD, PS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 Myocardiopathy</td>
<td>3 Interrupted Aortic Arch</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 TAPVC and Tracheal Agenesis</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: ECD = Endocardial Cushion Defect; HLH = Hypoplastic Left Heart Syndrome; PDA = Patent Ductus Arteriosus; TAPVC = Total Anomalous Pulmonary Venous Connection; TGA = Transposition of the Great Arteries; VSD = Ventricular Septal Defect; PS = Pulmonic Stenosis; Coarct = Coarctation of the Aorta; Ao. Stenosis = Aortic Stenosis; Pulm. Dis = Pulmonary Disease; PI = Pulmonary Insufficiency.

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Deaths in Infants and Children

There were two deaths associated with catheterization of 942 infants and children above one month of age. The first occurred in a six-month-old infant with transposition of the great arteries and severe subpulmonic stenosis who had undergone a Blalock-Hanlon atrial septectomy and Waterston aortopulmonary anastomosis. Congestive failure resulted in a progressively deteriorating course. He was moribund and had a cardiorespiratory arrest as he was being brought into the catheterization laboratory and another during the cutdown. Despite continued resuscitation efforts he expired 45 minutes later while we attempted to perform a partial cardiac catheterization. Autopsy demonstrated an adequate aortopulmonary anastomosis and very small interatrial communication.

The second occurred during the catheterization of an 11-year-old girl with severe pulmonary vascular disease in whom a patent ductus arteriosus had been divided at three years of age. Recent exercise limitations and syncopal episodes prompted referral for evaluation and consideration of a pulmonary-aortic shunt. Catheterization was performed without sedation and demonstrated severe pulmonary vascular disease with tricuspid insufficiency. During performance of indicator-dilution curves the patient became nauseated, retched, and had a vasovagal episode with marked bradycardia and peripheral circulatory collapse. Resuscitative measures were unsuccessful. It is thought that since the patient had severe pulmonary vascular disease with tricuspid insufficiency, she was unable to increase right ventricular stroke volume to compensate for the bradycardia. Systemic output and consequently coronary perfusion of the right ventricle probably decreased with resulting further circulatory collapse.

It has been noted that patients with severe pulmonary vascular disease without an aortopulmonary or intracardiac communication are at particularly high risk during cardiac catheterization. Based on this, if it is deemed necessary to study these patients, it may be useful to place a pacing electrode catheter in a separate vein prior to the procedure.

Arrhythmias

A wide variety of arrhythmias were encountered and their incidences are listed in table 3. Transient right bundle branch block occurred quite frequently; however, because of its benign nature it was not recorded as a complication. Similarly, mild first degree atrioventricular block was not recorded.

Paroxysmal Atrial or Junctional Tachycardia (PAT)

This was the most common of the significant arrhythmias and occurred 102 times in 45 catheterizations or in 3.9% of all catheterizations. Eleven of the patients were receiving digitalis preparations at the time of catheterization. One of these patients was catheterized twice and was one of the three patients with pre-excitation syndrome. Twenty patients had more than one episode of PAT and all but six of these episodes were of brief duration lasting less than 2 min. The arrhythmia occurred more commonly in neonates and infants but was encountered in all age groups. It occurred in eight patients with transposition of the great arteries, and three with Ebstein's malformation (incidences of 7% and 100%, respectively).

Although the episodes were usually initiated when the catheter tip was in the atria, in several cases they occurred during manipulation within the ventricles. In one patient brief episodes occurred repeatedly when the catheter tip was in the hepatic portion of the inferior vena cava.

The duration of the episodes varied considerably, but most were brief. There were 83 episodes lasting under 2 min, ten lasting 3–10 min, and nine lasting more than 10 min.

Various methods were used to treat the supraventricular tachycardias. Quite often simply withdrawing the catheter to the inferior vena cava was followed by

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arrhythmias and Their Sequelae</strong></td>
</tr>
<tr>
<td>No. patients</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Paroxysmal atrial or junctional tachycardia</td>
</tr>
<tr>
<td>Atrial flutter-fibrillation</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
</tr>
<tr>
<td>Sinus Bradycardia</td>
</tr>
<tr>
<td>3° A-V block</td>
</tr>
<tr>
<td>2° A-V block</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

