

Editorial Review

Pediatric cardiology: then and now

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A brief history

It is difficult to date the start of interest in the clinical importance of congenital anomalies of the heart. Sporadic reports certainly appeared from autopsy and dissecting rooms from the seventeenth century onwards. By the eighteenth century, that most entrepreneurial of centuries, the basics of British cardiology were being laid down. Stephen Hales¹ physiologic researches were running in parallel to the anatomic observations being made in the Covent Garden dissecting rooms of William and John Hunter. I like to attribute the birth of pediatric cardiology to a nephew of the Hunters, Mathew Baillie. Baillie described mirror imagery of the viscera which he called "a strange transposition".² When he later described transposition of the great arteries, he did not call it anything,³ but he understood the hemodynamics. The reason I propose Baillie as the father of the discipline may be because I had an early opportunity, in the twentieth century I hasten to add, to work on transposition. My reason may, nonetheless, be regarded as perfidious and chauvinistic by my French colleagues. They will point to the clinicopathologic correlations of Arthur Fallot⁴ and of Henri Roger as the true beginnings of what was to become a recognized speciality throughout the world. Of these two great Frenchmen, my preference is for Henri Roger.⁵ He formulated the hypothesis that a particular murmur heard in asymptomatic children was due to a small ventricular septal defect. This he proposed purely on clinical grounds. His colleagues rejected his suggestion; in fact, they were pretty rude about it! But he persisted and soon was able to provide anatomic evidence that he was right. For the next eighty years, knowledge about congenital cardiac malformations continued to be accumulated following much the same pattern as that of Roger. He had added auscultation to the armory of clinical research. Subsequent workers added the chest x-ray, the electrocardiogram, cardiac catheterization and, finally, the methods of direct visualization of the heart. The technology changed dramatically, but the method remained that of

clinicopathologic correlation. And we continue in the same mold.

The major contribution during these eighty or so years was the systematization of the mass of knowledge being accumulated. Here we owe a great debt to Maude Abbott,⁶ Helen Taussig⁷ and the neglected James Brown. Brown's textbook,⁸ published in 1939, was full of insight, gained not in a great teaching institution but in the Dickensian atmosphere of 'Poor Law' hospitals in the north of England during the depression. The first pediatric cardiology text I owned, however, was the first edition of Dr. Nadas' book.⁹ Although we have been friends for more than 20 years, I still cannot bring myself to call him Alex. Perhaps because I still remember the respect amounting to terror I felt when we residents were waiting for him to make rounds. The lucidity of his book, based mainly on the experience of his unit in Boston, has rarely been surpassed. In a way, this book marked the coming of age of the speciality.

Of course, the subject could only have reached this point as a result of the major advances in diagnostic methods, particularly the introduction of angiography and cardiac catheterization. In 1938, Castellanos reported the use of angiography for the diagnosis of complete transposition.¹⁰ He used a peripheral injection of contrast material and a manual "cut film" changer and subsequently demonstrated the usefulness of the technique in other cardiac malformations. Angiocardiography did not achieve immediate popularity, and it was left to Lind and Kjellberg to systematize this approach, culminating in the publication of their classic book.¹¹ Cardiac catheterization had an even slower start. Following Forsmann's original description of the technical possibility of catheterizing the heart,¹² having first performed it on himself, it was then almost 20 years before it became a widely accepted clinical tool in the study of congenital heart disease.¹³

The impetus to employ these time-consuming diagnostic procedures, which were not without risk, came from the needs of the rapidly advancing sister speciality, cardiac surgery. Surgeons possessed new methods of

treatment which were themselves life threatening. Accurate diagnosis was necessary if risks were to be minimized. Bedside diagnosis was no longer sufficient. Thus, a new breed of cardiologists was developed who had the necessary skills. A close partnership, the true team approach, then followed. The increased diagnostic security, accompanied by more adventurous surgery, led to one of the most productive and exciting eras in the development of the speciality, namely the late sixties and the early seventies. During this time, the real clinical challenge, the conquest of heart disease in the infant and newborn, was confronted for the first time. The pioneers, such as Gross, Crafoord, Blalock, Brock and Lillehie, had made this possible. Their heirs, such as Cooley, Mustard and, above all, Kirklin, built a scientific surgical edifice on this foundation.

