SELECTIVE angiocardiography of the left side of the heart is of prime importance for the accurate preoperative diagnosis of those lesions involving the mitral valve, ventricular septum, outflow tract of the left ventricle, or the aorta itself. The injection of contrast medium into the pulmonary artery for the demonstration of the left atrium and left ventricle is less satisfactory than the direct injection into those chambers. Until recently, left atrial and left ventricular angiocardiography has been achieved only by retrograde left ventricular catheterization or direct transthoracic puncture of the left atrium or left ventricle. Many reports deal with the advantages and disadvantages of these methods.1-5

The introduction of transseptal left heart catheterization6-9 was a major step forward in achieving safe access to the left side of the heart. Since its first description, the method was modified mainly for the purpose of left heart angiocardiography.10-13 There are several reports in the literature about the safety and reliability of transseptal left heart catheterization,9, 10, 14, 15 whereas only a few studies on selective left heart angiocardiography by the transseptal route are available.10, 12, 16, 17 Recently, Braunwald and co-workers17 published their experiences with 60 patients investigated with this new technic. It is the purpose of this paper to discuss the findings obtained in 90 patients in whom transseptal left heart angiocardiography has been performed.

Materials and Methods

A total of 170 transseptal left heart catheterizations was performed. All but two of these patients were in the pediatric age group. Ninety patients had biplane angiocardiography with injection of contrast medium into the left atrium in eight patients, and into the left ventricle in 82 patients. Most of these patients had cardiac malformations of the left heart, ventricular septum, or aorta, and some had pure mitral insufficiency. Fifty-two of the 90 patients had congenital aortic stenosis, six had supravalvular aortic stenosis, 36 had valvular, nine had organic subaortic stenosis, and one patient had functional subaortic stenosis.

Infants and children of all ages received light sedation during transseptal left heart catheterization and, shortly before the injection of contrast medium, light general anesthesia with Fluothane (bromehlor trifluoroethan) was administered. The contrast medium Urografin 76 per cent (N,N'-diazetyl-3,5-diamino-2,4,6-triodo-benzoic acid) was injected in a dosage of 1.2 ml. per Kg. of body weight. The injection was made through the catheter by means of a Gidlund (Elema) power-injecting syringe.

For the purpose of left heart angiocardiography, Ross et al.9 originally designed a special transseptal puncture needle. The needle had several side holes at its distal end and the tip was sealed. Following the puncture of the atrial septum, the needle was held in place and a contrast medium was injected into the left atrium. The injection of contrast medium into the left ventricle, however, was not possible with this method. Only three of the patients in this series have had left atrial injections with this technic.

In a modified technic of Brockenbrough and Braunwald10 and others,11-13 the special catheter is pushed over the transseptal needle into the left atrium and further advanced into the left ventricle. We are now using exclusively the Brockenbrough-Braunwald set,14 which is commercially available. If, in addition to hemodynamic studies in the left atrium and left ventricle, angiocardiography of the left heart is desired, injection of contrast medium is made either into the left atrium or left ventricle. There has been no mortality during or after the injection of contrast medium, but
there has been one cardiac tamponade in this series, following puncture of the pericardial sac.

**Results**

**Differentiation of Aortopulmonary Window from Patent Ductus Arteriosus**

In this series, there is one patient, a 15-year-old girl, with an aortopulmonary window. The murmur was systolic in time and of grade-III intensity, loudest in the third left intercostal space. There was also a grade-II diastolic murmur in the same area. However, the murmurs were diphaseic. The electrocardiogram showed right axis deviation and right ventricular hypertrophy. Hemodynamic studies indicated that pulmonary blood flow was greater than systemic blood flow, but the systolic pressures in the pulmonary artery and aorta were equal. There was slight systemic oxygen desaturation. At right heart catheterization, the greatly dilated pulmonary artery was entered but the catheter could not be advanced into the aorta. The dilatation of the pulmonary artery extended from its normal anterior position posteriorly to the vertebral column. The ascending aorta was pushed anteriorly by the dilated pulmonary artery. Following transseptal left heart catheterization, contrast medium was injected into the left ventricle for biplane angiography. Figure 1 shows the opacification of the ascending and descending aorta and of the pulmonary artery through a large aortopulmonary window; the ventricular septum is intact. Figure 2 is the left ventricular angiogram in the anteroposterior and lateral projection of a child with a patent ductus arteriosus. There is opacification of the pulmonary artery after the filling of the aortic arch.