*Circulation, Volume 50, September 1974*
spontaneous resolution (50 episodes). If the arrhythmia persisted, premature atrial or ventricular contractions were induced by manipulating the catheter against the atrial or ventricular wall; this terminated the arrhythmia in 29 of 37 episodes. Several patients responded to vagal maneuvers, i.e., unilateral carotid massage (3/11), supra-orbital pressure (13/18), or intragastric icewater delivered by nasogastric tube (1/4). Two patients with persistent arrhythmia responded to intravenous edrophonium (Tensilon); however, in one the response was transient and the patient subsequently required digitalization. Countershock was used in four patients with PAT. The first patient had tetralogy of Fallot and became more hypoxemic and moderately acidic during the episode. Following reversion to sinus rhythm and intravenous bicarbonate he improved. The second patient had an anomalous left coronary artery and a history of recurrent ventricular tachycardia. During catheterization an episode of junctional tachycardia with aberrant conduction was interpreted as ventricular tachycardia and he received countershock. In the third patient countershock caused ventricular fibrillation which converted to sinus rhythm after a second shock. The fourth patient developed ventricular fibrillation while provoking ventricular ectopics to treat PAT and converted to sinus rhythm with countershock. None of the other patients with PAT developed clinical deterioration sufficient to warrant countershock therapy and only one other patient required discontinuation of the procedure, i.e., the persistent arrhythmia that required digitalis therapy. Both patients who developed ventricular fibrillation while treating PAT had pre-excitation syndrome and neither was receiving digitalis.

It is of interest that PAT was rare in patients with severe aortic or pulmonic stenosis. These patients might be expected to tolerate tachyarrhythmias very poorly as coronary perfusion could be greatly compromised with rapid rates. We would therefore be inclined to use cardioversion more readily in patients with these lesions. The one patient with severe aortic stenosis who did develop PAT was a small infant with a rapid sinus rate. His heart rate was not greatly altered by the tachyarrhythmia and he tolerated it well.

Atrial Flutter

Atrial flutter occurred once in each of four patients. Each episode was associated with some degree of A-V block with normal or slightly increased ventricular rates and no symptoms. The episodes were all brief (1–8 min). Two resolved spontaneously, one ended with induction of ventricular ectopic beats, and one with icewater instilled through an intragastric tube.

Atrial Fibrillation

This arrhythmia occurred in two patients. One episode was brief and self-limiting; the other responded to intravenous propranolol which was given after the arrhythmia had persisted for 15 min.

Ventricular Tachycardia

Many patients had multiple (three or more) ventricular ectopic beats in series when the catheter was touching an irritable portion of the myocardium. In almost all instances withdrawal of the catheter promptly resulted in cessation of the ectopics. These episodes were not classified as ventricular tachycardias for the purpose of this study. Only those instances in which the ectopic beats persisted after catheter withdrawal were classified as ventricular tachycardia. In four patients, there were five episodes of ventricular tachycardia. Three of these episodes were of very brief duration, lasting 5–10 sec and each resolved spontaneously. One of the three episodes occurred transiently after defibrillation for ventricular fibrillation and two were initiated while manipulating a catheter in the right ventricle. The remaining two episodes occurred in a critically-ill newborn with meconium aspiration. The first episode occurred while the patient was being prepared on the catheterization table and a second occurred during catheter manipulation. Both episodes responded to countershock.

Ventricular Fibrillation

There were six brief episodes of ventricular fibrillation in six patients, five of whom were less than six months of age and were receiving digitalis. Three episodes occurred while manipulating in the right ventricle and two occurred during treatment of PAT in patients with pre-excitation syndrome. One resulted when ventricular ectopic beats were being produced by manipulation of the catheter in the right ventricle and the other occurred following countershock; this was the only complication of countershock and it occurred in a patient not on digitalis. The other episode of ventricular fibrillation was in the moribund 12-hour-old infant described in the section on deaths and occurred after an aortogram in the descending aorta. All six episodes responded promptly to countershock, and the duration of each was less than one minute.

Atrioventricular Block

Six episodes of first degree A-V block were readily recognizable on the oscilloscope. It is quite possible that this arrhythmia was considerably underreported as mild degrees of first degree A-V blocks might not have been recorded and first degree block occurring
during recovery from second or third degree block were not recorded separately.

Second degree A-V block was relatively uncommon and occurred in only six patients. One episode occurred in a severely ill, acidosic child with hypoplastic left heart and undoubtedly hastened his death (see section on Deaths). In five patients the arrhythmia was not associated with clinical deterioration. Second degree A-V block occurred briefly during recovery from third degree block in several patients but was not separately recorded.

Third degree A-V block occurred 20 times in 17 patients. The durations of the episodes varied between 1-10 min. Only one patient showed profound bradycardia with mild clinical deterioration but responded well to temporary ventricular pacing.

Sinus Bradycardia

Sinus bradycardia occurred 14 times in 12 patients, two of whom were receiving digitalis. Twelve episodes were brief and self-limiting. One cyanotic patient had an 8 min episode with increasing hypoxemia and metabolic acidosis of moderate severity, but responded to oxygen, intravenous atropine, and NaHCO₃. An episode of sinus bradycardia was associated with one of three deaths attributable to catheterization in the study period, viz., the 11-year-old girl discussed in the section on deaths.

