Techniques and Modes of Insertion of Permanent Pacemakers*

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In this report, I intend to mention most of the methods of implantation of permanent pacemakers while indicating those methods which are currently favored.

The special advantages of epicardial implantation of pacemaking electrodes are the accuracy and reliability of this technique, and the insignificant subsequent rise in pacemaking threshold. However, the indications for epicardial stimulation have contracted in direct proportion to the increased ease and reliability of endocardial catheter pacing, a method which carries a lower morbidity and mortality, particularly in the aged patient.

Permanent Epicardial Pacing. The indications for pacing by direct epicardial stimulation are: (1) for temporary atrial or ventricular pacing in conjunction with cardiac surgery for surgically induced heart block, for the control of sinus or nodal bradycardia, improvement of cardiac output, stabilization of cardiac rhythm, or to overdrive and prevent or correct ventricular arrhythmias, all in conjunction with cardiac surgery. Thus in most patients with acquired heart disease, a pacing wire is implanted on the right atrium at the time of surgery; (2) for control of chronic heart block in children or young adults in whom the risk of thoracotomy is negligible. However, such patients are infrequently seen; (3) if atrial synchronous pacing is being considered and thoracotomy can be tolerated, direct implantation of an atrial electrode is used, since the pervenous techniques are not yet fully reliable; (4) when transvenous endocardial pacing has not been achieved initially or has subsequently failed, epicardial implantation is used. It is in this category that epicardial pacing finds its most common application in chronic heart block.

A variety of surgical procedures can be employed for epicardial pacing. Formerly, the standard procedure was a transpleural, left anterolateral thoracotomy, allowing access to the left ventricle and left atrium. Secondly, the left parasternal, extrapleural approach through the fifth and sixth costal cartilages, which exposes the midanterior right ventricule. Thirdly, the subcostal, transdiaphragmatic approach which transgresses neither the peritoneal cavity nor the pleural space, and which exposes the posterior right ventricle. Finally, for the sake of complete description, there is the midsternotomy approach to the anterior right ventricle and right atrium.

Certain technical points deserve emphasis in regard to each of these surgical approaches: The standard anterolateral thoracotomy procedure is usually carried out through the fifth intercostal space. We prefer to position the patient in the full right lateral decubitus since the left ventricle is then more easily exposed. An excellent exposure is obtained after division of the costal cartilages. If an atrial lead is also to be implanted, the fourth intercostal space is used. Electrode position on the myocardium too close to the phrenic nerve may lead to diaphragmatic stimulation. There is some disagreement regarding the proper position for the electrode. It has been suggested that more effectual contraction of the ventricle can be obtained from stimulation near the apex of the left ventricle. Others deny this. Close to the base of the heart there is greater likelihood of damaging intramyocardial coronary arteries. One of our patients succumbed from ventricular fibrillation on the seventh postoperative day, and at postmortem examination one of the sutures could be seen to encompass a significant intramyocardial coronary artery. As a method of determining optimal electrode position, testing to locate the position on either the left or right heart which yields the most narrow QRS has been suggested. We prefer the commonly employed coil type of electrode originally designed by Chardack, but I am very much intrigued by the electrode presented by Dr. Paul Zoll. Because of the increased susceptibility to ventricular fibrillation, a fixed-rate pacer should no longer be considered for use with epicardial leads in the early postoperative period. The threshold of capture, determined with decreasing current, is recorded for future reference. After a demand or standby

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pacer has been inserted, and if the patient is in sinus rhythm, the pacer must be converted to a fixed-rate mode by magnet to verify the integrity of the system.