More accurate diagnosis was not the only benefit to be driven along by these surgical advances. Surprisingly, it was realized that the natural history of many anomalies was imperfectly understood. A case in point is ventricular septal defect. Roger described it in 1879.⁵ By 1918, French¹⁴ had recognized the possibility of spontaneous closure. Studies of natural history, however, were still worthy of publication during the nineteen sixties¹⁵ and seventies,^{16,17} even though palliative and corrective surgery had been practiced since the early nineteen fifties.^{18,19} Another issue which has been confronted is the etiology of congenital cardiac anomalies. In particular, the understanding of the genetics has advanced. The study of recurrence rates in families produced a working hypothesis for the inheritance of 'sporadic' occurrence of malformations.²⁰ Pediatric cardiologists now have a mathematical model with which to counsel families on the risks they face when embarking on a pregnancy.

By the mid seventies, a fairly standard pattern of practice of pediatric cardiology had been established. Cardiologists with expertise in the care of children and skilled in cardiac catheterization of infants were teamed with cardiac surgeons who possessed skills in the surgery of this age group. Interested specialists, such as geneticists and psychiatrists, were available to help support the families. The definitive diagnostic method was catheterization and angiocardiology. The definitive treatment was surgery. Surgeons steadily lowered the age at which surgery was performed and also reduced the risks to the patients. Pediatric cardiologists argued about what to call the hearts they encountered. Then it all changed.

What happened then?

The first major change was the introduction of cross-sectional echocardiography. This had been presaged by

the M-mode technique which, although providing useful data, posed no threat to the role of angiocardiology as the absolute diagnostic method. Cross-sectional echocardiography, however, was a different matter. Careful correlative studies between this imaging method and the results of angiography and anatomic observations proved, that in most instances, ultrasound was the equal of angiography and, in many, was superior.^{21,22} The addition of measurements of velocity by the Doppler technique improved diagnostic accuracy by adding a hemodynamic aspect to the purely anatomic images. Now, with the availability of color flow mapping, the need for preoperative cardiac catheterization has been reduced to a minimum. Other imaging methods are now only needed in special circumstances, for example, to demonstrate the detailed anatomy of the coronary arteries, the distal aortic arch, or the branch pulmonary arteries. The ease with which an echocardiogram can be performed, the accuracy of the diagnosis it provides, the safety to the patient, and the minimal discomfort experienced makes the technique the main, if not the only, cardiac investigation necessary in outpatient consultations. Pediatric cardiologists should now question more mundane aspects of their practice. Is chest radiography ever necessary for diagnosis in a cardiac unit? Does it have any place other than for the follow-up of the size of the heart to assess progress or response to treatment? The value of the X-ray is undoubted as a primary investigation in the pediatric department of a district general hospital. Its routine use is contraindicated, however, in a setting where echocardiographic hardware and expertise are readily available.

Even with expert echocardiography, some questions remain difficult to answer. Radionuclide angiography can help. Information concerning left and right ventricular performance can be obtained, and the magnitude of left to right shunts can be accurately measured.²³ Nuclear angiography is probably the most undervalued investigative method in pediatric cardiology. In expert hands, it can provide information which further obviates the need for catheterization. In addition to the advantages to the patient, these noninvasive investigations are inexpensive when compared to catheterization and angiocardiology. They are, therefore, extremely cost effective when used as alternatives rather than as adjuncts. Unit managers should, and will, audit the use of investigations resulting in cheaper delivery of cardiac care without lowering standards.