Comment

Although the number of arrhythmias was quite large, most abated spontaneously or with simple therapy. Very few were associated with clinical deterioration.

Arrhythmias were much more frequent in infants than in older children (table 4). This was particularly true of atrioventricular block and ventricular arrhythmias, but also, to a lesser extent, of supraventricular tachycardias. The higher incidence in infants occurred despite the use of soft small diameter catheters (4F NIH or Elecath). The use of Swan-Ganz balloon-tip catheters was rarely associated with arrhythmias.

Although cyanotic newborns tolerated tachyarrhythmias reasonably well for moderately long periods, bradycardia was not well tolerated even for short periods. As the newborn has a limited ability to increase stroke volume, bradycardia may have profound circulatory effects. Since intensely cyanotic newborns are particularly prone to develop sinus bradycardia, we have often given them atropine 0.01 mg/kg in order to avoid bradycardia. This has, on occasion, temporarily decreased the depth of cyanosis. It is possible this is the result of a dilating effect of atropine on the ductus arteriosus. Atropine has been shown to decrease the vasoconstrictor effect of oxygen on isolated ductus arteriosus rings obtained from fetal lambs; however, there have been no clinical trials.

Since the study period we have been inclined to use propranolol for treatment of persistent supraventricular tachycardias that do not respond to catheter-induced ectopic beats, provided there are no contraindications to the use of propranolol.

We have not found an increased incidence of arrhythmias during catheterization of patients receiving digitalis.

Arterial Complications

During the latter part of the study period we used percutaneous catheterization techniques. The study therefore includes several types of arterial entries. There were 881 arterial entries which included 441 arteriotomies, 119 percutaneous arterial catheterizations, 232 punctures of exposed arteries, and 89 umbilical arterial catheterizations (see table 5). There were 361 catheterizations in which no arterial entry was made. The venous catheter was manipulated into the aorta directly or via a ventricular septal defect or

| Table 4 |

<table>
<thead>
<tr>
<th>Frequency of Arrhythmias During Cardiac Catheterization at Various Ages</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Procedures</td>
</tr>
<tr>
<td>PAT</td>
</tr>
<tr>
<td>Atrial flutter-fibrillation</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
</tr>
<tr>
<td>2° atrioventricular block</td>
</tr>
<tr>
<td>3° atrioventricular block</td>
</tr>
<tr>
<td>Sinus bradycardia</td>
</tr>
<tr>
<td>Total (No.)</td>
</tr>
<tr>
<td>Incidence (%)</td>
</tr>
</tbody>
</table>

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atrial septal defect in all but 54 of these patients. Table 6 lists the complications for each type of arterial entry.

Our experience before this study had taught us that a poor or absent pulse immediately after arteriotomy repair indicated a poor prognosis. If pulsations could not be seen in the repaired vessel or a distal pulse not felt, spontaneous improvement was unlikely. There were nine patients in whom the arterial pulsations were very poor or absent after arteriotomy (six), or puncture of the exposed artery (three). The artery was reopened by the cardiologist in each case. A clot was removed in eight and seven had normal pulses thereafter. There were 24 patients with compromise of arterial circulation within hours after catheterization. There were 18 with absent (eight) or weak (ten) pulses but warm extremities and good capillary filling. No re-entry was made into the arteries of these patients. There were five patients with major arterial obstruction, i.e., absent pulses and ischemia sufficient to warrant correction by a vascular surgeon. In four of these patients, there was evidence of intimal damage and thrombosis. In all four embolectomy and repair of the intima or resection of the involved segment resulted in normal pulses and flow to the involved extremity. In the fifth patient no intimal damage was found; however, the involved segment of brachial artery repeatedly thrombosed after embolectomy.

These thrombi were extremely adherent to the intimal wall. Resection of the involved segment and replacement with a saphenous vein graft resulted in marked improvement; however, the graft disrupted, and a second graft was required. There was good flow and a brisk pulse initially; the pulse then gradually decreased and disappeared after several months during which time collateral flow became well established. The patient has no functional limitation of that extremity one year later.

An additional patient had good pulses following catheterization but developed an infected arteriotomy site with septic emboli. Subsequent hemorrhage from the necrotic arteriotomy site required excision of the involved segment and direct anastomosis. Flow and pulses were normal immediately following the vascular surgery and 1½ years later.