Lower thresholds are obtained with electrodes which penetrate into the myocardium. A flat coil epicardial electrode, such as that used for the atrium, can also be used on the ventricle. The late stimulating threshold is somewhat higher, but perfectly acceptable. To avoid the possibility of phrenic stimulation, we have usually placed a thin layer of polyvinyl sponge between the electrode and the pericardium. A wide loop of electrode wire is led into the mediastinum and down into the upper abdomen. Every effort should be made to prevent kinking of the electrode wire or flexion stress. This concept dictates placement of the lead internal to the costal arch and through the diaphragm, if a transpleural approach has been used. If a parasternal approach is used, the lead should traverse the subcostal angle where motion is minimal. We have rarely used axillary placement since the application of the above principles in conjunction with Elgiloy (an alloy of nickel, cobalt, and chromium) wire has completely eliminated lead fracture. We have not favored implanting a generator behind the rectus fascia because of the increased difficulty at the time of subsequent battery replacement. When a unipolar system is used, the ground plate of the generator should be faced anteriorly in the subcutaneous tissue so as to avoid the possibility of muscle stimulation. The subcutaneous pocket should be large enough to prevent tension during closure, but it should not be so large as to allow rotation or turning of the generator unit with resulting stress on the leads. The pocket should not be placed in the lower abdomen, since bending at the waist will lead to increased flexion stress on the leads. The pocket is developed one-third cephalad to the transverse skin incision and two-thirds caudad to it. Absolute hemostasis is essential to minimize the potential for infection in the presence of a foreign body, and we make every effort to avoid catheters or drains. When used within two inches of the generator unit, the coagulation cautery may cause temporary malfunction of the unit. An adequate loop of wire leads should be coiled behind the generator to permit easy and safe extrusion of the unit at reoperation. Antibiotics are instilled into the pocket and used systemically for forty-eight hours postoperatively. Adherence to the above principles, together with a very careful and accurate closure of the subcutaneous tissue with nonabsorbable interrupted sutures, has yielded a record of no wound breakdowns in about 70 cases and only one infection, this beginning in the subcutaneous tissue. A temporary transvenous catheter is employed in all patients with complete heart block who must undergo general anesthesia, such as would be required for a thoracotomy procedure. This type of pacing control facilitates the epicardial implantation of the electrode since sudden discontinuance of rapid pacing achieves a prolonged asystole and quiet heart (Fig. 1). When an atrial surface electrode is employed with atrial synchronous pacing, this is sutured to the epicardium near the base of the auricular appendage.

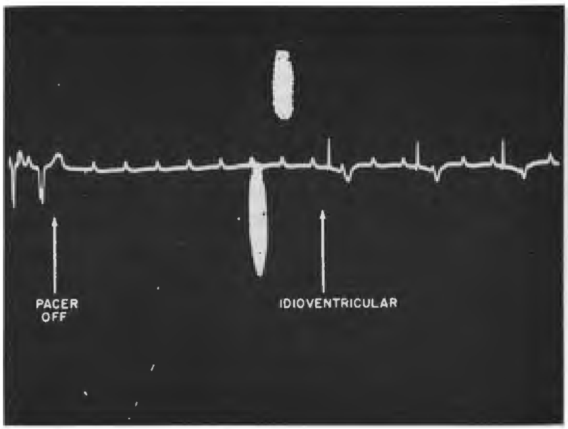

Fig 1—Sudden discontinuance of rapid pacing achieves a prolonged asystole and quiet heart.

Alternate methods of direct implantation are important and more commonly employed. As evidenced, the transdiaphragmatic, subcostal incision, an approach which requires general anesthesia, is well tolerated by aged patients, providing endotracheal intubation is used and maintained until full recovery. Through a subcostal incision the rectus sheath is incised and the muscle retracted laterally. Some of the rectus fibers must necessarily be detached from the costal arch. Properitoneal fat is swept away from the undersurface of the diaphragm and an incision made in this structure to gain entry into the pericardial cavity. The undersurface of the right ventricle is exposed where one or two electrodes can always be implanted in an area devoid of epicardial fat. Three maneuvers may facilitate the exposure: the creation of an inverted flap of diaghragm to which traction is applied; the caudad retraction of the diaphragm; and induced paralysis of the diaphragm. The patient with a very narrow costal angle or the very fat individual presents difficulties with this operative approach, and an alternative method may be more suitable. Postoperative endotracheal extubation should not be permitted until full recovery of ventilatory function is assured, and this must be very carefully monitored in the group of elderly patients. The generator unit is conveniently implanted subcutaneously in the left upper quadrant. There is remarkably little pain associated with this approach and it is well tolerated by the aged.

The left parasternal approach may sometimes be accomplished under intercostal nerve block and local infiltration anesthesia, but one should be prepared to supplement this with general anesthesia when necessary. After resection of the fifth and sixth costal cartilages and division of intercostal bundles, the pleura is retracted laterally, the pericardium incised, and one or two electrodes implanted on the anterior midright ventricle. One surgeon has managed to accomplish this after the resection of only one costal cartilage, but he utilizes a pacemaker catheter sutured into the right ventricular myocardium rather close to the septum.

