Radiologic Aspects of Operable Heart Disease

II. Retrograde Brachial Aortography

By HERBERT L. ABRAMS, M.D.

Patent ductus arteriosus and coarctation of the aorta are common causes of congestive heart failure in infancy, yet are more difficult to diagnose than in later life. Retrograde brachial aortography is a relatively simple method of establishing the diagnosis with assurance. A description of the technic is followed by a discussion of the normal aortogram in infancy. A relatively large series of cases, in which a high diagnostic yield was obtained, is analyzed. The hazards of the procedure are few if highly concentrated media are avoided and careful attention is paid to details of technic.

RETROGRADE brachial aortography is a roentgen contrast method of opacifying the thoracic aorta by countercurrent injection of an opaque medium into the brachial artery. Its usefulness as an adjunct in the diagnosis of patent ductus arteriosus and coarctation of the aorta in infancy has been heightened with the development of surgical technics applicable even in the first months of life, yet few systematic evaluations of its role in diagnosis have been undertaken. In this article, the experience with retrograde aortography in 86 cases at the Stanford University Hospital is summarized and evaluated.

1. Background

The historical aspects of aortography have been described within recent years, and require only brief recapitulation here. In 1929, Dos Santos demonstrated that direct puncture of the abdominal aorta permitted opacification of this vessel in humans during life. Seven years later, Nuvoli described direct puncture of the ascending aorta as a means of visualizing the thoracic aorta. This method never secured general acceptance.

Retrograde brachial aortography was first described by Castellanos and Pereiras in 1939 and they have elaborated upon the technic in subsequent publications. In North America, Keith and Forsyth emphasized the value of the method a decade later, and a number of supporting statements regarding its usefulness have since appeared in the literature.

Retrograde carotid aortography has also been advocated by some, but it is probably more hazardous than injection at the brachial site. Finally, opacification of the thoracic aorta through a catheter has been utilized since 1948, but is applicable mainly to adults.

Our own experience has been almost exclusively with retrograde brachial aortography, because this technic is readily applied to infants and children under the age of 4, and because this is the age group in which thoracic aortography has its most important indications.

2. Method

A. Premedication and Anesthesia

A general anesthetic was employed in our first 60 examinations. Although this proved quite satisfactory, the fear that the respiratory depression consequent to general anesthesia might augment reactions of apnea prompted us to substitute local anesthesia. The last 26 studies have been performed under local anesthesia, which has proved entirely satisfactory. Premedication usually consists of 25 to 60 mg. of secobarbital (Seconal) rectally and 0.6 to 1.0 mg. morphine ½ hour before the procedure is to begin. Almost invariably this is sufficient sedation so that the cut-down, injection, and closure can be done without incident. If a general anesthetic is to be used, vinethene and ether have given excellent results.

B. The Incision

The left brachial artery, lying medial and deep to the vein, is palpated and exposed. A transverse incision is made in the arterial wall, and the largest possible Robb needle is inserted. The artery is temporarily ligated distally and the needle anchored with a ligature (fig. 14).
Fig. 1. Technic of retrograde brachial aortography. A. Diagram. The filled syringe is attached to the Robb needle by way of a 3-way stopcock and a short flexible rubber tube. B. Roentgenogram following injection. The needle is in the left brachial artery, and the injection has just been completed. The brachial, axillary, and subclavian arteries are opacified, as is the arch of the aorta and the descending thoracic aorta.
C. Sensitivity Testing

An intravenous or intraarterial test dose of 0.5 ml of the medium should be given routinely, followed by an observation period of 10 to 15 min. If reactions occur, the procedure should not be undertaken.

D. The Preliminary Film

When the brachial artery is being isolated, and the needle inserted, a preliminary film of the chest is obtained. The shortest possible exposure time is desirable; we obtain 3 exposures at different kilovoltage. In general it is desirable to use slight overpenetration.

E. Radiographic Projection

The steep right posterior oblique or lateral projection is most helpful for the demonstration of patent ductus arteriosus and of coarctation of the aorta. When anomalies of the aortic arch are being investigated, however, the frontal projection is often useful.

F. The Electrocardiogram

A continuous electrocardiographic tracing should be obtained with each study. This may furnish the first sign of a severe reaction.

G. The Injection

When the preliminary film has been reviewed and found satisfactory, the injection may be performed. Five milliliters of physiologic saline solution are first injected through the needle in the brachial artery to insure the patency of the vessel. The syringe containing the opaque material is attached to the needle. The injection is then performed as rapidly as possible (fig. 1B).

H. Carotid Compression

At the moment of injection, both carotid arteries are compressed manually. In the absence of adequate carotid compression, a relatively large volume of the opaque medium may reach the brain (fig. 2).

I. The Number of Films

The equipment is energized just prior to the injection, and at least 2 films/sec. are obtained for a period of 3 to 5 sec. The most significant information is usually present on the films obtained during the first 1 1/2 sec. after injection; later films may give information about the collateral vessels, or, in the case of patent ductus arteriosus, will show left atrial, left ventricular, and finally ascending aortic opacification.

J. Closure of the Incision

Following the procedure, the needle is withdrawn, the arterial wall repaired transversely with 6-0 eye silk sutures, and the ligatures removed. In very small infants, the artery may have to be sacrificed. Digital compression may be needed for hemostasis. The skin is then closed.

K. The Urogram

A conventional film of the abdomen is obtained 10 to 15 minutes after the last injection and usually reveals a good urographic study.

L. Repeat Injections

No more than 2 injections should be performed during a single examination. If diagnostic information is not obtained after the initial injection, however, we have not hesitated to perform a second. If the study is still inadequate, the repeat examination should be delayed 24 to 48 hours.