Three different techniques of arteriotomy closure were used during the study period (fig. 2). Pursestring closures were used initially, but were abandoned as they frequently caused mild constriction of the artery. In large vessels this was of little consequence; however, in smaller vessels even minor constrictions were associated with decreased distal pulses and occasionally with clot formation. Not infrequently, removal of the pursestring suture and closure of the arteriotomy with interrupted sutures resulted in better pulsations distal to the arteriotomy. Interrupted U-

Table 5

<table>
<thead>
<tr>
<th>Mode of entry</th>
<th>Total</th>
<th>&lt;1</th>
<th>1-6</th>
<th>7-12</th>
<th>12-24</th>
<th>2-3</th>
<th>4-5</th>
<th>6-7</th>
<th>8-9</th>
<th>10-11</th>
<th>12-13</th>
<th>14-15</th>
<th>16+</th>
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<tbody>
<tr>
<td>Cannula</td>
<td>58</td>
<td>8</td>
<td>11</td>
<td>9</td>
<td>6</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td></td>
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<tr>
<td>Longdwell</td>
<td>174</td>
<td>14</td>
<td>17</td>
<td>28</td>
<td>26</td>
<td>22</td>
<td>25</td>
<td>9</td>
<td>8</td>
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<td>6</td>
<td>8</td>
<td>5</td>
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<tr>
<td>Arteriotomy</td>
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<td>70</td>
<td>64</td>
<td>34</td>
<td>49</td>
<td>46</td>
<td>47</td>
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<td>30</td>
<td>22</td>
<td>14</td>
<td>15</td>
<td>18</td>
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<tr>
<td>Seldinger PQ</td>
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<td>6</td>
<td>10</td>
<td>5</td>
<td>7</td>
<td>17</td>
<td>10</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Sheath PQ</td>
<td>55</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>9</td>
<td>7</td>
<td>10</td>
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<td>7</td>
<td>5</td>
<td>4</td>
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<tr>
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<td>89</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>All techniques</td>
<td>881</td>
<td>181</td>
<td>92</td>
<td>72</td>
<td>82</td>
<td>84</td>
<td>95</td>
<td>63</td>
<td>53</td>
<td>41</td>
<td>44</td>
<td>39</td>
<td>35</td>
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Table 6

<table>
<thead>
<tr>
<th>Mode of entry</th>
<th>No. cases</th>
<th>No.</th>
<th>All complications</th>
<th>Major complications</th>
<th>Minor complications</th>
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<tr>
<td>Cannula</td>
<td>58</td>
<td>1</td>
<td>1.7</td>
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<td>1</td>
</tr>
<tr>
<td>Longdwell</td>
<td>174</td>
<td>9</td>
<td>5.2</td>
<td>3</td>
<td>6</td>
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<tr>
<td>Sheath PQ</td>
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<tr>
<td>Umbilical</td>
<td>89</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>All techniques</td>
<td>881</td>
<td>34</td>
<td>3.9</td>
<td>6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

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shaped mattress sutures provided excellent hemostasis and had the added advantage of evertting the edges so that intima was apposed to intima; however, this type of suture also caused slight vessel constriction. It is currently used primarily for larger vessels. Interrupted sutures did not constrict the artery appreciably, but bleeding between sutures was more common, and if pulsatile, required additional sutures.

During the latter part of the study period, we began performing most of our catheterizations in older infants and children by the percutaneous sheath method. In our experience there were no arterial complications with this technique. The use of the sheath permits frequent catheter changes and the use of various types of catheters. In addition, the friction caused by catheter manipulation is transmitted to the sheath rather than the vessel lining. Its main disadvantage lies in the extra diameter of the sheath.

Comment

The incidence of arterial complications varied with the method of arterial entry (see table 6). Cannulation of an exposed artery with a teflon cannula and arteriotomy were the techniques associated with the highest complication rates as well as all of the major complications. In contrast, cannulation of an exposed artery with a metal cannula was associated with only one minor complication. In general, arterial catheterization by percutaneous techniques proved safer than by arteriotomy or puncture of an isolated artery. Those performed by the Seldinger technique had only minor complications; while those performed by the percutaneous sheath method had no complications. During the study period, our experience with percutaneous techniques included only one infant. In the year following the study period we performed 217 percutaneous arterial catheterizations in 32 infants and 185 children by the sheath method with very infrequent and only minor complications. These included pulse loss in one child, occasional inguinal hematomas, two postcatheterization hemorrhages that did not require transfusion, and rare vagal episodes associated with arterial entry. The latter occurred primarily in adolescents.

