EVALUATION OF ELECTROCARDIOGRAPHY DURING CONGENITAL HEART SURGERY

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THE NEED for more exact information concerning patients during anesthesia is being answered by the introduction of variety of monitoring instruments. Although very desirable, these monitoring devices may involve high initial expense, additional personnel, some delay and confusion in the operating room, diversion of anesthetist's attention, and possible hazards to the patient himself. The usefulness of different monitors will perhaps vary with each type of operation so that no one instrument will answer all the needs.

Problems of a different nature may develop inasmuch as anesthetists and hospitals may be in danger of exploitation by manufacturers of various alarm-ringing mechanisms advertised as being invaluable for patient protection. This in turn can lead to legal difficulties wherein neglect is charged if a patient succumbs when not wired to some ultrasonic pulse recorder.

The electrocardiograph has been used for several years as a monitoring device, and one might assume it to be of considerable assistance during surgery of congenital heart disease. The present study is a critical evaluation of the usefulness of the electrocardiograph in congenital heart surgery, not including operations upon the open heart under hypothermia or by-pass pump oxygenators.

An attempt will be made to answer the questions: (1) what information does the electrocardiograph give? (2) of what significance is this information? (3) is the use of the instrument mandatory? (4) what are its shortcomings? and (5) is there any danger to the patient?

METHOD

Electrocardiographic tracings were taken during 103 procedures for correction of congenital heart defects. The type of heart lesions are shown in table 1.

A variety of anesthetic agents was used, including cyclopropane, cyclopropane-ether, nitrous oxide-ether, as well as nitrous oxide, thiopental and curare. The techniques used were chiefly to-and-fro, semiclosed for children weighing less than 35 pounds, and circle absorption, closed and semiclosed for patients 35 pounds and over. Anesthesia

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was administered by staff anesthesiologists, anesthesia residents, and nurse anesthetists. The operations were performed by several different surgeons. Consequently the electrocardiographic changes should roughly approximate those that would generally be encountered, since individuality of type of anesthesia, anesthetist, and surgeon were eliminated.

Preoperative medication consisting of pentobarbital sodium (Nembutal®), morphine or meperidine (Demerol®), and atropine or scopolamine was given all patients. No patient was digitalized in preparation for operation, but many of those with atrial septal lesions were given quinidine to reduce myocardial disturbance. Calcium chloride was used as a cardiac stimulant during the course of several procedures.

Electrocardiograms were obtained in all patients just prior to operation. The standard bipolar limb leads were recorded after placing the patient on the operating table. A tracing was taken during induction of anesthesia, during intubation, and then at frequent intervals during the procedure. Special care was taken to record tracings during the

TABLE 1.

CONGENITAL HEART DEFECTS IN THE 103 OPERATIVE PROCEDURES

Patent ductus arteriosus	17
Coarctation of the aorta	15
Atrial septal defect	21
Tetralogy of Fallot	37
Pulmonary stenosis	13
Total	103

start of operation, opening of pleural cavity, mediastinal dissection, clamping and releasing major vessels, entering pericardium and heart, valvulotomy, periods of rapid blood loss or cardiac depression, and closure of pleural cavity, completion of surgery, and extubation and following completion of procedure.

The heart action was continuously monitored by stethoscope throughout all operations, and in several instances, by cathode ray oscillograph. Direct visualization of cardiac activity proved extremely valuable while the chest was open, and this served as an additional method of monitoring in all operations.

RESULTS

Preliminary Considerations.—In order to interpret electrocardiograms of patients undergoing surgery for congenital heart disease, two preliminary considerations must be borne in mind. (1) The electrocardiogram of the normal infant differs from that of the child and adult, there being right axis deviation in infants until they are approximately six months old, after which time conversion to normal pattern is made (1). (2) While the electrocardiograms are not definitely characteristic of the different congenital anomalies, the various cardiac