M. The Medium Employed

The medium* of choice at the present time is 35 per cent Diiodrast, which we have employed in

* The proprietary names for the commonly used opaque media are used throughout because of general
most of our studies. Neo-Iopax should never be used because of its irritating effect on the cerebral circulation, and its caustic effect on the vascular wall when injected intra-arterially. Although Urokion is apparently relatively safe in cerebral arteriography,\textsuperscript{15} we have been reluctant to use it in retrograde brachial aortography. Hypaque has also been employed in retrograde aortography, but sufficient experience has not yet been accumulated with this medium.

Figure 3 demonstrates the kind of electrocardiographic reaction that may follow the injection of an opaque medium into the brachial artery. This record suggests that Hypaque is more toxic than Diodrast, although Hypaque in 50 per cent concentration is here contrasted with Diodrast in 35 per cent concentration.

N. Dosage

Body weight is the most useful criterion of dosage, since chronologic and developmental age may differ widely in infants with congenital heart disease. Table 1 lists the dosage schedule that we have adopted.

\section*{3. The Normal Aortogram in Infancy}

Contrast roentgenologic studies of the normal aorta in man have been limited largely to older children and adults,\textsuperscript{16,17} although some material on infancy is available.\textsuperscript{10} It seemed worthwhile to describe the appearance of the normal aorta in the first few years of life in some detail. For this purpose, retrograde brachial aortographic studies of the normal aorta were analyzed. The aortogram usually was obtained in order to exclude a patent ductus arteriosus as the cause

\begin{table}
\centering
\caption{Dosage of 35 per cent Diodrast for Retrograde Brachial Aortography}
\begin{tabular}{|c|c|}
\hline
Weight (pounds) & Dose (ml.) \\
\hline
6-8 & 5 \\
8-10 & 6 \\
10-15 & 8 \\
15-20 & 9 \\
20-25 & 10 \\
25-30 & 12 \\
30-35 & 14 \\
35-40 & 15 \\
\hline
\end{tabular}
\end{table}

Fig. 3. Electrocardiographic changes following aortography. \textit{A.} Prior to injection. \textit{B.} Following the injection of 1 ml. Hypaque as a test dose, marked S-T segment and T-wave changes occur in 12 sec., and, \textit{C.}, disappear in 6 min. \textit{D.} A test dose of Diodrast causes much less alteration. \textit{E.} The changes 12 sec. after injection of 8 ml. of 35 per cent Diodrast are also less than those following the test dose of Hypaque.
of congestive heart failure in infancy. The
final diagnoses in these cases are listed in table
2. The number of examinations in each age
group is noted in table 3.

Table 2.—Final Diagnosis in 40 Cases with
Normal Aortograms

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventricular septal defect</td>
<td>18</td>
</tr>
<tr>
<td>Atrial septal defect</td>
<td>8</td>
</tr>
<tr>
<td>Endocardial fibroelastosis</td>
<td>5</td>
</tr>
<tr>
<td>Pulmonic stenosis and atrial septal defect</td>
<td>2</td>
</tr>
<tr>
<td>Pulmonic stenosis and ventricular septal defect</td>
<td>1</td>
</tr>
<tr>
<td>Atrioventricularis communis</td>
<td>2</td>
</tr>
<tr>
<td>Bing-Taussig anomaly</td>
<td>1</td>
</tr>
<tr>
<td>Subaortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Unknown</td>
<td>2</td>
</tr>
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</table>

Table 3.—Age Distribution of 40 Patients with
Normal Aortograms

<table>
<thead>
<tr>
<th>Age</th>
<th>No. of aortograms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 3 months</td>
<td>8</td>
</tr>
<tr>
<td>4 to 8 months</td>
<td>13</td>
</tr>
<tr>
<td>9 to 12 months</td>
<td>7</td>
</tr>
<tr>
<td>1 to 2 years</td>
<td>6</td>
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<tr>
<td>2 to 4 years</td>
<td>6</td>
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Table 4.—Vessels Opacified in 40 Normal Aortograms

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Number of times satisfactorily visualized</th>
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</thead>
<tbody>
<tr>
<td>Left axillary artery</td>
<td>40</td>
</tr>
<tr>
<td>Left subclavian artery</td>
<td>40</td>
</tr>
<tr>
<td>Left vertebral artery</td>
<td>35</td>
</tr>
<tr>
<td>Left common carotid artery*</td>
<td>21</td>
</tr>
<tr>
<td>Right innominate artery*</td>
<td>19</td>
</tr>
<tr>
<td>Right common carotid artery*</td>
<td>18</td>
</tr>
<tr>
<td>Right subclavian artery</td>
<td>10</td>
</tr>
<tr>
<td>Ascending aorta</td>
<td>10</td>
</tr>
<tr>
<td>Aortic arch</td>
<td>37</td>
</tr>
<tr>
<td>Descending aorta</td>
<td>40</td>
</tr>
<tr>
<td>Abdominal aorta</td>
<td>38</td>
</tr>
<tr>
<td>Aortic sinuses</td>
<td>1</td>
</tr>
<tr>
<td>Coronary arteries</td>
<td>1</td>
</tr>
<tr>
<td>Left internal mammary artery</td>
<td>33</td>
</tr>
<tr>
<td>Intercostal arteries</td>
<td>21</td>
</tr>
<tr>
<td>Left parascapular arteries</td>
<td>26</td>
</tr>
</tbody>
</table>

* Only the proximal portions of these vessels were opacified.

A. The Vessels Opacified

The number of instances in which satisfac-
tory opacification of many different vessels was
obtained is recorded in table 4. As might well
be expected the axillary and subclavian arteries
were invariably visible, and the left internal
mammary artery was usually seen (fig. 4A).
Similarly, in most cases the arch of the aorta
(fig. 4B), the descending aorta (fig. 4C), and
the abdominal aorta (fig. 4D) were opacified.
In only one fourth of the cases was satisfactory
opacification of part of the ascending aorta
obtained (fig. 4D) however, and the aortic root
was rarely delineated. The left vertebral artery
was commonly visualized (fig. 4E) and the
carotid arteries were less commonly seen (figs.
5A and 5B), and then only in their proximal
portion, since carotid compression was usually
employed. On occasion, the intercostal arteries
were shown with great clarity (fig. 4F). The
origin of the left subclavian artery was quite
variable in relation to the aortic arch (figs. 4A,
4C, 4D, and 4E).