Although patients undergoing brachial arteriotomy were, as a group, much older than those undergoing femoral arteriotomy, the incidence of complications was more than twice as great in brachial as compared with femoral arteriotomies. Particularly striking was the high incidence of brachial arterial complications in patients with coarctation of the aorta (16.1%) (table 7). If one considers only those patients without coarctation, the incidences of brachial and femoral arterial complications were remarkably similar. It was also noted in two patients with coarctation who had absent radial pulses after cardiac catheterization that circulation to the involved limb improved following resection of the coarctation. In one the radial pulse returned and in the second perfusion improved. These findings suggest that the high incidence of complications of brachial arteriotomy in coarctation may be related to the high vascular resistance in the involved limb, as well as a "steal" by the collateral vessels. In view of the high complication rate in patients with coarctation undergoing brachial arteriotomy, we are modifying our approach to catheterizing these patients. Percutaneous femoral arterial catheterization is performed first. If the catheter cannot be passed through the coarctation into the ascending aorta, a second arterial entry is not necessarily made. If the clinical and roentgenographic examinations indicate that there are no unusual features and a right-sided angiogram provides a reasonable demonstration of the anatomy of the coarctation and the collateral circulation, we tend to avoid a brachial arteriotomy. If there are unusual features, a

### Table 7

<table>
<thead>
<tr>
<th>Complications of Brachial and Femoral Arteriotomy</th>
<th>All patients</th>
<th>Patients without coarctation</th>
<th>Patients with coarctation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Complications</td>
<td>No.</td>
</tr>
<tr>
<td>Brachial arteriotomy</td>
<td>89</td>
<td>7 (7.9%)</td>
<td>38</td>
</tr>
<tr>
<td>Femoral arteriotomy</td>
<td>330</td>
<td>12 (3.6%)</td>
<td>290</td>
</tr>
</tbody>
</table>

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brachial arteriotomy and brief retrograde catheterization with minimal manipulation is performed. Should it be necessary to pass a catheter through the aortic valve for measuring a gradient, this can be done at a second catheterization after correction of the coarctation.

An increased incidence of arterial complications has been reported in patients with aortic stenosis, however, in the present series this association was not found.

Data for long-term evaluation of patients having arterial entries in this study are not yet available. Published reports, however, have indicated favorable results in several years follow-up of infants and children. Discrepancies in extremity size were minimal and very infrequent following arteriotomy, puncture of an exposed artery, or even after ligation of infants’ arteries. Possible effects of arterial entries in advanced years is unknown.

**Accidental Perforation of the Heart or Great Vessel by Catheter or Contrast Material**

Accidental perforation of the heart was thought to have occurred in one patient, a 12-hour-old infant with transposition of the great arteries, small ventriculo septal defect, and patent ductus arteriosus. Immediately following performance of balloon atrial septostomy, the patient developed systemic hypotension, bradycardia, and cardiorespiratory arrest lasting less than 20 sec. The infant was successfully resuscitated with external massage, intubation, and administration of bicarbonate and isoproterenol. Systemic arterial pressures were low, the venous pressures were high, and the heart showed little motion on fluoroscopy. Within an hour the mediastinal shadow widened. We believed that there had been some hemorrhage into the mediastinum and pericardial cavity with resulting tamponade. The cardiac silhouette subsequently did not increase further, and the patient spontaneously improved while being treated conservatively with careful monitoring of arterial and venous pressures as well as blood gases. Surgical exploration was deferred because of the child’s rapid improvement and the lack of knowledge of the site of perforation. It was thought that the hemorrhage was the result of either perforation of the right atrium or superior vena cava while trying to curve the balloon catheter in order to pass it into the left atrium. More recently the problem of curving the tip of the earlier septostomy catheters has been obviated by the use of Fogarty dilation catheters with a preformed bend at the tip.

Perforation of the heart during injection of contrast material did not occur in any patient in this series, but there were several instances of intramyocardial injection of contrast medium (myocardial staining). Minimal stains without ST or T wave changes were not recorded as complications. There were two moderate stains and one severe stain associated with transient ST and T wave changes lasting 10, 15, and 30 min, respectively.

**Catheter Problems**

There were no instances of complete catheter knotting. A heretofore undescribed catheter problem occurred in a 4½-year-old boy. During the course of a retrograde arterial catheterization from the groin a 5F NIH catheter became lodged in the left coronary artery and could not be withdrawn. There were no electrocardiographic changes; however, traction on the catheter resulted in bilateral neck pain. A thoracotomy was performed and gentle traction along the inner curve of the aortic arch was applied simultaneously with traction on the distal catheter; this resulted in its release. Examination of the catheter showed that the varnish coating had cracked and the tip formed an acute angle. The latter had probably stuck in the coronary artery and prevented withdrawal.

Six minor catheter problems were related to the use of balloon catheters. In each the balloon had burst but did not cause any problems. There was no loss of rubber mass in any case. Two of the catheters were of the Swan-Ganz type and were filled with carbon dioxide. Since we have limited the volume to 1.5 ml of gas in 5F Swan-Ganz catheters we have had no further balloon ruptures. The remaining four balloon ruptures occurred during atrial septostomy. A total of 40 balloon septostomies were performed during the study period. Each of the septostomy balloons were filled with diluted contrast material; however, a small bubble of gas invariably remains within the balloon. Because the latter may conceivably result in air embolism we recommend inflating the balloon with CO2 and deflating it before filling it with contrast media.