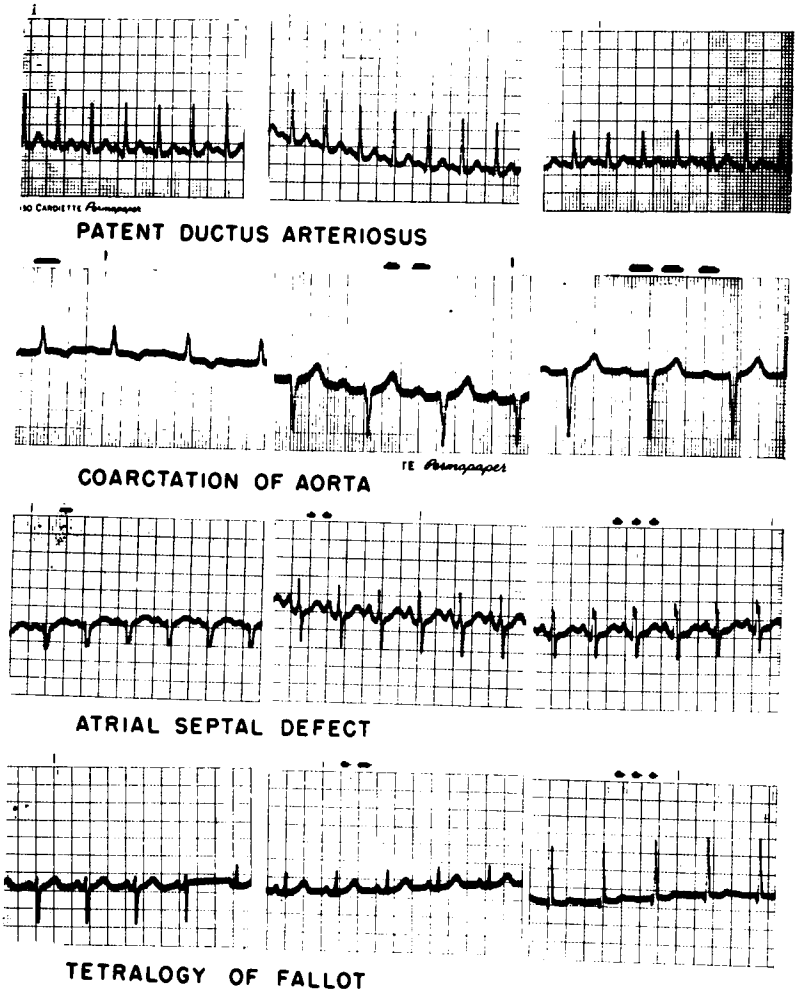


FIG. 1. Usual patterns in congenital heart disease, leads I, II, and III. Patent ductus arteriosus here shows entirely normal electrocardiogram. Large shunts may cause left ventricular strain and axis deviation, while elevated pulmonary artery pressure may cause right axis deviation. Coarctation of aorta here shows marked left axis deviation (upright QRS_1, inverted QRS_3), and bundle branch block. Atrial septal defect shows right axis deviation (inverted QRS_1, upright QRS_3) and bundle branch block. Tracing of tetralogy of Fallot demonstrates right axis deviation. That of pulmonary stenosis gives similar patterns.

defects may show basic differential features which must be considered when one is judging the patients' responses to anesthesia and operation. The degree of departure from normal varies with each individual. Consequently, it is important to be familiar with the preoperative tracing of each patient before surgery is begun (fig. 1).

Information Gained by Preoperative Electrocardiography.—PREOPERATIVE TRACINGS: Of the 103 patients studied, only 11 showed normal preoperative electrocardiograms. The abnormalities shown by the

TABLE 2

PREOPERATIVE ELECTROCARDIOGRAPHIC SIGNS IN CONGENITAL HEART DISEASE

Heart Lesion	Total	Normal	Left Axis Deviation	Left Ventricular Hypertrophy	Right Axis Deviation	Right Ventricular Hypertrophy	Bundle Branch Block
Patent ductus arteriosus	17	8	1	0	6	2	0
Coarctation of aorta	15	1	2	12	0	0	1
Atrial septal defect	21	2	0	0	14	5	16
Tetralogy of Fallot	37	0	0	0	5	32	9
Pulmonary stenosis	13	0	0	0	1	12	2

remaining 92 patients consisted of axis deviation, ventricular hypertrophy, and bundle branch block (table 2).

Patients with patent ductus arteriosus often have normal electrocardiograms, as the increased output demanded of the left ventricle is counterbalanced by the increased pressure developed in the right ventricle. Left axis deviation is more often found than right axis deviation, hence our findings of 8 instances of right axis predominance is unusual, but perhaps was due to a chance sampling which included several patients with pulmonary vascular obstruction.

The preponderance of left ventricular hypertrophy or axis deviation found in the group with coarctation of the aorta was to be expected, since the lesion causes increased resistance to left ventricular output. In atrial septal defects, on the other hand, blood is shunted from left auricle into right; hence right ventricular strain or axis deviation will be the usual pattern. All of the patients having tetralogy of Fallot or pulmonary stenosis showed right heart strain, with or without bundle branch block. This would be expected in view of the increased work of right ventricle against the obstructed pulmonary valve present in both syndromes.

The significance of the above information was limited. Left or right heart strain was diagnosed by roentgenogram, and the cardiogram merely assisted in defining its degree. The diagnosis of bundle branch

TABLE 3

TYPE AND INCIDENCE OF ARRHYTHMIAS DURING SURGERY FOR CONGENITAL HEART DISEASE IN 103 CASES

Regular throughout	39	T wave inversion	2
Sinus tachycardia	58	A-V nodal rhythm	21
Sinus arrhythmia	1	Wandering pacemaker	5
Sinus bradycardia	2	A-V block	5
Auricular flutter	2	Ventricular premature contraction	37
Auricular premature contraction	2	Ventricular paroxysmal tachycardia	6
Auricular paroxysmal tachycardia	1	Sinus arrest	3
PR prolongation	1	Ventricular fibrillation	2
QRS aberration	4		
ST deviation	10		

block, on the other hand, gives some evidence of myocardial damage, and this diagnosis is not made without electrocardiography.