For the sake of completeness, one should mention the sternotomy approach to the anterior right ventricle. This can be achieved through a complete midsternotomy or by a combined upper midline abdominal and lower midsternotomy incision. Poor healing in the very elderly and debilitated must be considered a drawback to this approach.

Permanent Transvenous Endocardial Pacing. We do not electively insert a temporary pacing catheter as a preliminary step for this procedure. However, perhaps 30 percent of our patients have had a temporary catheter in place at the time permanent implantation is undertaken. The temporary catheter should be removed under fluoroscopy before the conclusion of surgery since its withdrawal may dislodge the permanent catheter when withdrawn.

The electrocardiogram should be monitored throughout the procedure and the cardiac rate and rhythm influenced by isoproterenol, lidocaine, or atropine, as needed. All means must be available for possible resuscitation.

The external jugular, the cephalic, and the internal veins are the available routes. The cephalic vein provides the most desirable route on theoretical grounds, but in elderly females the vein is not infrequently atrophic. When this route is elected, the entire surgical procedure is carried out infraclavicular; the initial skin incision being extended medially and inferiorly from the deltopectoral groove for the purposes of developing the subcutaneous pocket. Reports of wire breakage, due to torsion of the leads, strengthen our opinion that a left-sided approach to the cephalic vein provides a better and more gentle curve for the lead. Most often we have used the right external jugular vein. If entry into the superior cava cannot be promptly gained, the transverse incision is extended medially to expose the internal jugular vein between the heads of the sternomastoid muscle. We do not ligate the internal jugular vein, but secure the lead at the point of penetration with several purse string sutures of nonabsorbable suture. After a short loop in the neck, the catheter is carried subcutaneously across the medial end of the clavicle, where there is minimal movement of the catheter with shoulder motion. We have preferred a unipolar catheter. The stylet should be gently curved at its end to facilitate passage of the lead into the right ventricle, but a straight stylet is used for the final positioning in the right ventricular apex. The tip of the catheter should be wedged under the trabeculae at the apex so that cardiac contraction causes a synchronous and slight buckling near the tip, but a gentle curve lies in the right atrium without angulation. The flange on the catheter tip serves admirably to minimize catheter displacement, and this is now an infrequent occurrence. The fibrous sheath developing later tends to minimize dislodgment. Attempted forceful withdrawal at a considerably later date could cause damage to the tricuspid valve where the catheter may be adherent. If there is any doubt about the position of the catheter in the apex of the right ventricle, a lateral X ray should always be obtained before the procedure is terminated. In the correct position the catheter tip lies immediately retrosternal. A position in the coronary sinus may stimulate a correct placement as seen in the anteroposterior view, but a lateral film usually, but not always, discloses the error. In the coronary sinus position, the electrocardiogram reveals current activation from the left ventricle and shows RBBB in Lead V_1 rather than LBBB. Rarely, according to Gulotta, an intracardial electrogram is required to distinguish between an epicardial position anteriorly in the coronary sinus system and the endocardial position at the right ventricular apex. We have not employed this modality. These difficulties, however, can all be obviated if one first sweeps the catheter tip through the right ventricle to identify its position in the RV chamber before seeking a final position at the apex.

Stable pacing at a low threshold should be sought; i.e., under 2 milliamps, and repeated repositioning may be required to achieve this. A postion in the coronary sinus system usually, but not always, gives a high threshold. The threshold is measured with an external pacemaker. By decreasing the current after initial capture, the point at which capture is lost determines the threshold. The threshold may be expected to increase several fold before final stabilization.

When a satisfactory position is clearly obtained, the vein should be securely ligated around the catheter with several nonabsorbable sutures of the plastic variety. The emerging loop of catheter is stabilized with a small plastic sleeve which is sutured to surrounding tissue to eliminate kinking. Additional sutures which may be required about the leads should be of absorbable material so that some play in the fibrous sheath which forms will ultimately be permitted. It is essential to close the platysma muscle in the neck to prevent the possibility of late erosion of the catheter through the overlying skin.