**Comment**

Only about half of the cases of aortopulmonary window that have been published have had a continuous murmur because of the pulmonary hypertension, which is almost always present in this lesion. The murmur is usually similar to the murmur of patent ductus arteriosus with severe pulmonary hypertension and is a systolic and diastolic diphaseic murmur. The differential diagnosis

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**Figure 1**

Transseptal left ventricular angiogram of a patient with aortopulmonary window. Confirmed at operation. A, anteroposterior projection; B, lateral projection.
is important because of the different surgical approach. Prior to the recent report of Morrow and co-workers,\textsuperscript{18} only four reported cases that have been operated upon were diagnosed preoperatively. Retrograde aortography was the most helpful means of establishing the diagnosis and contrast visualization of the defect. As is demonstrated in figure 1, transseptal left ventricular angiocardiography is an ideal method for the angiocardiographic demonstration of an aortopulmonary septal defect. It will show, at the same time, an additional ventricular septal defect or obstruction of the outflow tract of the left ventricle. Since in these cases right heart catheterization has to be carried out anyway, transseptal left heart catheterization and left ventricular angiocardiography should be done at the same time to save the patient the discomfort of a second procedure. The measurement of right and left heart pressures is necessary in order to establish the correct relationship between systemic and pulmonary hemodynamics.

Coarctation of the Aorta

Figure 3 shows the left ventriculogram of two patients with coarctation of the aorta. There is the usual short coarctation of the aorta in figure 3A. The patient whose angiocardiogram is shown in figure 3B presented the same symptoms and clinical findings, but the coarctation is unusually long and the risk of operation and the prognosis will be different in this patient.

Comment

In coarctation of the aorta, the narrowing of the aorta is well demonstrated, if the injection is made into the left ventricle. Ventricular septal defect or aortic stenosis may be associated with coarctation of the aorta, and transseptal left heart catheterization and left ventricular angiocardiography would visualize the coarctation as well as the associated lesions.

Ventricular Septal Defect

The left ventricular angiocardiograms of patients with different types of ventricular
septal defects are shown in figure 4. In figure 4A a muscular ventricular septal defect is demonstrated, and the patient shown in figure 4B had a defect of the membranous ventricular septum. Figure 4C is the anteroposterior projection of a patient with a ventricular septal defect of moderate size. Figure 4D is the left ventriculogram of a patient with a ventricular septal defect, a large left-to-right shunt and a hypertrophied crista supraventricularis.19 Below the aortic valve there is a jet of contrast medium into the right ventricle, and the narrowing of the right ventricular outflow tract is well demonstrated. The aortic and pulmonary valves are delicate. At right heart catheterization the pulmonary artery was entered and there was a systolic gradient of 40 mm. Hg between the outflow tract and the inflow tract of the right ventricle. A significant left-to-right shunt could not be demonstrated with certainty by oxygen determinations and systemic arterial oxygen saturation was normal.

Comment

Right heart catheterization has been considered to be sufficient for preoperative studies in patients with ventricular septal defects. However, the demonstration of the location of a ventricular septal defect and its relationship to the aortic valve and crista supraventricularis is important. At operation it may be difficult to locate multiple defects in the artificially arrested heart. Furthermore, as was pointed out recently by Steinfeld and co-workers,22 left ventricular angiocardiography is even superior to dye-dilution studies for the detection of small left-to-right shunts at the ventricular level. We had the same experience with foreign-gas methods. As shown in figure 4 transseptal left ventricular angiocardiography is able to demonstrate the size and location of different types of ventricular septal defects. It is also an ideal method for the demonstration of acyanotic tetralogy of Fallot, where the shunt is predominantly from left to right (fig. 4D). The recognition
Figure 4

Transseptal left ventricular angiocardiograms in patients with ventricular septal defect. A, muscular defect; B, membranous defect; C, high ventricular septal defect; D, acyanotic tetralogy with left-to-right shunt. Diagnosis confirmed at open-heart surgery.

of left ventricular-right atrial communications is very important, since the operative approach is different from that in atrial septal defects.