ELECTROCARDIOGRAPHY DURING ANESTHESIA AND SURGERY: A complete tabulation of the electrocradiographic abnormalities in this study is given in table 3. There was considerable variation in both the type and the incidence of arrhythmias. Those most frequently seen were simple sinus tachycardia, ventricular premature contractions (extrasystoles) and A-V nodal rhythm (fig. 2). Fortunately, these appeared to be of little significance. The majority of the remaining electro-

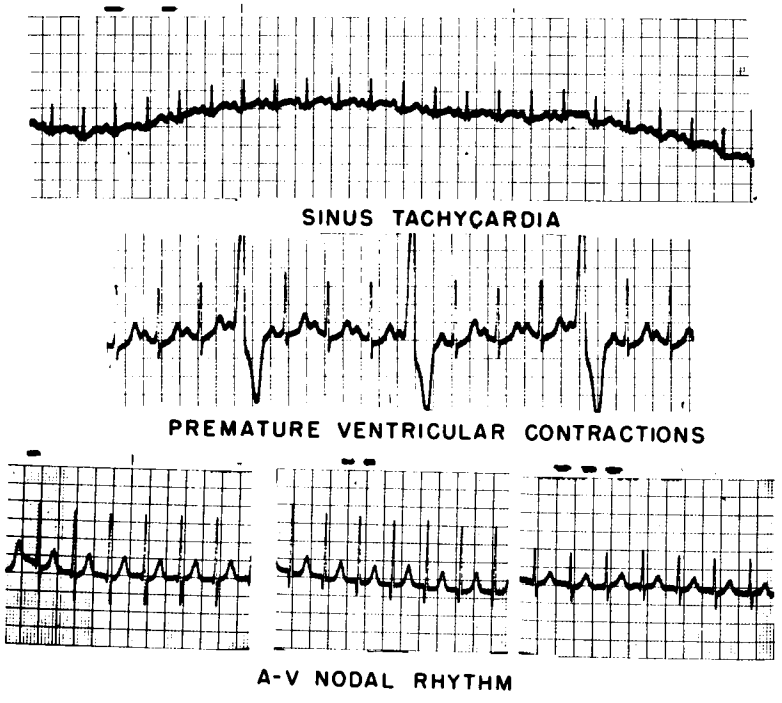


FIG. 2. Arrhythmias most frequently seen in study, and of little significance. (A) Sinus tachycardia. (B) Premature ventricular contractions (extrasystoles), here in regular occurrence of one to every three normal beats. (C) A-V nodal rhythm. P wave absent in leads I, II, and III. Since P may be hidden by superimposition on T in any one lead, single lead is inadequate for diagnosis.

cardiographic abnormalities were not necessarily dangerous, but might prove to be if they became marked in degree or persisted for a long time. They were regarded as signs of potential danger at the time of their occurrence, but in general their appearance was fleeting and apparently unrelated to any appreciable changes in the condition of the patient. Consequently, they did not give significant indication of the patients' condition.

Three types of arrhythmias were considered of grave importance. These were ventricular tachycardia, sinus arrest and ventricular fibril-

lation. Fortunately, ventricular tachycardia was due to mechanical stimulation during atrial septal repair, and reverted to normal on withdrawal of stimulus. When ventricular tachycardia occurred, a severe arrhythmia was obvious visibly, and the electrocardiogram was chiefly of academic value. Ventricular fibrillation occurred as a late manifestation in two dying patients, and was visible. The occurrence of sinus arrest was perhaps the instance where the electrocardiogram could have been of most value, for the disturbance appeared in short bursts early in the operation, recurred in spells of increasing length, and finally after closure of atrial defect, became continuous and fatal, in spite of attempts to the contrary.

Incidence of Arrhythmias in Relation to Cardiac Lesion and Stage of Procedure.—There was some difference in the type and incidence of arrhythmias associated with each form of congenital cardiac lesion, and in the phase of the operation in which they occurred.

PATENT DUCTUS ARTERIOSUS: In general, patients with patent ductus arteriosus are well oxygenated and have strong myocardial function.

TABLE 4

ARRHYTHMIAS DURING SURGERY FOR PATENT DUCTUS ARTERIOSUS (17 CASES)

Arrhythmia	Induction	Intrathoracic Phase	Closure
Sinus tachycardia	2	0	0
Auricular paroxysmal tachycardia	1	0	0
Auricular flutter	0	1	0
ST deviation	0	3	0
Ventricular premature contraction	0	5	2
Wandering pacemaker	0	1	0
Sinus arrest	0	1	0

In these patients, anesthesia is well tolerated, and surgery offers little hazard. Neither pericardium or heart is entered, and the effect of clamping, dividing, and suturing the ductus is not reflected by any electrocardiographic change. The chief danger in surgery of such patients lies in hemorrhage, and in this situation electrocardiography is certainly of secondary importance.