**Infections**

One major infection and four reported minor infections occurred. The major infection involved the artery and is discussed in the section on arterial complications. Of the four minor infections, one patient had a staphylococcal wound infection and cellulitis that responded dramatically to antibiotics. An additional three patients had minor superficial infections requiring brief therapy. It is likely that this figure for incidence is low, as minor infections developing after discharge might have been treated by the primary physician without our knowledge. There were no cases of bacterial endocarditis. Antimicrobial
prophylaxis was not used routinely, but only when there was concern about sterility, e.g., a broken glove.

**Allergic Reactions**

Although there were no serious allergic reactions related to cardiac catheterization, there were three minor allergic reactions. All were urticarial eruptions, two of which were generalized. Generalized urticaria occurred immediately after angiography in one child and was probably a reaction to the iodinated contrast media. The other generalized urticaria occurred during partial exchange transfusion done during catheterization of an infant with coarctation of the aorta, congestive heart failure, and anemia. Both eruptions responded promptly to intravenous diphenhydramine hydrochloride. The third patient had a mild, localized urticarial eruption around the site of premedication injection which resolved spontaneously.

Three patients had moderate elevations of temperature (39.5°C rectal) following catheterization. The fevers began within one hour after the procedure and lasted up to ten hours. These may have been pyrogen reactions; however, the possibility of fever of dehydration cannot be excluded. In each case fluids had been withheld for a number of hours and 2–3 ml/kg of contrast were administered at catheterization.

**Embolism**

There were no instances of pulmonary or systemic embolism during or after cardiac catheterization.

**Cardiac Complications**

Typical hypoxic episodes with hyperventilation, irritability, a marked increase in cyanosis and depression of consciousness occurred in two of 55 patients at risk of developing these episodes, viz., those with ventricular septal defect, severe pulmonic stenosis, right-to-left shunting, and no aortopulmonary shunt or an inadequate one. Fifteen of the 55 patients had previous histories of hypoxic episodes while an additional 13 squatted, seven tired easily, and 20 were cyanotic but without symptoms.

Both hypoxic episodes occurred in the early part of the study when 24 patients with tetralogy of Fallot received our customary premedication, meperidine 1 mg/kg, and hydroxyzine hydrochloride 1 mg/kg, i.m. In 1971 we began to premedicate patients with tetralogy of Fallot with morphine sulfate 0.15 mg/kg in the hope of preventing hypoxic episodes during catheterization. There were no hypoxic episodes in 25 patients in this latter group of patients even though their histories indicated that as a group they had more severe symptoms than those receiving meperidine and hydroxyzine (table 8). Infants under 6 months received no premedication and also had no hypoxic episodes during catheterization.

Previously it had been noted that passing a catheter into the pulmonary artery might compromise a very stenotic outflow tract and might lead to a hypoxic episode. Although the pulmonary artery was entered in one of the two patients with hypoxic episodes, it was also entered in an additional 31 patients without incident. Furthermore, the length of time the catheter remained in the pulmonary artery was greater in patients receiving morphine premedication as pulmonary arteriograms were frequently obtained.

It is our impression that morphine as premedication is useful in preventing hypoxic episodes in patients prone to develop them.

**Pneumothorax**

Pneumothorax did not occur in this series.

**Bleeding**

Although small blood losses were common at catheterization, large blood losses were infrequent. Blood losses sufficient to require transfusion occurred in six patients. In two, the losses were the sequelae of severe arterial complications described in that section (infected arteriotomy and venous graft). An additional patient had separation of a femoral vein and substantial blood loss occurred while the proximal end was sought and ligated. Another three neonates had significant blood loss around a catheter in an isolated femoral vein; bleeding occurred primarily during crying, i.e., when venous pressure was elevated. Similar

**Table 8**

*Factors in Hypoxic Spells in Patients with Tetralogy of Fallot*  

<table>
<thead>
<tr>
<th>Severity of lesion</th>
<th>Demerol &amp; Vistaril</th>
<th>None</th>
<th>Morphine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of patients</td>
<td>24</td>
<td>6</td>
<td>25</td>
</tr>
<tr>
<td>1) History of spells</td>
<td>2</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>2) Squatting</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>3) Tires easily</td>
<td>5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4) No symptoms but cyanotic</td>
<td>10</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Small PDA or Blalock-Taussig Shunt</td>
<td>5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Pulmonary artery entered during catheterization</td>
<td>16</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Hypoxic spells during catheterization</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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blood losses did not occur from saphenous veins or with percutaneous catheterizations. More recently we have found that hemostasis may be helped by passing the proximal suture around the femoral vein a second time and providing gentle traction. This provides a ligature that completely encircles the femoral vein and provides a better seal around the catheter.