Although the size of the internal mammary
artery varied considerably, it was usually a
relatively large trunk (figs. 4A and 5A), and in
some studies the parascapular vessels were also
quite prominent.

B. The Aortic Silhouette

When satisfactory opacification of the tho-
racic aorta is obtained, its radiographic appear-
ance resembles an inverted “J” (figs. 4B and
4C). The ascending aorta joins the arch at the
level of the second costal cartilage; the arch
curves gently upward, backward, and to the
left, and finally downward to become continu-
ous with the descending aorta at the lower
border of the fourth thoracic vertebra (fig. 4D).
The ascending segment is the widest portion of
the aorta (figs. 4B, 4C, and 4D), and arises
from deep within the cardiac mass (fig. 4D).
The aortic arch normally narrows slightly
beyond the origin of the innominate artery
(fig. 4F). A more striking narrowing may be
observed in the “isthmus” of the aorta, the
segment between the origin of the left sub-
clavian artery and the ligamentum arteriosum.
Fig. 4. The normal aortogram below 6 months of age. A. 6 weeks. The left subclavian artery, internal mammary artery, much of the aortic arch, and the descending aorta are densely opacified. Distal to the origin of the left subclavian artery, there is an area of diffuse dilatation of the aortic arch that gradually merges with the descending aorta. B. 7 weeks. The aortic arch and its great branches are clearly defined. The silhouette of the arch and the descending aorta resembles an inverted “J.” A localized bulge at the site of the ligamentum arteriosum (arrow) is present. This corresponds to the “ductus diverticulum” or “infundibulum” of the ductus. C. 7 weeks. Just opposite the origin of the left subclavian artery is a localized indentation or constriction (arrow), beyond which is a zone of dilatation. This dilatation is largely confined to the anterior wall, and is probably related to the ligamentum arteriosum. The indentation is slight in degree and of no dynamic significance. Note the variable location of the origin of the left subclavian (compare with 4A, 4B, and 4F). This variation probably reflects differing degrees of cephalad migration of the left subclavian artery in early development. D. 8 weeks. The entire aortic arch and the aortic sinuses are visible. A localized area of narrowing (arrow) in the isthmus of the aorta is followed by a rather diffuse area of dilatation. The narrowing was insufficient to produce a disparity between the blood pressures of the upper and lower limbs during life. At autopsy the zone of constriction was noted but the aortic lumen seemed quite ample. This zone represents the residuum of the normal narrowing of the aortic isthmus present at birth.
At times this narrowing may be localized (figs. 4C and 4D), and it is then followed by a distinctive dilatation of the aorta beyond. In other instances, the narrowing may be diffuse but relatively slight in degree. It then usually involves the entire isthmus, and is followed by a definite widening of the aorta at the junction of the aortic arch and descending thoracic aorta (figs. 4E and 5B). The descending aorta in the steep right posterior oblique projection gradually crosses the spine, usually lying over the anterior portion of the spine when it reaches the diaphragm (fig. 5B). As it descends, there is a slight but definite decrease in aortic caliber until, at the level of the diaphragm, it is about two thirds of the diameter of the proximal descending aorta (figs. 5A–5D).

C. The "Ductus Diverticulum"

Dilatation of the aorta distal to the origin of the left subclavian artery and in the region of the ligamentum arteriosum was noticed in 13 of the 40 patients (figs. 4B, 4F, and 5D). This bulge varied in size, was generally more pronounced in patients in the youngest age group, and usually, but not always, involved the anterior more than the posterior wall. In figure 4A a diffuse dilatation of the aorta beyond the isthmus is apparent. In figure 4B, a localized bulge at the site of the ligamentum arteriosum may be observed.

D. The Effect of Increasing Age

Although there is definite variation in the configuration of the arch, within the limits of this study no consistent age effect beyond the gradual loss of the narrowed isthmus was apparent. Even this finding was by no means constant, however. Thus, in figures 5A and 5C, there is no visible narrowing of the isthmus at the ages of 7 and 10 months respectively; but in figures 5B and 5E, at the ages of 8 months and 4 years, some residual narrowing of the isthmus is present.

In a general way, the semicircle described by the aortic arch in infancy is usually more shallow than that found in the adult aorta. This probably relates to the relatively large
Fig. 5. The normal aortogram between 6 and 12 months. A. 7 months. The aortic arch is smooth, with no evidence of local narrowing or dilatation. The origin of the innominate artery is clearly shown, and the internal mammary artery is well opacified. B. 8 months. The aortic arch, its great branches, and the descending aorta are densely opacified. There is slight narrowing of the isthmus of the arch followed by an area of diffuse dilatation at the junction of the arch and descending aorta. Note the reverse “J” configuration. C. 10 months. The aortic silhouette is smooth, and the caliber demonstrates no distinctive change in the region of the isthmus. Compare with D. D. 10 months. The bulge at the site of the ligamentum arteriosum is quite prominent (arrow) in contrast with the appearance in another 10-month-old infant (5C).
observed in the later films in the series. Recirculation, with opacification of the right atrium, right ventricle, and pulmonary artery, was observed in 7 of 40 normal aortograms. Four of these anteceded the introduction of carotid compression as an integral part of the procedure; in 3, however, carotid compression was applied but apparently was inadequate. Maximal opacification of the right heart chambers and pulmonary artery may occur within 2 ½ sec. after injection. The opacification of the pulmonary arteries may be sufficient to suggest a misdiagnosis of patent ductus arteriosus. Careful observation of the sequence and foreknowledge of the amount of recirculation that may occur are useful safeguards against this possibility.