Patients are occasionally encountered, however, in whom the ductus is very large and associated with pulmonary vascular obstruction, high pulmonary pressure, and occasionally reversal of flow through the ductus. Surgical occlusion of the ductus in these patients has met with high mortality owing to development of extreme pressure in pulmonary artery and right heart. Terminal arrhythmias will appear, but only as late changes secondary to hemodynamic strain. Intracardiac pressure manometers would be of far greater value than the electrocardiograph in foretelling events in these complicated cases.

In this study, 17 patients were operated upon for patent ductus

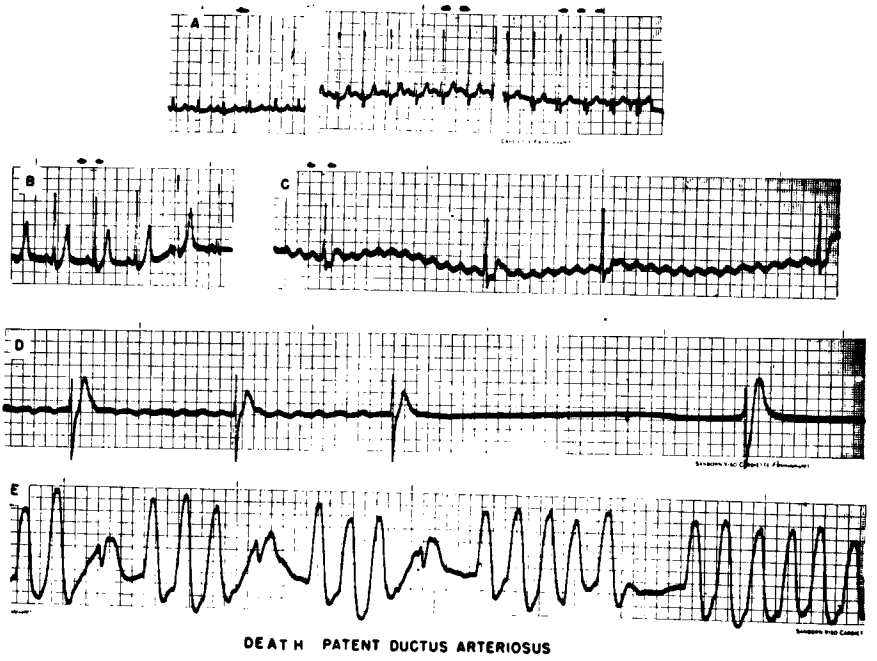


FIG. 3. Terminal pattern in 4-year-old patient with ductus arteriosus. (A) Starting surgery. Normal patterns in leads I, II, and III. (B) Following severe hemorrhage there is spiking of QRS and T, possibly owing to citrate toxicity. (C) Auricular flutter. (D) Ectopic ventricular beats with sinus arrest. (E) Cardiac massage.

arteriosus (table 4). Of the few arrhythmias noted, most were of short duration and not associated with clinical problems. Sudden hemorrhage during dissection about the great vessels caused the death of a 4-year-old girl. Auricular flutter and sinus arrest occurred as terminal mechanisms here (fig. 3), but recognition of these changes was of no help. It appeared that electrocardiography was of little practical assistance in this group.

COARCTATION OF THE AORTA: The 15 patients with coarctation of the aorta showed extremely few arrhythmias of any type and none of a serious nature (table 5). This is in accordance with an earlier study of Alimurung and Smith (2). Patients with coarctation usually have

TABLE 5

ARRHYTHMIAS DURING SURGERY FOR COARCTATION OF AORTA (15 CASES)

Arrhythmia	Induction	Intrathoracic Phase	Closure
Sinus tachycardia	2	0	0
Auricular flutter	0	1	0
ST deviation	0	1	0
Ventricular premature contraction	0	1	0
Wandering pacemaker	1	0	0

strong, well oxygenated myocardia if operated upon as children or young adults, as were these. The strain of corrective surgery lies in the prolonged procedure, the considerable blood loss, and the acute hemodynamic changes, first, on occlusion of the aorta prior to anastomosis, and then upon release of the aortic clamps following anastomosis.

In the clinical course of this series of operations for coarctation, no truly critical periods were encountered. The electrocardiogram was of academic value in diagnosing the short-lived arrhythmias noted, but did not influence management of any case. It should be added that when patients with coarctation reach 30 to 40 years of age, atherosclerosis and heart strain may become advanced. Heart failure and arrhythmias may be encountered during operation, and electrocardiography then seems definitely indicated during operation.