Congenital Mitral Regurgitation

Figure 5 is the left ventricular angiocardiogram of a 9-year-old girl with congenital mitral regurgitation. A cardiac murmur was
first heard during the first year of life. There were marked cardiac enlargement and left ventricular hypertrophy in the electrocardiogram. There was also a pansystolic murmur at the apex and lower left sternal border. At right heart catheterization, including nitrous oxide studies, a right-sided lesion or left-to-right shunt was excluded. There was no right-to-left shunt. The pulmonary artery pressure was slightly elevated. At transseptal left heart catheterization the left atrial pressure was elevated (mean = 14 mm. Hg; V peak = 24 mm. Hg). Angiocardiograms taken after injection of contrast medium into the left ventricle show marked regurgitation of contrast medium into the enlarged left atrium (fig. 5). There was no filling of the pulmonary circulation and no evidence of any additional lesion.

Comment

Congenital mitral regurgitation is considered to be a very unusual lesion. Including the eight cases published recently by Carney and co-workers, only a total of 27 patients with isolated congenital mitral regurgitation has been reported in the literature. Since this anomaly is now amenable to surgical correction, its early recognition and the assessment of its severity are very important. Transseptal left atrial and left ventricular catheterization and left ventricular angiocardiography are the best means for studying this lesion. They will differentiate between isolated congenital mitral regurgitation and mitral regurgitation in association with septal defects or corrected transposition. A quantification of the amount of blood regurgitating into the left atrium is possible and the size of the left atrium is demonstrated (fig. 5).

Differentiation of Different Types of Aortic Stenosis

There are 52 patients with congenital aortic stenosis among the 90 patients in this series. Figures 6 to 9 are left ventricular angiocardiograms of patients with different types of aortic stenosis. The patients shown in figure 6A-C had severe valvular aortic stenosis. Valvular aortic stenosis can be seen in both projections. The thickening of the stenosed aortic...
valve can be seen in figure 6A. The jet of contrast medium through a stenosed aortic valve is well demonstrated in figure 6B. Figure 6C shows the dome-shaped aortic valve in a patient with severe valvular aortic stenosis.

Figure 7 is the left ventricular angiocardiogram of a patient with organic subaortic stenosis and mitral insufficiency. The subaortic diaphragm can be seen about 1 cm. below the intact aortic valve. The valve leaflets are thin and delicate.

Figure 8 is the angiocardiogram of a patient with supravalvular aortic stenosis. There is no evidence of any additional lesion. The narrowing of the aorta right above the sinus of Valsalva is well demonstrated. One leaflet of the aortic valve is fused with the stenotic area of the aorta. This interpretation was confirmed at surgery.

Figure 9 shows the left ventriculogram of a patient with functional hypertrophic subaortic stenosis. It can be seen that there is systolic narrowing deep within the left ventricle and marked mitral regurgitation. The hypertrophied ventricular septum is bulging into the cavity of the left ventricle. The marked difference in systole and diastole is well demonstrated. There was a systolic gradient of 100 mm. Hg. Mitral regurgitation was also evident in the left atrial pressure tracing.

