Cryosurgical Ablation of the A-V Node-His Bundle

A New Method for Producing A-V Block

LURA HARRISON, PH.D., JOHN J. GALLAGHER, M.D., JACKIE KASELL,
ROBERT H. ANDERSON, M.D., EILEEN MIKAT, M.A., DONALD B. HACKEL, M.D.,
AND ANDREW G. WALLACE, M.D.

SUMMARY A cryosurgical instrument was used to ablate atrioventricular conduction. The procedure was carried out in 20 dogs and subsequently in three patients with drug resistant, life-threatening supraventricular tachycardias. In patients, the cryosurgical unit lowered the temperature of the His bundle area to 0°C, effecting complete but reversible heart block. Rewarming resulted in resumption of normal atrioventricular conduction. The His bundle region was cooled to −60°C; complete heart block was produced with two or more 90–120 second freezes. Postoperative evaluations revealed persistent atrioventricular conduction block. The lesion showed no tendency to rupture, form aneurysm, or interfere with valvular function. In the clinical cases, postoperative studies demonstrated a stable pacemaker arising proximal to the branching portion of the His bundle. A potential application of the cryosurgical technique might be ablation of sites of dysrhythmia (i.e., ectopic foci, re-entry circuits, accessory pathways).

SUPRAVENTRICULAR ARRHYTHMIAS arising at the atrial or junctional level can be disabling or life-threatening if associated with a rapid ventricular response. Usually, these dysrythmias can be managed successfully by pharmacological or pacemaker techniques. In refractory cases, surgical creation of complete atrioventricular (A-V) block offers another approach to the treatment of such intractable supraventricular arrhythmias. Previous attempts to ablate atrioventricular conduction in clinical and experimental situations have included ligation of tissue near the A-V node, electrocautery of the A-V node-His bundle, injection of formalin into the tissue surrounding the His bundle, surgical transection of the His bundle, mechanical crushing, and septal infarction. These interventions have been associated with variable success in achieving permanent ablation of conduction. In some cases tricuspid insufficiency, ventriculo-septal defects, and injury to the aortic sinuses have resulted.

The purpose of this communication is to describe results of animal and clinical experience with the cryosurgical instrument we have devised to effect reversible or permanent A-V block with appearance of stable subsidiary rhythms.

Methods

The Cryosurgical Probe

The cryosurgical instrument (fig. 1) employed in these experiments utilized expanding nitrous oxide as the coolant. Cooling by expanding gas or vapor is achieved by utilizing the Joule-Thomson effect whereby temperature falls when the pressure of a gas is allowed to drop without doing work. The nitrous oxide was stored in pressurized "E" cylinders coupled to a control console which allowed passage of the gas to the inside of a hand-held probe (fig. 2); expansion of the gas within the probe tip (5 mm diameter) resulted in cooling. The probe tip temperature was monitored on the control console via a thermocouple in the tip and temperature could be varied from room temperature to −60°C (+ 5°C) by controlling the back pressure on the escaping gas. The instrument was designed so that controlled cooling to 0°C could be delivered to an area, resulting in cessation of physiologic function with return of normal function on rewarming. In this manner, the result of cooling an area of tissue suspected of containing conduction tissue could be examined in a reversible manner before applying an irreversible freeze. Once the area to be frozen was located, the instrument had the capacity to produce an ice ball of 15 mm diameter at a temperature of −60°C.

A. Animal Studies

Twenty mongrel dogs weighing 20–25 kg were anesthetized with intravenous sodium pentobarbital (30 mg/kg). Each dog was ventilated with room air via an endotracheal tube attached to a Harvard pump respirator. A control electrocardiogram was obtained. The chest was then opened via a right thoracotomy and preparations for inflow occlusions were made. The azygous vein was ligated and the pericardial sac opened to expose the right atrium. To initiate the period of inflow occlusion, the superior and inferior venae cavae were occluded and the right atrium was opened. The period of inflow occlusion never exceeded three minutes, making intracavitary mapping of the His bundle as well as "trial" cooling at 0°C impractical due to time constraints. In these animal studies, the cryosurgical probe was placed in the floor of the right atrium just above the tricuspid valve in a line connecting the coronary sinus orifice with the atrial portion of the membranous septum. The area was then cooled to −55° to −60°C for 90 to 120 seconds and the probe rewarmed. Freezing time was determined from previous work by others and experimental work done in our laboratory in which myocardium was subjected to sub-freezing temperatures for 30–120 seconds for one or two consecutive periods. Flow was re-established by releasing the venae cavae and closing the right atrial incision acutely.
by a Satinsky clamp. If A-V block was not present, a second occlusion-freezing procedure was undertaken 15 minutes later. When block was achieved, the atrium was suture-closed and a Medtronic demand pacemaker set at 70/min was implanted. The stimulating electrodes were sewn to the epicardial surface of the right ventricle, and the pulse generator placed in a subcutaneous pouch on the animal’s back. The chest was closed with a temporary chest tube in place, and the animal allowed to recover.