Pediatric cardiologists built their speciality on the skills needed for the investigation and care of infants, particularly the newborn. Why stop there? It was only a matter of time before they targeted the fetus. There had been sporadic reports of ultrasonic visualization of the fetal heart, but no systematic anatomical correlations

had been performed. In 1980, Allan and her colleagues published such a study.²⁴ This was not an isolated effort. Workers in France and the United States were working along similar lines. Once it had been demonstrated that normal fetal cardiac anatomy could be reliably demonstrated, the feasibility of prenatal diagnosis could be studied. It has now been established that most major anomalies can be reliably detected, or excluded, by 18 weeks of gestation.²⁵ A whole profile of fetal cardiovascular health is being developed. Fetal cardiac failure can be diagnosed and its causes studied. Doppler techniques and color flow echocardiography have been as important to these developments as to those in postnatal life. Using M-mode techniques, cardiac rhythm can be determined and arrhythmias can be diagnosed.^{26,27} A major breakthrough was the recognition that pathologic tachycardias, and more rarely, complete heart block, can cause heart failure in the fetus. This led to successful attempts to treat tachycardias by giving drugs to the mother and, more recently, directly to the fetus by umbilical venous puncture. This latter approach can also be used to monitor the levels of drugs in the blood of the fetus. Today, we suggest that no rational line of drug therapy should be abandoned until it has been established that therapeutic fetal blood levels have been achieved, or that they cannot be achieved without endangering the mother. This approach means that another member has been added to the pediatric cardiology team, the invasive obstetrician. The impact of prenatal diagnosis is already apparent. In our unit, it provides a significant and increasing source of referral. In countries where termination of pregnancy is legal, as it is in Britain, a large proportion of parents elect for this course when they are informed that the fetus has a major malformation. In 1989, 67 terminations resulted from diagnoses made in our unit alone. In many instances the cardiovascular malformation was associated with anomalies in other organ systems or with chromosomal anomalies. Thus, before a decision is made to continue a pregnancy in the presence of a fetal heart defect, other systems must be scanned and the chromosomes examined. It is our contention that fetal cardiology is now an integral part of pediatric cardiology as an essential component of the clinical service.

With the increasing confidence in noninvasive investigation, the rates of cardiac catheterization began to fall during the nineteen eighties. Those of us whose expertise was in the catheterization laboratory began to have an easy time. Echocardiography associated with the use of E-type prostaglandins allowed us to diagnose securely and treat safely most of the newborn infants referred to us. Thus, as the overall numbers of catheterizations fell, those being catheterized as emergencies at night and on weekends became fewer. We

could sleep nights. Even when we performed diagnostic catheterizations, we knew most of the diagnoses before we started. This state of affairs did not last long. The rise of therapeutic, or interventional, catheterization put a stop to that. Of course, it had been in the cards for a long time. Bill Rashkind, back in 1966, had exposed pediatric cardiologists as closet surgeons when he introduced balloon atrial septostomy.²⁸ This application was extended with the introduction of blade septostomy.²⁹ Others had attempted the relief of valvar stenosis³⁰ and the transcatheter closure of atrial septal defect.³¹ The advance to effective relief of stenotic lesions by catheterization had to await the development of effective balloon catheters and their adaptation for use in the cardiovascular system of the child. Their introduction to clinical practice was preceded by considerable animal experimentation, much of it performed by James Lock.^{32,33,34}