Discussion

(1) Ductus diverticulum vs. the "aortic spindle." Anatomic studies have revealed that the portion of the aorta between the origin of the left subclavian artery and the site of entrance of the ductus arteriosus (the aortic "isthmus") is narrowed in the newborn infant (fig. 6). The fetal narrowing at the isthmus takes at least 2 months to disappear, and it has been suggested that this process is related to the cessation of ductus contribution to aortic

![Diagram](image)

Fig. 6. The aortic arch and its great branches at birth (after Arey). The isthmus of the aorta (the segment between the origin of the left subclavian artery and the ductus arteriosus) is normally narrowed at birth. A residuum of this narrowing may be seen in the normal infant aortogram. (Reproduced with permission of W. B. Saunders Co., publisher.)
flow. Beyond the ligamentum arteriosum, a fusiform dilatation may occur, which His has named the “aortic spindle” and which may persist into adult life.21

Our own studies have clearly shown that the aortic bulge may be localized, involving predominantly the anterior aortic wall, or more generalized with involvement of most of the circumference of the aorta. An intermediate stage with a relatively long segment of the anterior wall affected has also been observed.

The localized bulge may properly be considered a remnant of the enlarged mouth of the ductus (the “ductus diverticulum”) or a result of traction by the ligamentum arteriosum. The more diffuse dilatation probably represents the “aortic spindle,” and seems more specifically related to the dynamics of the fetal circulation, where blood to the abdomen and lower extremities flows largely from pulmonary artery to aorta via the ductus, and the segment immediately proximal to the ductus is little used.

In 1943, Steinberg, Grishman, and Sussman,22 in reporting the angiocardiographic findings in patent ductus arteriosus, described a localized dilatation of the descending aorta beyond the isthmus which they considered characteristic of patent ductus arteriosus. Although they revised this concept subsequently, they reiterated the belief that the bulge was not encountered in normal individuals.23 This view is not consonant with either earlier anatomic studies21 or subsequent in vivo roentgenographic studies of the aortic arch.18 17 Thus, Jönsson and Saltzman,27 in reporting their studies of the “infundibulum” of the ductus, noted its presence in 25 of 27 patients with patent ductus arteriosus. But they also observed a shallow bulge in the anterior wall at the site of the ligamentum arteriosum in 3 normal patients. They stated that this bulge was not greater than 1 mm. in any of the cases. The present studies offer convincing evidence that a more or less localized dilatation may be present in the normal aortic arch, adjacent to the ligamentum arteriosum, in infants and children under the age of 4.

Therefore it does not seem plausible that a bulge in the lower portion of the aortic knob demonstrable on a conventional posteroanterior chest roentgenogram and caused by a ductus diverticulum or “infundibulum” may be a “specific finding” in patent ductus arteriosus.24 Certainly, it cannot be said to apply to infants and small children. This diagnostic sign, described by Jönsson, may be present in the absence of patent ductus arteriosus and absent in the presence of patent ductus arteriosus. Indeed, the deformed aortic knob has, in my experience, become far more prominent after surgical interruption of a patent ductus arteriosus than before.

(2) “Normal” narrowing of the isthmus vs. coarctation of the aorta. The narrowing of the isthmus of the aorta that is present in fetal life and at birth has already been noted (fig. 6). This segment, formed by the distal end of the left fourth branchial arch during the early weeks of development, performs a relatively minor function during intrauterine life, since aortic blood is delivered to the head and upper extremities above it, and blood from the ductus arteriosus flows to the abdominal viscera and lower extremities below it. With the closure of the ductus, the isthmus becomes an essential avenue of transport of blood to the lower part of the body. The so-called “infantile” type of coarctation was thought to be a persistence of, or an extreme form of, the fetal isthmus; the etiology of the so-called “adult” type, juxta-ductal in location, was a source of greater controversy.

It has become increasingly clear that the distinction between the infantile and adult types is by no means as clear-cut as was once thought. Since the distal left fourth branchial arch, which forms the aortic isthmus, may be distal to the ductus arteriosus,25 it seems reasonable to conclude, as Blackford did many years ago,26 that both types of coarctation are related to atrophy or imperfect development of the left fourth arch, and that this may at times originate in the dynamics of fetal blood flow. Furthermore, it is known that constriction of the aortic isthmus may be present in adult life as a normal finding, although it is usually not marked. The term coarctation then becomes a matter of degree, and narrowing of functional significance merges imperceptibly
with narrowing that is only an anatomic curiosity. The wide spectrum of clinical disability present even among patients in whom a specific diagnosis of coarctation of the aorta has been made is well known. The marked variations in both systolic and diastolic pressures in upper and lower extremities in patients with coarctation are a further index of the range of gradation of the stenosis. In addition, so-called pseudocoarctation of the aorta has been described in recent years as an anomaly in which there is demonstrable aortic narrowing and deformity in the absence of clinical symptoms or signs. Obviously the critical issue is the degree to which the deformity of the aortic lumen offers resistance to blood flow. Figures 4C and 4D clearly illustrate discrete deformities of the aortic lumen in infancy, resembling coarctation of the aorta, but unaccompanied either by upper limb hypertension or lower limb hypotension. Autopsy performed on the child whose aortogram is shown in figure 4D demonstrated a definite narrowing of the isthmus, but the lumen seemed quite ample.

These findings in the infant aortogram must therefore be interpreted as variations of normal anatomy without clinical significance. Furthermore, the narrowing of the isthmus commonly observed in early life should not be classified as "hypoplasia" of the aortic arch unless marked in degree.

3) The size of the internal mammary artery. It has already been mentioned that the normal internal mammary artery may be a vessel of considerable size in the infant aortogram. Even the intercostal and parascapular arteries vary significantly in size. In comparing the size of the internal mammary artery in normal infants with that found in infants with coarctation, it becomes quite obvious that there is a wide range of overlap. Alone, the size of these vessels in infants is a poor index of their participation in a large collateral system that is designed to circumvent a constriction of the aorta. In addition, the gross tortuosity of the intercostal vessels visible in adults with coarctation of the aorta is not always present in infants. The demonstration of the collateral circulation in infants with coarctation is by no means as useful a sign as it has been considered in older children and adults. Thus, statements about the size of these arteries should be made with clear realization of the range of normal variation.