TABLE 6

ARRHYTHMIAS DURING SURGERY FOR ATRIAL SEPTAL DEFECT (21 CASES)

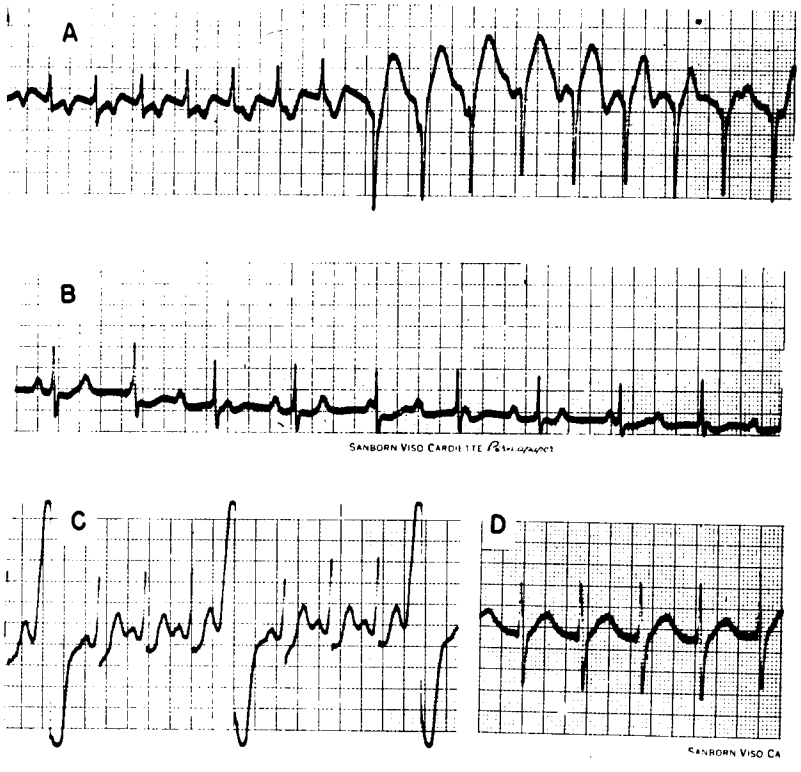
Arrhythmia	Induction	Intrathoracic Phase	Closure
Sinus tachycardia	12	0	0
Sinus arrhythmia	1	0	0
Sinus bradycardia	1	1	0
Premature auricular contraction	0	1	0
PR prolongation	1	0	0
QRS aberration	0	2	0
ST deviation	1	0	0
T wave inversion	1	0	0
A-V nodal rhythm	2	12	1
A-V block	0	3	0
Wandering pacemaker	0	1	0
Ventricular premature contraction	3	2	0
Ventricular paroxysmal tachycardia	0	2	0
Sinus arrest (S-A block)	0	1	0
Ventricular fibrillation	0	1	0

ATRIAL SEPTAL DEFECT: The arrhythmias encountered in the 21 patients with atrial septal defect were more numerous and more severe than in any other group (table 6). Prior to operation many patients had weakened, enlarged hearts, and conduction disturbances which gave evidence of increased irritability. Intolerance to rapid induction was shown by several. This was reflected both by the appearance of arrhythmias and by fall in blood pressure. Intolerance to deeper planes of anesthesia was even more pronounced. However, marked fall in cardiac output and myocardial depression occurred in several cases without causing any change in the electrocardiogram.

The severest disturbances during operation consisted of entering the heart and suturing the septal defect. The technique of repair in this series consisted of inserting a finger into the right auricle, and introducing the sutures from outside the heart. A variety of arrhythmias

occurred here, including A-V nodal rhythm, frequent extrasystoles, A-V block, and ventricular tachycardia (fig. 4). Electrocardiographic diagnosis of these arrhythmias seemed definitely desirable, and helped considerably in our understanding of the events. On three occasions bradycardia of some duration occurred immediately following septal repair. This was shown to be heart block, apparently caused by passing sutures into the conductive tissue about the septum.

One patient with atrial septal defect died shortly after closure of the lesion. This case was briefly discussed above, and the progression of



CLOSURE OF ATRIAL SEPTAL DEFECT

FIG. 4. Arrhythmias occurring during closure of atrial septal defect. (A) Ventricular tachycardia. (B) Complete or third degree A-V block. Auricles and ventricles beat in regular but independent rhythm. (C) Ventricular premature contractions and ST depression. (D) A-V nodal rhythm (only lead II shown here).

his difficulty is shown in figure 5. The patient had recurrent spells of sinus arrest which became longer, and finally continuous. Atropine was given unsuccessfully, and following prolonged attempts to activate the heart, ventricular fibrillation occurred. Attempts at defibrillation were not effective. This patient was one who had elevated pulmonary vascular pressure prior to operation. It has since been found that operation in these patients results in a prohibitive mortality (3).

The use of electrocardiography during surgery for atrial septal defect appeared to be of definite value and seemed clearly indicated in view of the increased irritability of the weakened heart and the disturbances caused by operation.