The pacer pocket is prepared in the infraclavicular region. We have not favored the axillary position where shoulder motion has been reported to cause wire fracture. In very emaciated patients, we have extended the leads subcutaneously to the upper abdomen where more abundant covering is usually found.

If the original implantation has been made properly, subsequent generator changes are simple. However, before the unit is lifted completely free of the pocket, the entrapped lead posteriorly should be freed from its sheath so that withdrawal of the unit does not lead to dislodgment of the lead farther distally, indeed, even from the endocardium.

The implantation of pacemakers which stimulate the atrium or synchronize from the atrium necessitates some alteration in the techniques described above. The indications for this generation of pacemakers are primarily the hemodynamic advantages of the atrial pump and the avoidance of parasystoles. It is the most physiological responsive mode of pacing, and there may be a gradual return to this mode by physicians as reliability of these pacers increases. Theoretically, this mode increases the exercise capability of the healthy individual and provides an advantage for the patient in heart failure. However, the older patient not in heart failure should be provided with a ventricular pacemaker. The atrial pacer is clearly not indicated for the patient with coronary artery disease where a controlled slow rate is to be preferred. When atrial arrhythmias are present or develop subsequently, an atrial synchronous pacer may well increase the difficulties of management.

The most reliable method of atrial pacing is obtained by suturing an epicardial lead directly onto the atrium; to the left atrium, via a left anterolateral thoracotomy, or to the right atrium via a midsternotomy, or if only an atrial lead is to be applied, the right anterolateral approach. The electrode is placed near the base of the atrial appendage. Bruck has described an approach to the right ventricle and right atrium through the subxiphoid route, but this would seem to be both difficult and unreliable.

Currently, the most popular route is transvenous, usually the external jugular, for the atrial lead, with the ventricular lead being inserted through the cephalic vein. The straight catheter has proved unreliable; only the J-shaped catheter against the right lateral wall or in the atrial appendage has yielded an acceptable and reasonably stabile atrial pickup. The position is not so critical for atrial stimulation as for atrial pickup. Dodinot has urged that if a P-wave potential throughout the entire atrium of 1.5 mv is not obtained, the procedure should be abandoned. A position in the appendage is to be preferred since potentials of up to 3.0 mv may be obtained in this position. A pacer sensitive to an input signal of .5 mv is used. Carlens and Lagergren have described the insertion of the atrial electrode via mediastinoscopy. The scope is inserted behind the right pulmonary artery slightly to the left of the midline and the lead deposited in a small area behind the left atrium. This approach has been used infrequently or not at all in this country. For the patient with sinoatrial arrest, an atrial pickup electrode used in con-