Comment

The number of bleeding problems described above undoubtedly represents an underestimation. An additional small number of patients who had substantial blood losses at catheterization that were not sufficient to require transfusion are not included. Some of these might have had subsequent blood losses for other reasons and required transfusions at a later date.

Should separation of a vessel occur, it is imperative that the catheter be left in the vessel until the proximal end is secured by sutures. Securing the proximal end is readily accomplished if a sufficient length of proximal vessel has been dissected free. If it has not, the incision should be extended cephalad, a more proximal segment of vein dissected free and a ligature placed around it.

Other Complications

There were no other serious complications; however, there were a number of minor complications not classifiable in the preceding sections.

Two patients, ages 7 and 20, had transient paraesthesias shortly after angiograms. The younger patient experienced five minutes of mild tingling and decreased sensation in the left hand. The adolescent patient had a fifteen minute episode of incomplete "numbness" of her left arm and leg; however, she had previously experienced similar sensations on several occasions. Both patients were hyperventilating before or during these episodes and blood gases showed respiratory alkalosis. There were no sequelae following these episodes. We interpreted both episodes as being secondary to hyperventilation alkalosis.

An 11-month-old with transposition of the great arteries developed brief episodes of bradycardia immediately following injections of contrast material. These occurred repeatedly with small sited injections for checking catheter position, as well as with angiograms. This was probably a nonallergic reaction to the contrast material, and it was unique in our experience.

The premedication we have used in patients over six months of age has been meperidine, 1 mg/kg and hydroxyzine HCl, 1 mg/kg intramuscularly. This has not been associated with any instances of respiratory depression. Approximately 20% of patients require additional medication during the procedure. We have used small amounts of meperidine intravenously (0.25 mg/kg, occasionally as much as 1 mg/kg), or diazepam 0.1 mg/kg. Using this approach only one patient developed respiratory depression. This 11-month-old infant developed apnea and mild bradycardia following the administration of additional meperidine. Bag-to-mask ventilation was necessary for 15 min, and after this there were no problems. Mild hyperventilation with mildly elevated pulmonary venous Pco2, was not uncommon, particularly early in the procedure or shortly after intravenous meperidine.

Renal complications of contrast medium were rare. Transient mild macroscopic hematuria occurred in one patient a few hours postcatheterization. This resolved spontaneously and was not associated with impairment of renal function. Microscopic hematuria was not specifically sought in this study and consequently cannot be evaluated. It was occasionally reported. There were no instances of renal shutdown after catheterization except in two neonates who underwent emergency cardiac surgery immediately after catheterization. It is possible that the contrast received during catheterization might have contributed to the postoperative renal problems.

An 18-day-old infant had ST depression lasting 2 min after flushing an NIH catheter while its tip was in the right ventricle. In all likelihood the catheter tip was lodged in the trabeculae or myocardium with some of the holes entrapped and some within the ventricular chamber. This complication was quite rare as fluoroscopy was supplemented by continuous pressure monitoring during manipulation.

Discussion

The 1968 Cooperative Study on Cardiac Catheterization stressed the relatively high morbidity and mortality in infants, particularly in those under one month of age. Review of this experience has prompted a number of changes in our management of infants and children during the procedure, and in techniques of catheterization. The incidence of fatal complications has been reduced considerably in the 1160 infants and children catheterized in our laboratory in the three-year period 1970-1972.

The total number of major complications in the present study was 34 (2.9%) as compared with 156 major complications (3.9%) in pediatric patients in the cooperative study. Although the incidences of all major complications in the two studies were not very dissimilar, the nature and severity of the complications were quite different. Of 34 major complications in the present study, 19 responded to simple therapeutic measures (12, electroversion, one, digitalization, six, transfusion); seven required surgical intervention;

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three, intensive medical therapy; and three patients died. The three deaths (0.26% attributable to
catheterization) were considerably fewer than the 31
to 36 deaths (0.76 to 0.89%) attributable to
catheterization in the cooperative study. The
difference was largely the result of fewer fatal com-
plications in infants (2 deaths/349 neonates and in-
fants, or 0.57%, vs 28 to 33 deaths/116 neonates and
infants, or 2.4 to 2.8%). Varghese and his coworkers,10
Ho et al.,11 and more recently, Nadas and his co-
workers,12 have also reported very low incidences of
death attributable to cardiac catheterization of in-
fants. All three groups stressed the high “peri-
catheterization” mortality that must be expected
when studying patients with severe and non-
remediable lesions.

The main changes which have contributed to this
improved mortality are treatment of metabolic dis-
orders and pulmonary difficulties in infants, decrease
in the total amount of contrast medium used, and
modifications of the types of catheters used.