TETRALOGY OF FALLOT: Thirty seven patients were studied during operation for tetralogy of Fallot. Many of these were extremely hypoxic and offered great operative risk. Several required surgery during infancy in order to survive. In addition to hypoxia, hypotension was frequently a major problem throughout operation. It has

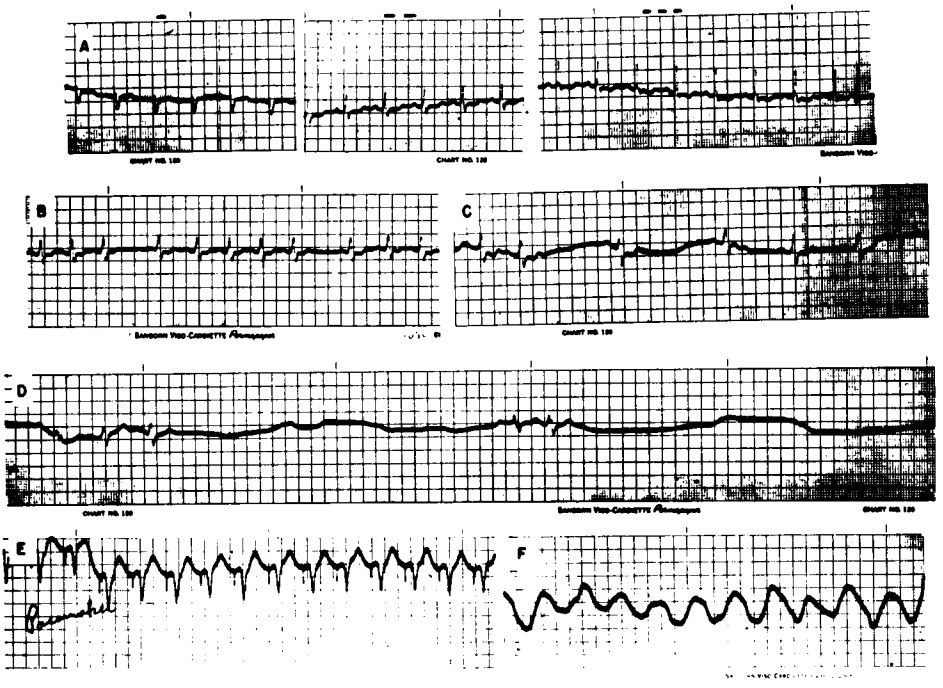


FIG. 5. Terminal pattern in 37-year-old patient with atrial septal defect. (A) Start of operation, leads I, II, and III, showing right axis deviation. (B) Two short periods of sinoauricular block. (C) Increased duration of S-A block. (D) Prolonged S-A block or cardiac arrest with two normal beats interposed. (E) Tracing caused by use of "pacemaker." (F) Ventricular fibrillation.

been our experience that maintenance of blood pressure is often more difficult than keeping the patient oxygenated.

Three different types of operations were performed on patients with tetralogy of Fallot. These were the Potts anastomosis of pulmonary artery and aorta (4), the Blalock anastomosis of subclavian artery and pulmonary artery (5), and the Brock transventricular pulmonary valvulotomy (6). The first two procedures require occlusion of the pulmonary artery during anastomosis. Oxygen deprivation is even more severe during this phase, and cardiac activity may become depressed. This was not reflected in the electrocardiogram, however.

The Brock valvulotomy avoids occlusion of pulmonary artery, but instead involves the irritation of piercing the ventricular wall, and the danger of abrupt and severe blood loss. A definite electrocardiographic burst of ventricular extrasystoles usually was seen at valvulotomy (fig. 6).

In spite of these problems, this large group included relatively few arrhythmias (table 7). Sinus tachycardia with induction was common