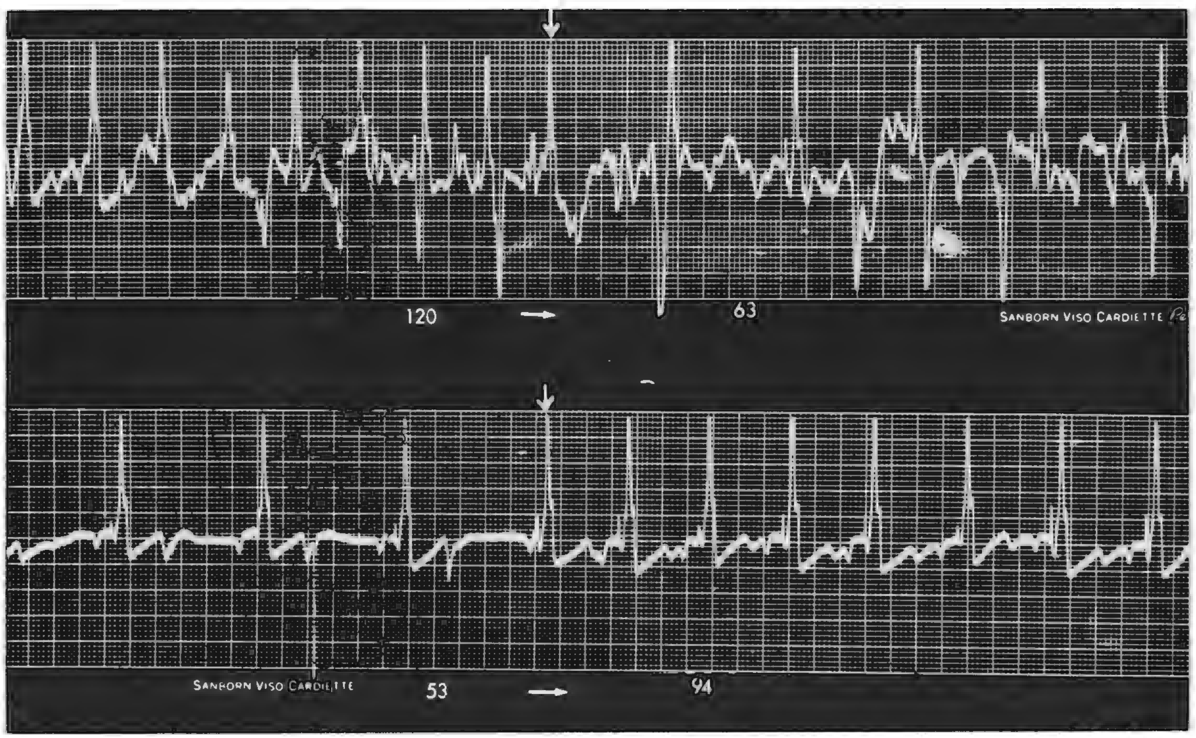

Fig 2—A tracing obtained by telemetry which reveals one of the problems with P-wave pacing.