Animals were studied and sacrificed at 1, 4, 8 or 12 weeks after surgery. On the day of sacrifice, the animal was anesthetized with sodium pentobarbital (30 mg/kg), intubated and respired or sedated with morphine (20–40 mg) and diazepam (10 mg). An electrocardiogram was recorded after disconnecting the pacemaker: the QRS duration and rate of the escape rhythm were noted in the control state. The response of this escape rhythm to overdrive ventricular pacing (two minutes’ duration) at cycle lengths 1000, 750, 600 and 500 msec was observed. Subsequently, the response to the infusion of incremental doses of isoproterenol was recorded at infusion levels of 0.5, 1.0, 2.0 and 4.0 μg/min. After all isoproterenol effect had dissipated, atropine sulfate was administered in a dose of 0.5 mg i.v., followed at two minutes by another dose of 0.5 mg and again two minutes later by a 1.0 mg dose.

The animal was sacrificed and the contents of the thorax were examined grossly. The hearts were fixed in 10% buffered formalin for 18 to 24 hours. The junctional area, containing the cryosurgical lesion, was identified and excised by making four cuts across the atrioventricular ring and through the interatrial and interventricular septa using the coronary sinus, central fibrous body, membranous septum, and crista supraventricularis as markers. This block containing the A-V node, His bundle, portions of the right and left branches and the lesion was cut into six smaller tissue blocks, each cut being made perpendicular to the A-V ring. The tissue blocks were then embedded in paraffin and sections cut at 6μ.

In the first two animals studied, these blocks were completely serially sectioned in a posterior to anterior direction. All sections were mounted in sequence on 35 mm mylar film. Every 20th and 21st sections were placed on a glass slide and stained with Masson trichrome and hematoxylin and eosin stains. All tissue sections mounted on mylar film were stained with Masson trichrome stain. These serial sections were examined on an Eastman still picture viewer Type AR-10(2).

In all animals studied subsequently, five step sections were taken through each of the six tissue blocks and at each level, separate adjacent sections were stained with hematoxylin and eosin or Masson trichrome. The stained sections were then examined microscopically.

B. Clinical Studies

Three patients presenting with intractable supraventricular arrhythmias underwent cryosurgical ablation of the His bundle. Electrophysiologic studies including recording of the His bundle and pacing and refractory periods were performed preoperatively following informed consent concerning the nature of the study and proposed surgery.

The specialized conduction system was mapped intraoperatively in all three patients during cardiopulmonary bypass. The His bundle was first mapped with a hand-held bipolar electrode probe with the electrodes situated 2 mm apart. This signal was connected by field effect amplifiers (input impedance 1011 ohm) to high gain amplifiers and recordings were made with filter settings of 5Hz — 1.2 kHz. The cryosurgical probe was then placed over the area where the His bundle was recorded and cooling initiated at the probe tip to 0°C. Complete heart block resulted in all cases which readily reversed with rewarming. This area was then irreversibly ablated by cooling to −60°C for 90 seconds. After rewarming, an identical freeze was carried out in the same area for an additional 90 seconds.

A permanent, rate-adjustable, bipolar pacemaker (Medtronic Model 5954) was then implanted connected to screw-in epicardial electrodes. This pacemaker could be programmed to 30/min, allowing postoperative study of underlying escape rhythms.