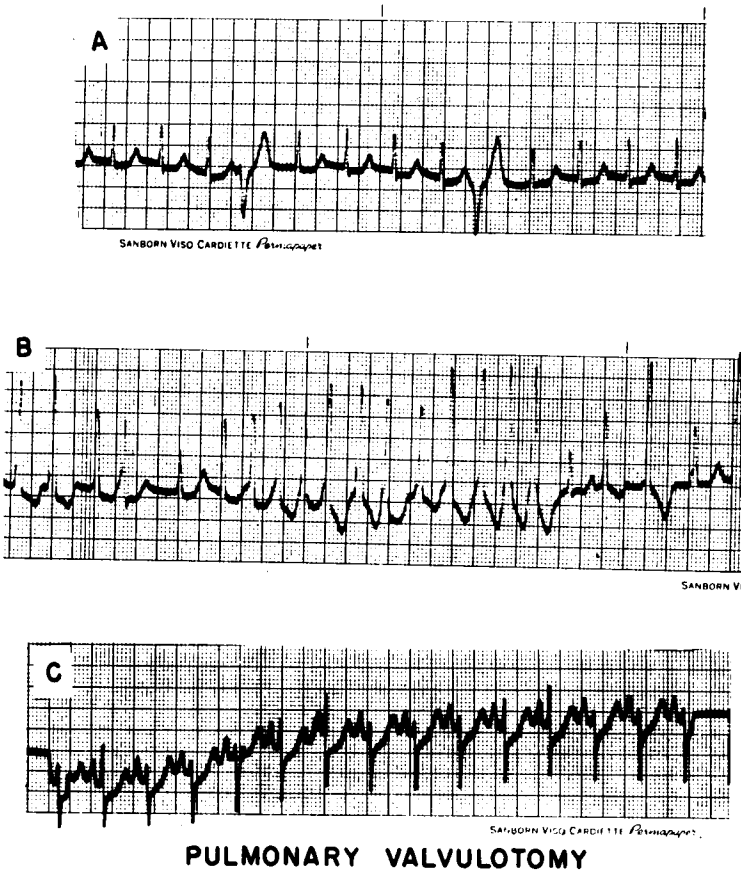


FIG. 6. Irregularities seen during valvulotomy for pulmonic stenosis. (A) Nodal rhythm with two premature ventricular contractions on placement of retaining sutures in myocardium. (B) Passage of valvulotome causes run of ventricular premature contractions. (C) Depression of ST segment following valvulotomy.

but unimportant. This might have been due to the early age at which many patients came to operation. The majority of disturbances consisted of extrasystoles associated with valvulotomy and other intrathoracic maneuvers. No arrhythmias occurred during closure.

It seems remarkable that there were no deaths nor even any truly critical situations in this large group. Ziegler (7), in his classical study of cardiac activity during operations of this type, reported a high

TABLE 7

ARRHYTHMIAS DURING SURGERY FOR TETRALOGY OF FALLOT (37 CASES)

Arrhythmia	Induction	Intrathoracic Phase	Closure
Sinus tachycardia	31	0	0
QRS aberration	1	0	0
ST deviation	0	3	0
T wave inversion	0	1	0
A-V nodal rhythm	1	2	0
Wandering pacemaker	0	1	0
Idioventricular rhythm	1	1	0
Ventricular premature contraction	2	12	0
Ventricular paroxysmal tachycardia	0	1	0

incidence of arrhythmias owing to hypoxia, noting bradycardia especially. The absence of bradycardia in this series, we hope, reflects that surgery and anesthesia have been combined to cope with this lesion more physiologically.

The value of the electrocardiograph was slight in this series. As mentioned above, the two major hazards lie in hypoxia and hypotension. Electrocardiographic signs of these changes appeared late, and then were poorly defined. We believe there is a real need for a better device than the standard pneumatic arm cuff to follow blood pressure during the procedures on cyanotic children. A strain gauge manometer, or comparable apparatus would seem of considerable advantage in poor risk cases. An oximeter would give information of interest, but would be of less practical value.

PULMONARY STENOSIS: In this group of 13 cases, there was a greater relative incidence of arrhythmias than in those with tetralogy of Fallot. This was chiefly due to the fact that operation was limited to the more upsetting Brock valvulotomy, with its increased danger of myocardial irritation and acute blood loss. It is significant that with the exception of sinus tachycardia, all arrhythmias occurred during the intrathoracic phase of operation (table 8).

TABLE 8

ARRHYTHMIAS DURING SURGERY FOR PULMONARY STENOSIS (13 CASES)

Arrhythmia	Induction	Intrathoracic Phase	Closure
Sinus tachycardia	11	0	0
Auricular premature contraction	0	1	0
QRS aberration	0	1	0
ST deviation	0	2	0
A-V nodal rhythm	0	3	0
Wandering pacemaker	0	1	0
Ventricular premature contraction	0	10	0
Ventricular paroxysmal tachycardia	0	3	0
Sinus arrest	0	1	0
Ventricular fibrillation	0	1	0

The insult of valvulotomy in cyanotic patients is somewhat comparable to that involved in atrial septal repair. Patients with pulmonary stenosis generally have less preoperative myocardial disease, however, and less serious disturbances are usually seen. Nevertheless, death occurred in one 14-year-old patient who had pulmonary stenosis associated with a markedly dilated and irritable heart. In this patient, valvulotomy was followed by falling blood pressure, and visible deterioration of cardiac impulse. Irregular bursts of activity soon