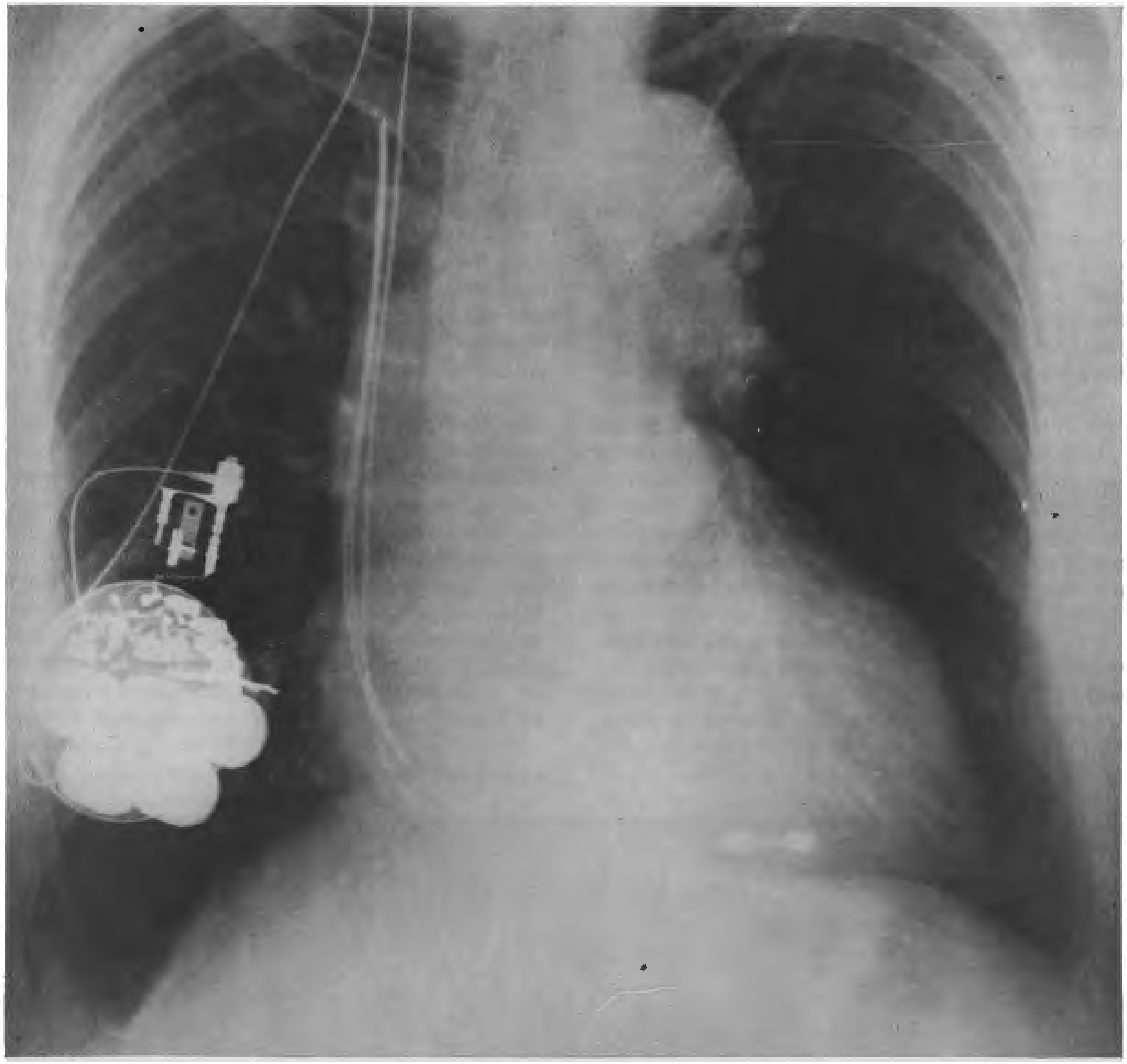

Fig 3—The phrenic nerve at the superior thoracic inlet being stimulated retrograde up the original broken lead.

junction with a sensitive demand pacer is most suitable.

I have had no personal experience with atrial catheter placement except in a few instances of temporary atrial pacing. However, Dr. Nick Smyth of Washington, D.C., kindly supplied me with his own personal statistics relative to his success with a special J-shaped catheter in which placement has been made in the atrial appendage. Of 20 attempts, there were 5 failures either because of low P-wave voltage or high threshold for stimulation. Two of 15 initially successful cases were not stabile and subsequently converted to ventricular pacing. The other 13 have remained stabile.

Figure 2 is a tracing which was obtained by telemetry and it shows one of the problems with P-wave pacing. The patient was exercised until the rate rose to 120, at which moment the blocking mechanism of the P-wave pacer intervened and rather abruptly the rate of the patient dropped from 120 to 50–60. As the patient rested, her intrinsic rate began to fall and the blocking mechanism was cancelled, and her rate suddenly accelerated from 53 up into the 90's. These sudden changes in heart rate are not desirable and represent a drawback of synchronous pacing.

I wish now to present illustrations of pacemaker problems:

A child of eight with congenital heart block had been resuscitated several times by her father. A P-wave synchronous pacer was implanted with epicardial leads which crossed the costal arch. Flexion creasing was soon noted at the costal arch in this very active