4. Diagnostic Value and Pitfalls

There has been recent emphasis on the "malignant" ductus in infancy, productive of congestive heart failure early in life in the absence of the classical murmur. Similarly, reports of left heart failure and death in infancy from coarctation of the aorta continue to appear regularly. When medical therapy has failed in the infant with congenital heart disease, and intractable congestive failure has supervened, it seems reasonable to demand an aggressive approach to diagnosis. Coarctation of the aorta is not as easily recognized in infants as in adults on clinical grounds alone. Patent ductus arteriosus cannot always be differentiated from intracardiac left-to-right shunts. One method of diagnosis is retrograde aortography.

An analysis was undertaken of 86 cases in which retrograde aortography was performed (table 5). Thirty-four patients were below the age of 6 months, 54 below the age of 12 months, and 71 below the age of 3 years.

In 16 cases, the presence of patent ductus arteriosus with left-to-right shunt was shown either by demonstration of the ductus itself or by indirect evidence (figs. 7 and 8). Indirect evidence constituted immediate opacification

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patent ductus arteriosus</td>
<td>16</td>
</tr>
<tr>
<td>Coarctation of the aorta</td>
<td>15</td>
</tr>
<tr>
<td>Total interruption of aortic arch</td>
<td>1</td>
</tr>
<tr>
<td>Right aortic arch with retroesophageal aortic diverticulum</td>
<td>1</td>
</tr>
<tr>
<td>Right aortic arch</td>
<td>1</td>
</tr>
<tr>
<td>Reverse patent ductus arteriosus*</td>
<td>2</td>
</tr>
<tr>
<td>Normal</td>
<td>44</td>
</tr>
<tr>
<td>Unsatisfactory</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>86</strong></td>
</tr>
</tbody>
</table>

* Angiocardiograms were required to demonstrate reversal of flow. In an additional 2 cases in which coarctation of the aorta was present, reversal of flow through a patent ductus arteriosus was also demonstrated.
of the pulmonary arteries from the descending limb of the aortic arch. When the ductus was visualized, its site of origin was variable; in a number of cases it arose directly opposite the left subclavian artery, whereas in other studies it arose in a more distal position. In no case did it arise proximal to the origin of the left subclavian artery. Although the main pulmonary artery was not always shown in its entirety, the right and left main branches and their radicles were usually clearly opacified. Within 2 to 3 sec. after injection, left atrial, left ventricular, and subsequently aortic opacification were observed. Thirteen of these patients were below the age of 1 year. In all instances but 1 the diagnosis was proved at surgery; in the remaining case, additional complicating anomalies were present, and the infant died before attempts at correction were possible. Necropsy demonstrated a patent ductus arteriosus.

The presence of coarctation of the aorta was demonstrated in 15 patients. In most instances the site of coarctation was distal to the origin of the left subclavian artery, and the zone of constriction was localized (fig. 9). In 1 case there was marked narrowing of most of the aortic arch (so-called "infantile" coarctation). There was associated reversed flow (from right to left) through a patent ductus arteriosus in 1 instance. The collateral circulation was usually clearly demarcated when well developed. In 10 cases the diagnosis was proved at surgery and in 2 at necropsy. Ten of the 15 patients were below the age of 1 year.

In a single case, complete interruption of the aortic arch, associated with reverse flow through the ductus arteriosus, was shown. In another case, a retroesophageal aortic diverticulum was opacified.

In 2 instances aortograms were performed in infants with reverse flow through the ductus arteriosus in the presence of a normal aortic arch. Slight reflux into the ductus was visible
on the aortogram, but no opacification of the pulmonary arteries was seen.

Forty-four studies were normal, and 6 examinations were unsatisfactory. On 20 occasions, a second injection was made in order to obtain adequate visualization of the aortic arch.

There were 3 errors in diagnosis, all of them included in the 6 unsatisfactory studies. In 1, the diagnosis of patent ductus arteriosus was suggested and proved wrong; in another, the examination was called negative when a ductus was subsequently proved to be present; and in the third case, it was stated that there was "suggestive but inconclusive" evidence of a patent ductus arteriosus; no ductus was found at surgery.

A. The Indications for Retrograde Aortography

1. Patent ductus arteriosus. The differentiation of a patent ductus arteriosus from a large intracardiac shunt on clinical and conventional radiologic grounds alone is difficult in infancy.

In the absence of the characteristic murmur, it may be impossible. Short of exploratory thoracotomy, 2 methods of establishing the diagnosis are available, cardiac catheterization and retrograde aortography. Cardiac catheterization may be a difficult and time-consuming procedure in infancy. A significant hazard is attached to it.35 Below the age of 12 months, catheterization of the pulmonary artery is likely to be feasible in less than 50 per cent of infants.36 Furthermore, even if the pulmonary artery is entered, the differentiation of a patent ductus arteriosus from a ventricular septal defect cannot always be made unless the ductus itself is catheterized. On the other hand, the procedure, when successful, supplies valuable information about intracardiac shunts and pressures in the right heart and pulmonary artery.

Retrograde brachial aortography is a relatively simple procedure, which is effective diagnostically in a high percentage of cases, and

Fig. 9. Coarctation of the aorta in a 4-month-old girl. Retrograde brachial aortogram. 'A sharply demarcated zone of stenosis is visible, beyond which marked poststenotic dilatation is present.
affords a graphic representation of the anatomy of the aortic arch in the region of the ductus.

Both of these procedures are thus available. We have employed aortography in infants and have usually reserved cardiac catheterization for older age groups, but the essential objective is to establish the diagnosis promptly and not to overlook an operable anomaly. Of the 15 cases of patent ductus arteriosus diagnosed by aortography and subjected to surgery, all have had an excellent response. On the other hand, we have incontrovertible evidence in our autopsy files of the hazards of nonrecognition.