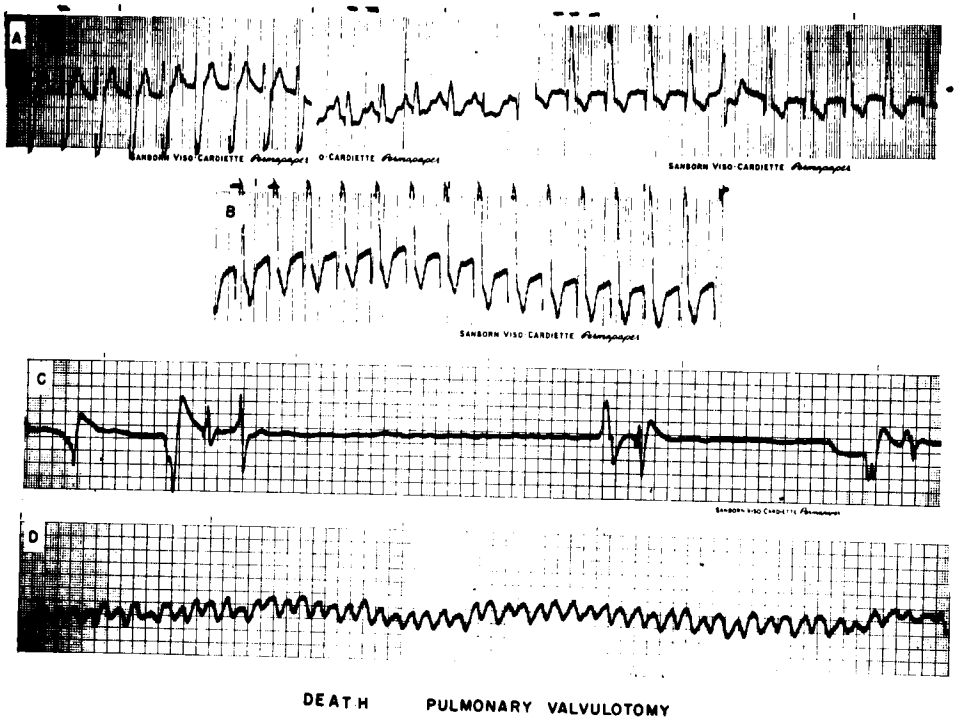


FIG. 7. Terminal pattern in 14-year-old patient with pulmonary stenosis. (A) Leads I, II, III of initial electrocardiogram showing marked right ventricular hypertrophy, bundle branch block, and QRS widening. Extrasystole in lead III. (B) Lead II following septal closure, increased irritability of heart indicated by progression of QRS widening and spiking of QRS and T. (C) Lead II, ineffective agonal ectopic beats separated by asystole. (D) Ventricular fibrillation (lead II).

changed to ventricular fibrillation and death. These events were associated electrocardiographically with increasing ST depression widening QRS, then ectopic ventricular beats separated by sinus arrest, and finally the unmistakable pattern of ventricular fibrillation (fig. 7). The reason for the death was not definitely determined. The electrocardiographic changes followed rather than preceded clinical signs, and the information rendered was of little assistance.

Although the electrocardiograph was not of real importance either

in patients with tetralogy of Fallot, or in those with pulmonary stenosis, we do feel that it is advisable to use it when the risk is severe, and when valvulotomy is to be done.

Discussion

In planning this study, it was intended to answer certain questions concerning the value of electrocardiography during congenital heart surgery. The information obtained by electrocardiography has been presented, and can be summarized briefly as follows. A variety of arrhythmias were encountered, and their occurrence varied considerably with the primary cardiac defect as well as the type and phase of the operation. The significance of the information included both practical and academic phases. From a practical standpoint most of the arrhythmias seemed of little importance with the exception of such terminal tracings as sinus arrest and ventricular fibrillation. In these situations, clinical observation usually preceded electrocardiographic changes. In a few instances, electrocardiography was of definite value, especially in differentiating sinus bradycardia from A-V block and auricular tachycardia from the more serious ventricular tachycardia.

From an academic standpoint, it was of interest to be able to determine electrocardiographically the nature of various arrhythmias picked up by stethoscope or visual observation.

Actually, definite clinical management of the patient was altered in only one instance because of electrocardiographic information. This would make it difficult to uphold the use of electrocardiography as being mandatory. Our conclusions, therefore, are that the instrument is of sufficient value to make its use advisable in the following situations: (1) in all poor risk patients undergoing cardiac surgery, (2) in patients with preoperative conduction defects, (3) in patients of 35 years or older (who have congenital heart disease), and (4) when surgery involves entering the heart, as in valvulotomy or closure of atrial septal defect.

The chief deficiency of the electrocardiograph in congenital heart surgery is that it does not show the effects of altered hemodynamics, shock, hemorrhage or hypoxia until the situation is advanced, and even then the electrocardiographic changes are nonspecific. Furthermore, considerable training is necessary to enable one to interpret the signs that do appear during surgery.

The only possible hazards involved in the use of the electrocardiograph as a monitoring device are: (1) the explosive hazard and (2) the danger owing to distraction of the anesthetist's attention from the patient himself. This occurred in one instance in the present series. The most important signs of cardiovascular competence were those observed by actually watching cardiac action, stethoscopic monitoring of heart sounds, and frequent determination of blood pressure.

Summary

An evaluation of the practical use of the electrocardiograph as a monitoring instrument was made on the basis of information from 103 operations for congenital heart lesions. This series did not include surgery upon the "open heart" under hypothermia or by-pass techniques.

A variety of conduction defects and arrhythmias were found. In many instances these proved clinically unimportant, nonspecific, or so late in appearance that the underlying problem was already obvious. Consequently, the value of the electrocardiograph seems limited.

In the presence of pre-existing myocardial weakness, however, and during operations involving direct stimulation of the heart (valvulotomy and atrial septal closure), sufficient information was gained by electrocardiography to make its use definitely advisable.

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