**Comment**

The risk and postoperative result of operation for aortic stenosis may be very different in valvular, subvalvular, supravalvular, or functional aortic stenosis. The measurement of a systolic gradient across the aortic valve does not determine the site of the stenosis and is not sufficient for preoperative assessment of the lesion. Transseptal left heart catheterization is the best method for the accurate investigation of aortic stenosis of any type. Left ventricular injection of contrast medium at the time of right and left heart catheterization will determine the exact site and nature of the lesion and demonstrate additional mitral regurgitation and ventricular septal defects. There was only one patient in this series with aortic stenosis and ventricular septal defect. In this patient the stenosis was subvalvular. Additional coarctation of the aorta and patent ductus arteriosus were present in two patients and were clearly visualized.
We believe that transseptal left heart catheterization and angiocardiography are superior to retrograde catheterization of the left ventricle, since with the latter method it is often impossible to pass the catheter across the lesion into the ventricle and the catheter may exaggerate the stenosis. At left ventricular angiocardiography we have seen many cases of valvular aortic stenosis without any poststenotic dilatation. The recognition or exclusion of poststenotic dilatation on conventional roentgenograms or fluoroscopy does not allow a definite differential diagnosis of valvular or subvalvular aortic stenosis. There were several patients in this series with valvular aortic stenosis and a narrow valve ring, whereas in the majority of the patients the aortic valve ring was of normal size. The recognition of this difference is also important, since at operation in the cases with a narrow valve ring, the obstruction to left ventricular outflow may not be relieved to the same degree as in the other cases.

The clinical diagnosis of functional subaortic stenosis may be very difficult. As we
Figure 9
Transseptal left ventricular angiocardiogram in a patient with functional hypertrophic subaortic stenosis. A, diastole; B, systole. Note extreme functional narrowing of ventricular cavity in systole, the hypertrophied ventricular septum, and contrast medium regurgitating into enlarged left atrium. Confirmed at open-heart surgery.

have seen on two occasions, transthoracic puncture of the left ventricle may not demonstrate the systolic gradient because the needle may be positioned above the systolic obstruction to left ventricular outflow.

Truncus Arteriosus
Figure 10 shows the angiocardiogram with left atrial injection in a patient with truncus arteriosus. The valve of the common truncus can be seen overriding the large ventricular septal defect. Also, some contrast medium first enters the outflow tract of the right ventricle and is then ejected into the common trunk. A pulmonary vessel of good size is seen to originate at the descending aorta.

Comment
Retrograde aortography has been the method of choice for the demonstration of the origin of the pulmonary vessels in truncus arteriosus. This is of importance, particularly if a Blalock-Taussig operation is planned. As shown in figure 10, transseptal left ventricular angiocardiography is also a good method for demonstrating the nature of the malformation.

Discussion
Transseptal left heart catheterization has been shown to be a safe and reliable method for the study of heart disease involving the left heart and ventricular septum. In many cases the measurement of pressures in the left atrium and left ventricle and the recording of indicator-dilution curves will be sufficient for the establishment of the diagnosis. In other patients, however, a more accurate demonstration of the malformation and the visualization of anatomic details are necessary for a precise preoperative assessment. Retrograde catheterization of the left ventricle, with injection of contrast medium into the left ventricle or ascending aorta, and transthoracic puncture of the left atrium or left ventricle have been used for left heart angiocardiography. These two methods have their definite limitations and hazards, and fre-
unusually high needle penetrated series of necessity of aortic valve. We have had no complications during or after the injection of contrast medium through the transseptal catheter into the left atrium or left ventricle in 90 patients. It should be pointed out that the tip of the catheter must lie freely within the cavity of the chamber which is to be investigated, since the tapered tip of the transseptal catheter may penetrate the endocardium during the forceful injection of the contrast medium. We have made subendocardial injections of very small amounts of contrast medium. In no instance, however, was there any discomfort for the patient or was the angiocardiogram of less quality than in other patients.

As shown in figures 1 and 2, the method is ideal for the differentiation of patent ductus arteriosus from aortopulmonary window. In unusually long coarctation of the aorta as seen in figure 3B, the heart-lung machine may be used preferably in contrast to the ordinary coarctation. Since we have had this experience several times, we are doing transseptal left ventricular angiocardiograms in every patient with coarctation of the aorta. In cases with isolated ventricular septal defects and a left-to-right shunt, transseptal left heart catheterization and left ventricular angiocardiography are carried out, particularly if cardiac surgery is to be expected. This will show the location and size of the defect and will also demonstrate multiple ventricular septal defects.