Initially, angioplasty was performed in pulmonary valvar stenosis,³⁵ postoperative restenosis of aortic coarctation,³⁶ and peripheral pulmonary stenosis.³⁷ From these beginnings, balloon angioplasty has been employed in an increasing number of applications. Congenital aortic stenosis was attacked³⁸ and, despite some initial skepticism, has now become an accepted form of treatment.³⁹ Likewise, its use in the primary treatment of coarctation is gaining in popularity⁴⁰ despite more prolonged foot-dragging.⁴¹ It would be fair to say that in all these conditions (with some diminishing reservations about coarctation), balloon angioplasty is now accepted as the treatment of first choice. The list continues to grow. In most other conditions, for example subvalvar aortic stenosis, balloon dilatation is still under evaluation.⁴² Balloon dilatation of the right ventricular outflow tract for the palliation of tetralogy of Fallot is another case in point. It was first proposed by the Liverpool group.⁴³ The advantages over shunt procedures are obvious. In particular, the risk of distortion of the pulmonary arteries is avoided. Furthermore, in many centers the risk of correction in the first months of life is greater than when it is delayed to, say, one to two years. The advantages of delay are amplified in the presence of unfavorable anatomy of the pulmonary arteries. This only applies if it works. In our unit, we have used balloon dilatation as our only method of palliation of tetralogy of Fallot for the past two years. The only indication for a shunt has been when corrective surgery has been contraindicated. Adequate palliation has been achieved with one or more dilatations in 16 infants with only one death. In addition, there is some evidence that successful dilatation is accompanied by growth of the pulmonary arteries. For all these reasons, we believe that this method is the best palliative treatment. But will it catch on? One is reminded of the

Brock valvotomy. This had similar advantages over shunt operations, but never attained the same popularity. Balloon dilatation probably will. The atmosphere in the world of pediatric cardiology is such that balloon angioplasty is being tried in almost any stenotic lesion, whether it is a primary lesion or is a complication of surgery.⁴⁴⁻⁴⁶ This emphasizes the need for critical analysis of the results.

Balloon angioplasty is now a major therapeutic component of all services of pediatric cardiology. There has been a similar spread of the use of catheter embolization techniques, albeit at a somewhat slower rate. Initially, coils and detachable balloons were used for embolization of such structures as arteriovenous malformations in the pulmonary and coronary circulations,^{47,48} and for the closure of unwanted surgical shunts and major systemic to pulmonary collateral arteries.⁴⁹ These indications are relatively rare. Here, once again, Bill Rashkind comes into the picture. Following the example of Werner Porstmann,⁵⁰ he began to work on the problem of occlusion of the arterial duct by means of a catheter. He developed a 'double umbrella' device that could be introduced via the femoral vein and which required a delivery system small enough to make its use possible in small children.⁵¹ A major disadvantage of Porstmann's method is the need for a very large arterial catheter to introduce the Ivalon plug. The Rashkind device comes in two sizes, 12 and 17 mm in diameter, which are introduced via eight and 11 French Mullins transeptal sheaths, respectively. The procedure is applicable to patients above eight kilograms in weight, and there is no upper size or age limit. The age of the oldest patient we have treated was 87 years. Results reported from several centers^{52,53} suggest that complete closure can be expected with one device in approximately 85 percent of cases. Where complete closure is not attained, it can be accomplished by implantation of a second device some months later. These results have been born out in practice in Europe where cardiologists in 14 centers in five countries have been trained in the method. They have reported on their experience in over 350 patients. Their results lead to the conclusion that this way of closing arterial ducts is now the method of choice. The major risk has been embolization of the device to the pulmonary arteries or, more rarely, to the aorta. This has occurred in some three percent of patients. Initially, when this happened, the patients were referred for surgery. Now the device is retrieved using a modified catheter system, and a new device is implanted. Hemolysis has been observed rarely with incomplete closure of the duct. This may be avoidable by paying special attention to the final disposition of the device and adjusting it where necessary before the close of the procedure. Whilst the duct occluder was designed for that

one purpose, it has been used in other situations, such as in closing ventricular septal defects. Here, it was successful in effecting closure in some. Now that closure methods using a catheter, like balloon angioplasty, are confronting common anomalies, they are occupying more of the energies of the pediatric cardiologist. The commitment to interventional cardiology obviously varies from unit to unit. However, in our unit such procedures account for about half of the cardiac catheterizations we perform, and the numbers are increasing. Furthermore, we perform nearly as many interventions as surgical operations. This means with only a modest increase in spending, our work load has nearly doubled. The benefits accrue not only to the hospital managers, but also to the patient. Less traumatic procedures and shorter hospital stays are self-evident advantages.