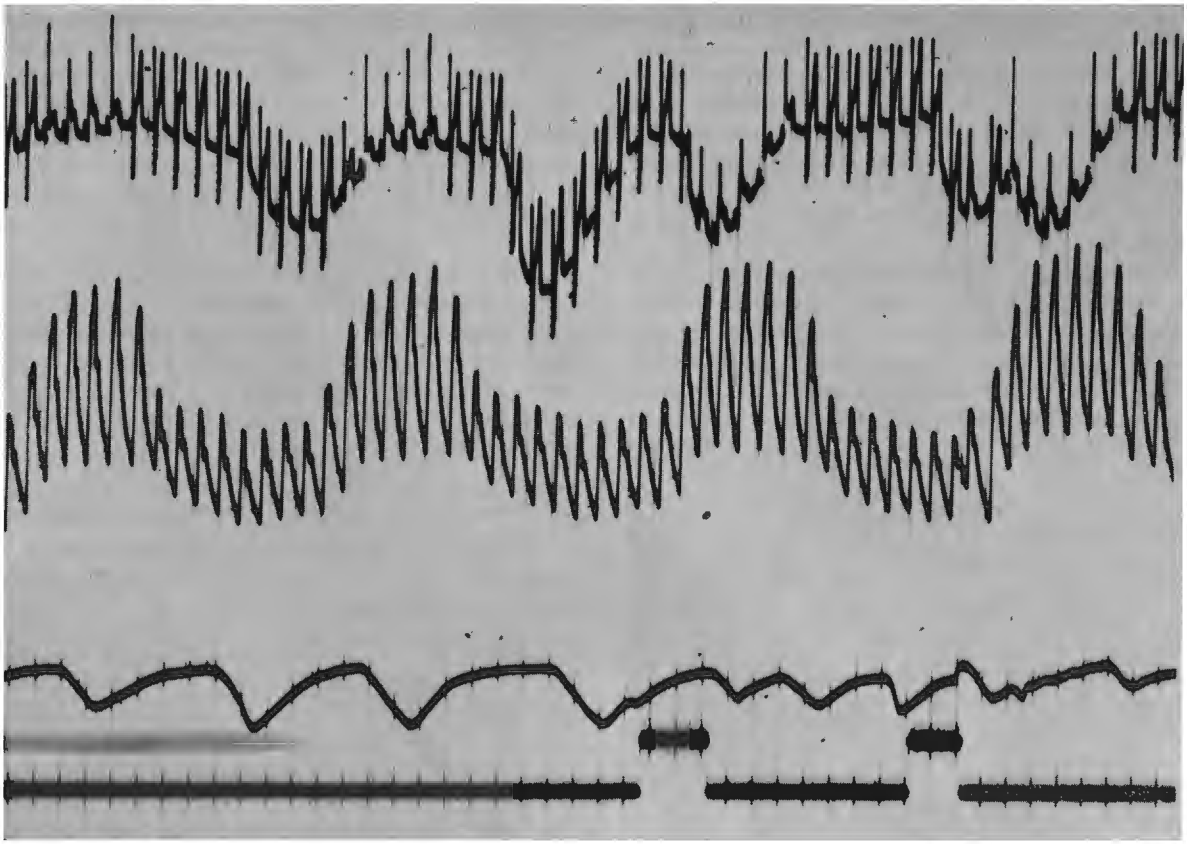

Fig 4—A direct measurement of arterial pressures before the pacer cut in.

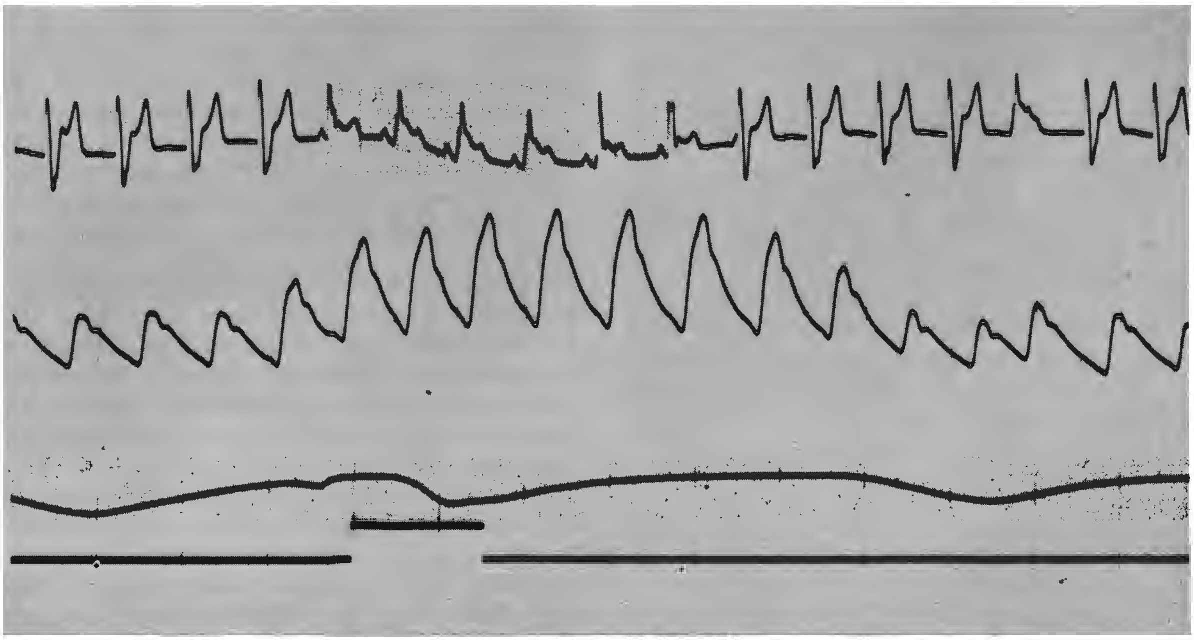

Fig 5—At the moment the pacer cut in, blood pressure decreased abruptly 30-40mm of mercury.

child, and subsequently breakage caused malfunction four months after implantation. Repair was accomplished by splicing the more durable Elgiloy wire to the broken lead, and, in addition, the leads were transposed below the costal arch and through the diaphragm. The P-wave pacer functioned well for another year until it caused a very rapid rate and the child died at school, an example of the so-called runaway pacemaker.