The most important indication for transseptal left ventricular angiocardiography is aortic stenosis. The method is capable of demonstrating the site of the lesion and the anatomic details are shown in figures 6 to 9. It is not only possible to measure the gradient across the aortic valve but also to judge the thickness and mobility of the aortic leaflets. Much more can be said about the prognosis without operation, or about the risk of opera-

Figure 10

sequently cannot be performed in patients with severe aortic stenosis (retrograde left ventricular catheterization) and in small children with a left atrium of normal size (transthoracic left atrial puncture). Therefore, the technic of transseptal left heart catheterization has been modified, so that left heart angiocardiography can be performed at the time of left heart catheterization. Furthermore, transseptal left heart catheterization and angiocardiography can be performed at the time of right heart catheterization. Hemodynamic studies will either indicate the necessity of selective angiocardiography of the right or left heart, and either one can be carried out at the time of the examination.

There was one cardiac tamponade in this series of 170 transseptal left atrial punctures. In this case the left atrium was positioned unusually high and the transseptal puncture needle penetrated into the pericardial sac. There was no instance of aortic puncture, and no additional complications have been encountered. Usually ventricular extrasystoles occur less frequently in the course of transseptal left heart catheterization than during the passage of a cardiac catheter through the tricuspid valve.
tion and the postoperative result to be expected, if such details as a fused aortic leaflet in supravalvular aortic stenosis (fig. 8) or the degree of left ventricular obstruction in functional hypertrophic subaortic stenosis (fig. 9) are seen.

In addition to the left ventricular angiograms shown here, we have had three cases of hypoplasia of the aortic orifice and the aorta without any shunt. Since these cases presented a clinical picture similar to valvular aortic stenosis, transseptal left ventricular angiography has been very helpful in establishing the correct differential diagnosis.

Retrograde left ventricular catheterization and angiocardiography have been used in the past for the quantitation of mitral regurgitation.\(^4\) The question arises whether transseptal left ventriculography can be used for this purpose. It may be suggested that the transseptal catheter may keep the mitral valve somewhat open when it is positioned with its tip in the left ventricle. In a few cases in this series, we have seen slight mitral regurgitation in the presence of normal pressure tracings in the left atrium. In these cases the size of the left atrium was also normal. If there is high pressure in the left atrium and mitral regurgitation into an enlarged left atrium is demonstrated by injection of contrast medium into the left ventricle, true mitral regurgitation is probably present and not caused by the catheter.

High-quality selective angiograms will be obtained with any method, only if the contrast medium can be injected into the right place with sufficient quantity and sufficient rapidity. It is believed that left ventricular angiocardiography by the transseptal route fulfills these requirements and is superior to the methods previously used.

Summary

Experiences with 90 left heart angiocardiograms in 170 patients with transseptal left heart catheterizations are discussed. Selective left heart angiograms of patients with aortopulmonary septal defect, patent ductus arteriosus, coarctation of the aorta, different types of ventricular septal defect, and isolated congenital mitral regurgitation are discussed. Examples of valvular, supravalvular, organic subvalvular, and functional hypertrophic subaortic stenosis are shown. The method is also suitable for the demonstration of endocardial fibroelastosis, truncus arteriosus, and hypoplasia of the aorta.

References


The coronary arteries were looked at before the time of Heberden; alterations were described and some symptoms noted, but the former remained as anatomic curiosities and all were buried until more inquisitive times. By giving to a group of symptoms a euphonious name that has survived until now, William Heberden (1768) opened a new chapter in nosography, and so the name deserves a brief consideration. "Angina" as a technical term came down from classic times, and for almost two centuries before Heberden it was used in England to designate cases of quinsy or sore throat in which a feeling of strangling and anxiety entered. "Chest pang" was therefore an apt name for the syndrome that arrested Heberden's attention. No theory was suggested, and the seat was indicated only in a general way.—George Dock, M.D. "Historical Notes on Coronary Occlusion: From Heberden to Osler. Frank Billings Lecture." J.A.M.A. 113: 563, August 12, 1939.
Left Ventricular Angiocardiography by Transseptal Puncture of the Left Atrium

A. J. BEUREN and J. APITZ

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