What of the future?

Back in the nineteen forties, Lord Beveridge predicted that, when all people had access to the best health care available, health services would wither away. Well! We can only safely prophesy the effect of advances that are already in the pipeline. Doing that, we must resign ourselves to missing out on anything totally novel.

It is difficult to see any great advance in the diagnostic technique used in the cardiac catheterization laboratory. In angiocardiology, the use of digital subtraction promised much, but its main value, at present, is the speed with which an angiogram can be replayed with no visually detectable loss of quality. Thus, it is the digital handling of the image rather than the subtraction that is its main advantage. Digital angiography is invaluable when performing tricky catheter interventions where measurements, or accurate positioning of catheters or devices, is needed. It is here also that advanced ultrasonic techniques such as transesophageal⁵⁴ and intravascular echocardiography will prove their worth.

The major new diagnostic procedure is magnetic resonance imaging. Already it provides anatomic information of such high quality that spin echo images are beginning to replace angiocardiology for the demonstration of abnormal cardiovascular anatomy.⁵⁵ The addition of cine mode⁵⁶ promises to make magnetic resonance imaging the morphologic gold standard of the future. Technical and software improvements will make available valuable functional information. Accurate measurements of flow, even at the rapid heart rates encountered in infants, will soon be a matter of routine. Who can tell what contributions echoplanar imaging will make? Similarly, when gating problems are overcome, spectroscopy should extend our knowledge of abnormal myocardial metabolism.

Without doubt, the full impact of prenatal cardiology will probably be felt over the next decade. The main advance will come through making prenatal diagnosis more widely available. This can be achieved with existing technology and, to a great extent, using existing facilities. The problem of disseminating the technique was addressed in the early nineteen eighties by the group at the Hopital des Enfants Malades in Paris. Their contention was that it was impractical to attempt to perform a complete fetal echocardiogram on every pregnant woman. They, therefore, investigated the utility of a limited cardiac scan, performed during a routine obstetric ultrasonic examination. The rationale was that a single echocardiographic section, the four chamber view, would detect cardiac anomalies in approximately two to three per thousand pregnancies and that all the anomalies would be severe, for example, the hypoplastic left heart syndrome. We have taken their approach and applied it in obstetric centers in our region. The protocol is that a member of our department visits the participating center at regular intervals to instruct, support, and provide quality control. The ultrasonographers obtain a four chamber view in all pregnancies scanned. The ideal stage of pregnancy is 16 to 18 weeks. If the four chamber view is unequivocally normal, no action is taken. If there is any doubt whatsoever, then the patient is referred to the perinatal cardiology unit for a complete examination of the fetal heart.⁵⁷ The success of this approach is shown by the increase in numbers of anomalies detected from 53 in 1986 to 127 in 1989. The importance of this is mainly related to the fact that about half the parents with affected fetuses choose not to continue the pregnancy. As stated above, this resulted in 67 terminations in 1989. This year is on track for almost double that number. This means that already, from our unit alone, eight percent of the total number of potential candidates for infant cardiac surgery in England and Wales will not be born. This decrease in numbers affects, predominantly, the more complex and severe anomalies and, thus, has major implications for the forward planning of pediatric cardiac services. New techniques, such as transvaginal ultrasonic scanning, should make cardiac diagnosis possible in early fetal life. How widespread this approach becomes depends on patient compliance. It will certainly have a place in patients in categories at high risk, such as those with a family history of congenital heart disease.