(2) Coarctation of the aorta. This anomaly is a common cause of congestive heart failure in infancy, and a remediable one. Furthermore, in the untreated infant in heart failure, the prognosis is poor. Thus, the need for early and exact diagnosis is clear. Retrograde aortography conclusively establishes the diagnosis even when it is not clinically apparent, and demonstrates the location, degree, and length of the coarctation, thus forewarning the surgeon of the possible need for a graft.

It has recently been stated that 'congestive failure in infants with uncomplicated coarctation of the aorta can be treated medically.' On the basis of 9 infants so treated it is suggested that surgery be deferred until late in childhood by carrying the patients over the stormy early period with medical therapy. The deaths caused by coarctation of the aorta in infancy are attributed to "failure of medical management."

It may be true that those infants can usually be managed medically, although that is certainly not universal experience. Nouaille and associates found, for example, that 8 of 10 infants with coarctation treated medically died, whereas only 1 of 5 infants treated surgically died. Certainly, medical management is the method of choice in infancy when adequate control of congestive heart failure can be obtained. It implies extraordinarily close supervision, and, in some instances, continuous hospitalization. Frequent, careful observations are not always possible when patients come to a medical center intermittently from outlying communities. In such circumstances we have seen infants sent home in excellent cardiac compensation, adequately digitalized with a maintenance program outlined and with infection controlled, only to develop congestive heart failure suddenly and die.

![Fig. 10. Retroesophageal aortic diverticulum and right aortic arch in a 13-month-old girl. A. Retrograde aortogram. The left subclavian artery is continuous with a small round pouch (arrow) to the left of the right descending aorta. This pouch is the "aortic diverticulum." B. Angiocardiogram at 5 sec. shows the aorta ascending on the right in continuity with the right descending aorta. The aortic diverticulum (arrow) gives rise to a left innominate artery, with the brachiocephalic vessels arranged as a mirror image of the normal.](image-url)
In those cases in which recurrent bouts of congestive heart failure accompany the best planned medical regimen, surgery offers a means of correcting the stenosis. The risk, of course, is significant, but the risk of medical management may at times be much higher.

(3) Aortic-septal defect. It has been shown that an aortic-septal defect may be demonstrated by retrograde aortography. In view of the relative infrequency with which the entire ascending aorta is opacified following retrograde brachial injection, this procedure is not reliable for diagnosis of this anomaly. Inserting a catheter into the ascending aorta from the brachial artery and then injecting via the catheter provides far greater assurance that an aortic-pulmonary communication near the root of the aorta will be clearly shown.

(4) Aortic arch anomalies. The overwhelming majority of anomalies of the aortic arch are readily diagnosable by conventional roentgenologic technics. In the rare instance when symptoms are severe and the nature of the anomaly unclear, retrograde aortography may help elucidate the anatomy of the malformation (fig. 10).

B. Unsatisfactory Examinations

Six of 86 studies were considered unsatisfactory. In these cases, the opacification of the aortic arch was not dense enough to warrant a conclusive diagnosis. In addition, a second injection was performed on 20 occasions. Although mechanical failure of the rapid cassette changer at times necessitated the second injection, the most important factor in the failures was usually the small size of the artery and hence of the needle that could be inserted. With too small a needle, the bolus of opaque medium could not be injected with sufficient speed to overcome the current of arterial blood flow, and hence was rapidly diluted. In other instances, inadequate compression of the carotid arteries resulted in a large amount of the opaque medium being swept into the cerebral circulation, leaving the aorta inadequately opacified.

C. Diagnostic Errors

The 3 diagnostic errors can properly, in retrospect, be classed as unsatisfactory examinations. Nevertheless, they warrant close scrutiny. In the first instance, the diagnosis of patent ductus arteriosus was made on the basis of apparent faint opacification of the pulmonary arteries. At surgery no ductus was found. Re-examination of the films suggests that the source of error lay in the failure to appreciate the amount of recirculation from the brain that may occur, with subsequent right heart and pulmonary artery opacification.

A second error consisted in ruling out a patent ductus arteriosus, when one was subsequently demonstrated to be present by cardiac catheterization. In this case, the poor quality of the examination should have precluded any attempt at interpretation; furthermore, this infant had marked pulmonary hypertension and a relatively small left-to-right shunt, which might have resulted in failure to opacify the ductus even if the examination were adequate. The third case, like the first, represented over-reading of a poor study; although a definitive diagnosis of patent ductus arteriosus was not made, the mention of “suggestive evidence” led to exploration and no ductus was found. Further comment on these errors is made in the next section.

D. Diagnostic Pitfalls

(1) Recirculation. The degree to which the opaque medium, having reached the brain, may return in relatively high concentration to the right heart and pulmonary arteries has already been emphasized. Careful examination of the series will obviate the error of mistaking recirculation for evidence of an aortic pulmonary communication.

(2) “Normal” narrowing of the aortic isthmus. In the absence of clinical evidence of a disparity of upper and lower limb blood pressures, minor degrees of narrowing in or adjacent to the aortic isthmus are of no dynamic significance. The one exception to this rule is the case in which coarctation is associated with a large patent ductus arteriosus and reverse flow; in such a situation, there need not be a significant difference in blood pressure between upper and lower extremities.

(3) Length of the coarcted segment. When the aortic arch and descending aorta are well opac-
just at the ductus arteriosus, through which there was reverse flow.

(4) *Patent ductus arteriosus with pulmonary hypertension and slight left-to-right shunt, or reversal of flow.* If there is a marked increase in resistance in the peripheral pulmonary arterial bed, the flow from left to right may be small, or even reversed. If the left-to-right shunt is small, the opacification of the pulmonary arteries from the aorta via the ductus arteriosus during retrograde brachial aortography may fail to reach a threshold of diagnostic significance. The presence of a patent ductus arteriosus may thus be falsely excluded. This happened in one of our cases in which a ductus was subsequently demonstrated; surgery was followed by a good postoperative result.