The next case illustrates a suboptimal position of the catheter in the right ventricle. In the lateral roentgenogram the catheter does not reach to the sternum, but pacing continued satisfactorily for three or more years. This position should not usually be accepted. Occasionally the left diaphragm may be stimulated by a catheter which penetrates partially or completely through the right ventricular myocardium. We have also observed stimulation of the right diaphragm by a unique mechanism. In this case, a platinum iridium lead over the right clavicle fractured one to two years after its placement. A new catheter was inserted into the right ventricle and the broken lead was cut off and allowed to retract. From this time on, the patient noted intermittent twitching in the right side of the abdomen and contraction of the right diaphragm was confirmed by fluoroscopy. The tip of the second catheter was seen to lie very close to the tip of the first catheter. We surmised, and I believe correctly, that the phrenic nerve at the superior thoracic inlet was being stimulated retrograde up the original broken lead (Fig. 3). When the generator unit is subsequently changed, we can probably use a low output unit which will suffice for pacing the heart without major leak of current to the other lead.

Another case illustrates the problem of myocardial perforation. Two months after the implantation the catheter appeared to be in good position and was functioning well. Soon thereafter direct diaphragmatic or left phrenic nerve stimulation was noted. One month later a change in catheter position was noted and pacing was now intermittent. One year later stabile stimulation of the heart was occurring, but the catheter had again changed position and the oblique roentgenogram revealed that the tip of the catheter was quite far posteriorly, presumably in the pericardium. When pacing ceased soon thereafter, we exposed the generator unit and measured a stimulating threshold of about 12 milliamps. A high output generator was implanted and satisfactory pacing was reestablished.

A Ph.D. engineer sustained a myocardial infarct. A temporary catheter was considered necessary at this time. Six months following discharge from the hospital he developed mild Stokes-Adams attacks due to intermittent heart block. A QRS-triggered demand pacer was inserted. Subsequently, he developed episodes of lightheadedness, faintness, and weakness, and he could detect the moment at which his pacemaker took over functionally. He had fewer symptoms when he was exercising and the intrinsic heart rate exceeded the demand pacer rate of 70. A direct measurement of arterial pressures was made and it was noted that at the moment the pacer cut in, the blood pressure decreased abruptly 30–40mm of mercury (Figs. 4 and 5). When the conducted rhythm returned, the pressure rose to the preëxisting level. With the patient resting the pacer cycled in and out. An explanation for this mechanism may be sought in the paper by Levy and Edelstein.

The above illustrations represent only a few of the many complications of a surgical and electronic origin associated with the art and science of pacemaking. Many of the frustations of the past have been overcome, but each new advance also brings its problems.

Author's note: I was aided in the preparation of this paper by Dr. David H. Sewell who at the time was a Cardiac Surgical Fellow at the Medical College of Virginia.

PANEL DISCUSSION

Dr. Drew: Do you in any way recommend that an internist and general surgeon team up to implant the permanent transvenous type pacemaker, or do you feel that the internist should concentrate on learning the technique of the temporary pacing catheter and transfer the patient to the nearest medical center?

Dr. Bosher: We have different situations at the Medical College of Virginia. Unfortunately, we do not have a cardiologist in the X-ray department when we implant the permanent pacer; they are much too busy with their own duties. However, at hospitals where I have had a cardiologist work very closely with us, I found this to be a very favorable situation. All of the temporary catheters are now implanted by cardiologists in our hospital, and I think this is the way it should be because they see these patients as emergency patients. I think the surgeon can help with the permanent implantation, but I am quite aware of the fact that cardiologists sometimes do the permanent implantation.

Dr. Drew: Am I correct in saying that you think permanent pacing would be better reserved for the medical center?

Dr. Bosher: No. I think permanent pacing can be carried out in any good hospital where you have an interested team; that is, doctors who have familiarized themselves with these techniques.

Dr. Drew: I think this is an interesting point, because we do see people put into ambulances with an isoproterenol drip.

Dr. Bosher: This is very bad. Where the patient is in this type of extreme situation, I think it is better to have the surgeon go to the hospital rather than have the patient go to the surgeon.