A departure whose potential is not predictable is intrauterine intervention. We have recently attempted aortic valvoplasty using a balloon in two fetuses. Our decision to intervene was based on another benefit from fetal echocardiography, namely our improved understanding of the natural history of cardiac malformations

in fetal and perinatal life. We attempted these procedures, because we had come to recognize the extremely grave prognosis of aortic stenosis accompanied by endocardial fibroelastosis when recognized in fetal life. Furthermore, we have observed, in a majority of such fetuses, arrest in growth of the left ventricle. In such cases, the ventricle having been of normal size, albeit poorly functioning, at, say, 20 weeks had, by 28 weeks, become severely hypoplastic. At our first attempt, a commercially available coronary arterial catheter was introduced on a wire via a transabdominal needle puncture into the left ventricle, but the aortic valve was not crossed. We had, nonetheless, demonstrated that the balloon could be delivered into the fetal heart. In the second patient, we had a similar experience as the first attempt, with the added complication that the balloon was sheared from the catheter and had to be left in the ventricle. On the second attempt, however, a custom-made balloon was passed across the valve, and dilatation was performed. The patient survived to undergo a postnatal valvoplasty, but only survived five weeks. The procedure is possible. At present, the indications are rare. Time will inform us as to the viability of the technique in clinical practice.

The future of interventional cardiology in postnatal life is already with us. Having demonstrated the effectiveness of transcatheter closure of the arterial duct, the next step was to close atrial septal defects. A device was produced similar to the double umbrella used for closure of the duct. The major difference is that the struts of the umbrellas are sprung at their mid-point so that distal and proximal struts flex towards each other to grip the septum. The device is known as the 'clamshell'. Following experimental work,⁵⁸ the method has proved very promising in the clinical trials conducted by James Lock. Almost certainly, it will have a place in the treatment of atrial, and some ventricular, septal defects.

Other methods of promise include the use of stents to maintain patency of vessels which do not respond to balloon angioplasty. In some instance, the failure is due to the elastic recoil of the vessel, whilst in others it is due to the fact that stenosis is due to extravascular pressure. At present their use is experimental in children, and their long term fate has yet to be determined. Pediatric cardiologists continue to strive to usurp the role of the surgeons. In our unit we have begun to study the possible use of an atherectomy catheter (Devices for Vascular Intervention) for cardiac myectomy. Having established that the catheter would cut myocardium in autopsied hearts, we then employed it successfully in a 14 month old child with tetralogy of Fallot.⁵⁹ A further procedure was also successful in the relief of an obstructed aortic outflow tract due to a restrictive ventricular septal defect in a child with tricuspid atresia and discordant