Many deaths in critically ill infants have been
associated with hypoxemia and acidemia, conse-
quently, blood gases and pH are routinely monitored
before and during the catheterization. In neonates a
catheter is inserted into the umbilical artery for this
purpose. Acidemia is rapidly corrected with sodium
bicarbonate infusion. Body temperature is measured
continuously with a rectal thermistor and the baby is
warmed throughout the procedure with a circulating
water heating pad or a cautiously used radiant heat
lamp. Since the importance of hypoglycemia in new-
born infants with heart disease was pointed out by
Benzing and coworkers13 blood glucose levels have
been monitored in all neonates with marked hypo-
xia and also those with severe cardiac failure. An im-
mediate assessment may be obtained by placing a
drop of blood on a Dextrostix while awaiting actual
blood glucose levels determinations. If blood glucose
level is below 45 mg/100 ml, glucose is administered
intravascularly.

An additional metabolic disturbance which we have
noted to be quite frequent in neonates with cardiac
disease is hypocalcemia. This has been encountered
most frequently in premature infants with car-
diorespiratory distress but has also occurred in infants
with aortic or mitral atresia or severe cyanosis. Usually
it follows an episode of acidemia with tissue hypoxia,
but recognition of severe hypocalcemia is important as
it may contribute to cardiac failure due to interference
with myocardial contractility. Since the presence of
hypocalcemia may not be readily recognized in the
electrocardiogram, we make a point of measuring
serum calcium routinely in these neonates and
treating promptly if indicated.

Oxygen administration has been customary in
management of infants with severe cardiorespiratory
distress. Recently, the potential risks of increased
arterial oxygen concentrations causing constriction of
the ductus arteriosus in infants with certain cardiac
lesions such as aortic or mitral atresia, aortic stenosis,
aortic arch interruption, and coarctation of the aorta,
have been stressed.14 We have therefore not increased
inspired oxygen concentrations in infants in whom
these diagnoses are suspected, unless it is quite ob-
vious that systemic arterial oxygen pressure is reduced
to levels below 30–35 mm Hg. When systemic arterial
oxygen pressure remains below this level in spite of
oxygen administration, there is little risk of con-
stricting the ductus, as it begins to constrict at oxygen
pressure levels of 35–40 mm Hg.4

Radiographic contrast media accounted for many of
the complications and several deaths in the
Cooperative Study.15, 16 Complications included
arrhythmias, pulmonary edema, cerebral, and renal
complications. The risks of oliguria or anuria were
greatest in infants, particularly those with reduced
systemic blood flow. Ho and coworkers showed a clear
relationship between type of contrast media used and
mortality, meglumine derivatives proving safer than
sodium derivatives.11 The lack of contrast com-
lications in the present study probably was the result of
using meglumine-containing contrast medium and
limiting the total amount of contrast agents. We use
Renografin 76 and generally do not exceed an amount
of 4 ml/kg body weight in children, 3 ml/kg in in-
fants, and in premature infants 1.0–1.5 ml/kg. The
risk of renal complications seems to be particularly
high in premature infants; therefore the contrast
medium is diluted to a concentration of about 40%
with isotonic saline before it is injected into the aorta
or left ventricle. If the amounts indicated have been
used and further angiographic studies are strongly in-
dicated, we check radiographically if the bladder is
well filled with contrast medium, indicating it is being
excreted rapidly, and after a 20–30 minute delay,
proceed. Since the amount of contrast agent should be
kept to a minimum, it is important to limit the
number of injections given. The availability of biplane
angiography is crucial, since it avoids the need for
more than one injection at a site. Also availability of
instant replay of the angiogram is very important so
that the adequacy of an injection can be assessed and
the optimal sites for additional injections can be
evaluated. We consider the use of biplane cineangiography with recording on video discs and
replay through two separate television monitors as the
most suitable arrangement.

Perforation of the heart was a fairly frequent com-
plication and also a cause of death in infants in the
Cooperative Study. This complication has been almost completely avoided in our laboratory by using rather soft catheters in infants. The Elecath catheters have relatively large lumens and are quite flexible but can readily be manipulated and are the preferred catheters for use in infants under about three months. In instances where manipulation of a catheter is difficult or produces marked arrhythmias gas-filled balloon catheters (Swan-Ganz) are very effective and in small infants the #4F catheter has been most useful. In patients with aortopulmonary transposition with intact ventricular septum, this is the preferred method of catheterization of the pulmonary artery, as it is simple, rapid, and does not induce arrhythmias.

We have commented on some of the modifications in technique and approach to catheterization in regard to specific complications. We would like to stress that misconceptions of the incidence or seriousness of complications were quite frequent among the individuals in our group. It is thus most important for each cardiac catheterization laboratory to record carefully all complications and to assess these repeatedly. Although experience of other groups is helpful, continuous analysis of one’s own technique and experience is crucial for modifications and improvement.

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Complications of Cardiac Catheterization of Neonates, Infants, and Children: A Three-Year Study
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