Similarly, when pulmonary resistance is so high as to provoke a right-to-left shunt through the ductus, aortography cannot demonstrate its presence except indirectly by dilution of the opaque column at the level of the ductus. Rarely, slight reflux into the ductus may be obtained (fig. 12A), even in the presence of a clear right-to-left shunt (fig. 12B). In most cases of reversal of flow through the ductus, the presence of cyanosis and differential oxygen saturation in the right brachial and femoral artery usually preclude the need for an aortogram, unless the possibility of coarctation proximal to the ductus warrants study of the aortic arch.

(5) *Truncus arteriosus.* Because the pulmonary arteries arise from the aorta (or truncus) in true truncus arteriosus, opacification of the aortic arch may be followed by immediate pulmonary artery opacification. Even in so-called “pseudotruncus” arteriosus with pulmonary atresia, large collateral arteries may fill the lungs from the aorta. The diagnosis of patent ductus arteriosus may then be made erroneously. If the clinical and radiologic findings in such a case are not distinctive, angiocardiography will usually clarify the diagnosis.

(6) *Over-reading and under-reading.* Efforts to squeeze diagnostic information out of unsatisfactory examinations invariably fail and may be grossly misleading. Conversely, faint but definite evidence of *early* pulmonary artery
opacification during retrograde aortography must lead to the diagnosis of an aortic-pulmonary communication, even though the ductus itself is not visible.

5. BY-PRODUCTS OF RETROGRADE AORTOGRAPHY

A. The Pyelogram

The 35 per cent Diodrast injected into the brachial artery reaches the kidneys in relatively high concentration, and within a relatively short time an excellent pyelographic study is obtained. As a routine part of our procedure, a film is obtained about 10 to 15 min. after injection. These pyelographic films have been quite rewarding because of the relatively high incidence of abnormalities in the genitourinary tract in association with congenital cardiac anomalies.

Among 52 such pyelographic studies available for analysis in our aortographic series, 50 were quite satisfactory for analysis of calyces, pelves, ureters, and bladder. Two were unsatisfactory. Among the 50 satisfactory studies, 8 showed the following abnormalities: bladder neck obstruction, malrotation of the left kidney, hydronephrosis of the left kidney, obstruction of the right ureteropelvic junction, obstruction of the left ureterovesical junction, dilatation of the left ureter of unknown etiology, absence of the left kidney with right hydronephrosis, and absence of the right kidney. In none of these cases was any abnormality in the genitourinary tract suspected. Because many of the patients subjected to aortography may undergo surgery, it is important to delineate the status of the urinary tract, and the single film obtained is usually quite satisfactory.

B. Abdominal Aortography

Since Dos Santos described the technic of translumbar aortography, its usefulness in the diagnosis of disease of the kidneys and of the
abdominal aorta and its branches has become increasingly widespread. Although translumbar aortography has been advocated in infants and children, blind aortic puncture in this age group has seemed hazardous to many. Retrograde brachial aortography offers a completely satisfactory substitute for blind translumbar injection in infants. In 63 instances in which the region of the abdominal aorta was included in the retrograde aortographic study, 57 demonstrated satisfactory visualization of the abdominal aorta and its branches (fig. 13). The degree of opacification is satisfactory with 35 per cent Diodrast, and the procedure may be performed without fear of missing the lumbar aorta and injecting into the retroperitoneal tissue instead.

C. Vertebral Angiography

In 1947, Radner described a practical method of opacifying the vertebral artery and the basilar system by injecting the medium through a catheter threaded via the brachial and subclavian arteries into the vertebral artery. This is a useful tool in the investigation of posterior fossa tumors. Just as in catheter angiography, retrograde injection of a medium into the brachial artery permits excellent visualization of the vertebral artery system. In virtually all the examinations that we have performed, the vertebral artery was clearly delineated and its point of origin well shown on films that include the skull (fig. 2). From a practical point of view, this has been of relatively little import as yet; in the age group in which retrograde brachial aortography is most effective, the need for vertebral arterial studies has been uncommon. Furthermore, since carotid compression decreases the amount of medium reaching the brain via the carotid arteries, the vertebral artery is the main source of cerebral filling. In a sense then, this represents an undesirable by-product: the less medium reaching the brain, the safer the procedure. There is no effective method of stopping flow through the vertebral arteries, however, and the amount of 35 per cent Diodrast reaching the brain can obviously be well tolerated. The main value of this by-product lies in the high quality of the anatomic studies of the normal vertebral artery system in infants that it permits. In addition, it represents a simple and well developed technic for exploring this otherwise inaccessible area in infants when diagnostic considerations require it.

6. Hazards

All the agents used in angiocardiography may cause death. The use of a 35 per cent concentration, rather than a 70 or 75 per cent concentration, significantly diminishes the danger of a general toxic response, but does not eliminate this possibility. A review of the literature indicates that a number of deaths have followed retrograde aortography. Scott reported such a death in 1951. The medium employed was stated to be 35 per cent Diodrast, but the site of injection was not mentioned. Furthermore, the infant had cyanotic congenital heart disease and was in “critical condition.” Gasul noted a death following the use of 70 per cent Diodrast via the carotid route, and considered the procedure both “difficult
and dangerous." Since then, however, he has used the procedure many times employing a less concentrated medium and the brachial artery as an injection site, and he no longer considers it dangerous.4 Chou and associates46 reported a death following retrograde aortography with 70 per cent Diodrast, and a number of other deaths have been ascribed to the procedure.3, 47 In addition, severe neurologic complications have been recorded following the use of 70 per cent Diodrast.48

In our own series, 79 of the aortograms were performed using our standard technic, i.e., retrograde brachial injection with 35 per cent Diodrast. No deaths were encountered in this group, nor was there a high incidence of significant reactions (table 6).