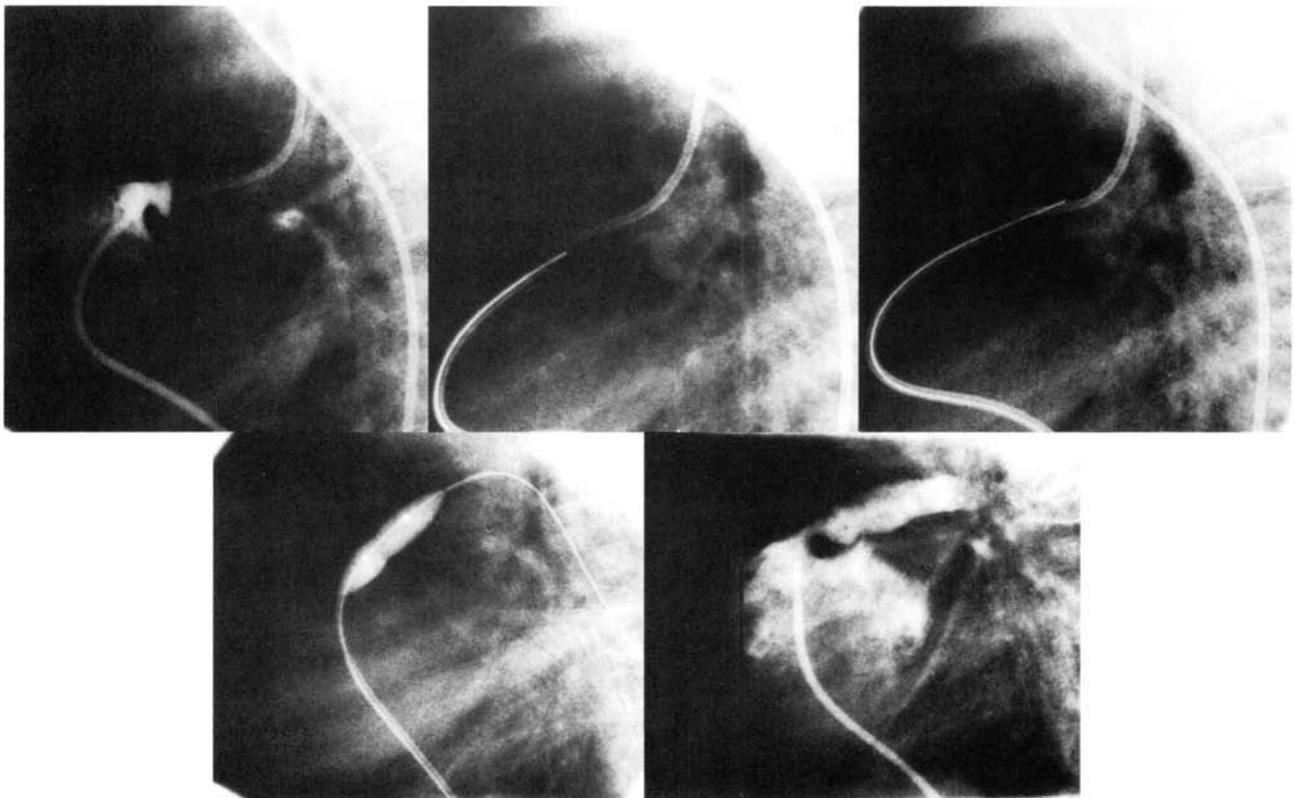


Figure. (Top left) Shows the right ventricular aspect of the atretic pulmonary valve; (Top center) Shows the guide catheter positioned below the pulmonary valve. The laser wire is at the tip of the catheter. A second catheter is positioned in the pulmonary trunk, via the Blalock shunt, as a landmark; (Top right) Shows the laser wire having been advanced into the pulmonary trunk; (Bottom left) Shows the final balloon angioplasty; (Bottom right) Shows good forward flow through the previously imperforate valve.

ventriculoarterial connections. This approach promises to be of value in a variety of settings. One last method in which we are involved is the use of lasers in the treatment of congenital cardiac defects. There is some experimental work to suggest that this is an appropriate use of this technology.⁶⁰ It appeared to us that the atretic pulmonary valve was begging to be perforated. We attempted perforation of such a valve in a child with pulmonary atresia, ventricular septal defect and a Blalock-Taussig shunt who was becoming progressively more hypoxic. An 0.018 inch 'hot tip' laser guide wire was used to pass across the atretic valve. This was then followed by angioplasty balloons which progressively dilated the valve. The procedure is illustrated in the Figure. In all, six similar procedures have been attempted. Five were in infants, including three less than one month of age. Five were successful. There has been one failure in a neonate with a short segment of muscular infundibular atresia. In this patient, the right ventricular outflow tract was perforated by the laser wire with resulting tamponade, which responded to needle drain-

age of the pericardium. The patient's condition stabilized, and he was referred for a surgical shunt, but he died during that procedure. The remaining patients are improved. A problem, in the avoidance of surgery, is the maintenance of pulmonary blood flow in the neonates. Prostaglandins are, of course, invaluable in the acute phase. Initially, balloon dilatation of the duct appears to have been effective, but its long term value is uncertain. Perhaps laser coagulation of the duct using a balloon could be the answer, but this needs an extensive experimental evolution before being used in patients.

Without being at all adventurous in prophesy, we can be certain that the practice of pediatric cardiology will undergo major changes in the next decade. There will be fewer patients born with complex heart defects. More of the simpler anomalies will be treated in the catheterization laboratories. Our managers will be constantly evaluating the cost benefits of what we do. Hopefully, the patients will reap the benefits. There are quite exciting times ahead for pediatric cardiologists and our colleagues.

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