In 7 instances retrograde carotid injection or a 70 to 75 per cent concentration of opaque medium was employed. Reactions in these cases are listed in table 7.

The fact that most of the reported deaths followed the use of a 70 or 75 per cent medium injected into the carotid artery, and that it has been our experience that of others49 utilizing 35 per cent media that the technic is a safe one, indicates rather strongly that the higher concentration of the opaque media should not be injected directly into the arterial system where the possibility of its reaching the brain in high concentration is significant. This is particularly true in that a 35 per cent me-

While the incidence of reactions in both series is relatively small, it may be that deaths have not been reported in the past owing to the improper technic and to the use of concentrated media. Diodrast has been used more widely than any other contrast medium, and it is the only medium that is effective in the brain and abdominal aorta. Its use in the aorta in infancy is hazardous because of the possibility of it entering the left heart and causing myocardial damage. Among the many reactions following the use of Diodrast, myocardial necrosis has been observed.60

Table 6.—Reactions Following Retrograde Aortography with 35 per cent Diodrast in 79 Cases

<table>
<thead>
<tr>
<th>Reactions</th>
<th>No. of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irregular, labored, or rapid respirations</td>
<td>8</td>
</tr>
<tr>
<td>Vomiting (all patients had general anesth...</td>
<td>6</td>
</tr>
<tr>
<td>Slight tremor</td>
<td>1</td>
</tr>
<tr>
<td>Disparity in pupil size</td>
<td>1</td>
</tr>
<tr>
<td>Electrocardiographic changes*</td>
<td></td>
</tr>
<tr>
<td>T wave changes</td>
<td>5</td>
</tr>
<tr>
<td>Ventricular premature beats</td>
<td>2</td>
</tr>
<tr>
<td>Nodal rhythm</td>
<td>1</td>
</tr>
<tr>
<td>Tachycardia</td>
<td>3</td>
</tr>
</tbody>
</table>

* Electrocardiograms were obtained in only 39 of the cases.

Table 7.—Reactions Following Retrograde Aortography in which a 70 per cent Concentration of Medium Was Used in 7 Cases

<table>
<thead>
<tr>
<th>Patient</th>
<th>Medium</th>
<th>Concentration (%)</th>
<th>Artery of injection</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urokon</td>
<td>70</td>
<td>Brachial</td>
<td>Death</td>
</tr>
<tr>
<td>2</td>
<td>Diodrast</td>
<td>70</td>
<td>Carotid</td>
<td>Laryngospasm</td>
</tr>
<tr>
<td>3</td>
<td>Diodrast</td>
<td>70</td>
<td>Carotid</td>
<td>Hemiplegia</td>
</tr>
<tr>
<td>4</td>
<td>Neo-Iopax</td>
<td>75</td>
<td>Carotid</td>
<td>Severe neck pain</td>
</tr>
<tr>
<td>5-7</td>
<td>Diodrast</td>
<td>70</td>
<td>Carotid</td>
<td>None</td>
</tr>
</tbody>
</table>

SUMMARY

The background and technic of retrograde brachial aortography are described.

An analysis of the normal aortogram in infancy indicates that there is relatively little change in the aortic silhouette during the first 4 years of life. At the "isthmus" of the aorta (the segment of the aorta between the left subclavian and the ductus arteriosus), an area of narrowing may be observed. This should not be construed as an example of coarctation of the aorta in the absence of clinical evidence of its dynamic significance. Distal to the narrowing, a localized or diffuse dilatation of the aorta is frequently visible. Both the constriction of the isthmus and the bulge adjacent to the liga-

mentum arteriosum constitute variations in the normal anatomy of the aortic arch.

Among 86 cases in which retrograde aortography was performed, patent ductus arteriosus was demonstrated in 16, coarctation of the aorta in 15, and other anomalies in 4.

Useful by-products of retrograde aortography include the postaortogram pyelogram, visualization of the abdominal aorta and its branches, and vertebral aortographic studies.
Although retrograde aortography is not without hazard, no serious reactions followed the brachial injection of 35 per cent Diodrast in 79 cases. In 7 cases in which a 70 per cent medium was employed, 1 death and 1 hemiplegia followed the procedure.

Retrograde brachial aortography, when properly performed, with careful attention to the indications and diagnostic pitfalls, is a relatively safe method with a high yield of operable lesions in infancy.

**SUMMARIO IN INTERLINGUA**

Es describite le historia e le technica de aortographia brachial retrograde.

Le analyse del aortogramma normal in infantes indica que relativemente paue alteraciones del silhouette aortic occurre durante le prime 4 annos del vita. Al “isthmo” del aorta (i.e. le segmento aortic inter le subclaviano sinistre e le ducto arterioso), un area de restriction pote esser observabile. Isto non debe esser interpretate como coarctation del aorta si signos clinic de su significacion dynamic es presente. In un sito distal al restriction mentionate, on trova frequentemente un localisate o diffuse dilatation del aorta. Tanto le constriction del isthmo como etiam le ballonamento adjacente al ligamento arterioso representa variationes in le anatomia normal del arco aortic.

In un serie de 86 patientes in qui aortographia retrograde esses interprendite, patente ducto arterioso esseva constatate 16 vices, coarctation del aorta occurreva 15 vices, e altere anomalies esseva trovate 4 vices.

Utile productos lateral del aortographia retrograde es inter alteres le pyelogramma post-aortographic, le visualisation del aorta abdoninal e de su brancas, e studios aortographic vertebral.

Ben que aortographia retrograde non es libere de risco, nulle serie reactiones esseva incontrate post le injection brachial de 35 pro cento de Diodrast in 79 casos. In un gruppo de 7 cases in que un medio de 70 pro cento esseva usate, le manipulation esseva sequite per 1 morte e 1 caso de hemiplegia.

Aortographia brachial retrograde—si executate correctemente e con grande attention al indicationes e riscos diagnostic—es un relative-mente secur methodo que revela in infantes un alte procentage de lesiones de character operabile.

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