Results

A. Animal Studies

Electrophysiologic Studies

In all animals, permanent heart block with a stable subsidiary rhythm was achieved. Table 1 demonstrates the
results of studies performed in 11 animals after one month of convalescence. Prior to induction of A-V block, all had QRS complexes ranging from 40-55 msec in duration (av = 47 msec). Following induction of A-V block, the QRS of the escape rhythms ranged from 50-130 msec in duration (av = 89 msec). In all there was complete A-V block, with escape rhythms ranging in cycle lengths from 770-2640 msec (av = 1557 msec). One animal (7554) had persistent atrial flutter. The two animals having the fastest escape rhythms (7613, 7554) also had the shortest QRS complex duration, suggesting that their level of A-V block was relatively high. Overdrive suppression of the escape rhythm occurred in all cases and was greater with shorter cycle lengths of pacing. Again, less suppression was noted in animals exhibiting escape rhythms with narrower QRS complexes. Administration of isoproterenol resulted in acceleration of the subsidiary rhythm in every case. Atropine also was administered to these animals but the result of these interventions could not be interpreted in the first seven animals because of pentobarbital anesthesia. Subsequent studies, done in four animals, performed with morphine sedation, demonstrated minimal response to atropine.

**Histologic Studies**

On gross examination all specimens had a right atrial sutured-lesion. In two of the animals sacrificed one week after operation, the epicardial surface of the right atrium and ventricle was slightly to moderately hemorrhagic. In the remaining animals examined two and one-half weeks to three months postoperatively, the epicardial surface of the right side of the heart exhibited a moderate amount of adherent fibrous tissue.

The endocardial changes seen grossly involved only the area of the lesion. After one week the endocardial lesion was a circular hemorrhagic focus with a pale grey border. In one of these animals a recent thrombus was adherent to the hemorrhagic focus. After one month the endocardial surface of the lesion was a grey fibrous scar. In some hearts small mural thrombi were present over the area of probe placement. In two hearts there were thrombi originating in the area of the coronary sinus and extending one to two centimeters into the atrial chamber at the level of the tricuspid valve orifice.

Microscopically, at one week the lesion showed necrosis of myocardial cells and conduction fibers, a polymorphonuclear leukocytic infiltrate and marked hemorrhage in the periphery of the lesion. No changes in the blood vessel walls were seen at this time. At two and one-half weeks the lesion in one dog was composed of fibroblasts, capillaries and a moderate amount of fibrosis. In this animal there were edematous and proliferative changes in the intima of the atrioventricular nodal artery. At one month the entire region of the lesion had been replaced by dense fibrotic connective tissue (fig. 3, panel B). The lesion generally involved the His bundle and proximal bundle branches, but frequently spared the left bundle branch entirely. The septal leaflet of the tricuspid valve was moderately to severely edematous in all hearts. At two and three

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**Table 1. Electrocardiographic Data from Dog Studies**

<table>
<thead>
<tr>
<th>Dog</th>
<th>N</th>
<th>QRS duration (msec)</th>
<th>QRS area (mm²)</th>
<th>QRS anterior/posterior</th>
<th>QRS left/right</th>
<th>QRS septal/ventricular</th>
<th>QRS endocardial</th>
<th>QRS epicardial</th>
<th>QRS atrial</th>
<th>QRS ventricular</th>
<th>QRS atrioventricular</th>
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<tbody>
<tr>
<td>A</td>
<td>30</td>
<td>150 250 350 500 750</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>B</td>
<td>40</td>
<td>150 250 350 500 750</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>50</td>
<td>150 250 350 500 750</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
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<tr>
<td>E</td>
<td>70</td>
<td>150 250 350 500 750</td>
<td></td>
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<td></td>
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<td>F</td>
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</tbody>
</table>

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Notes: 1. Values represent right atrial endocardial and epicardial.
2. Absence of atrial conduction is noted when atrial systole is absent.
3. A-V, atrioventricular; B, bundle; B, bundle branch; C, coronary; C, conduction; D, dog; E, endocardial; E, epicardial; F, fibrous; I, isoproterenol; L, lesion; N, necrosis; O, open; P, posterior; Q, QRS; R, right; S, septal; T, time; V, ventricular; V, ventricular cycle length; W, weeks.
months the dense fibrotic scar was like that observed at one month. These older lesions contained moderate chondroid metaplasia. No aortic changes were seen in any hearts. Table 2 presents a summary of the cardiac histopathology in animals sacrificed immediately to three months after surgery.

Two dogs that were not subjected to the cryosurgical treatment served as controls. One animal underwent a right thoracotomy. The right atrium was opened and the cryosurgical probe (set at room temperature) was held on the His bundle area for 120 seconds. The animal was sacrificed one month postoperatively. The other dog did not undergo surgical procedure or electrophysiological study. Their A-V conducting systems, prepared and examined in a similar fashion to those of the experimental dogs, showed no lesions (fig. 3, panel A).

Table 2. Summary of Canine Conduction System Histopathology in Cryoablation Study

<table>
<thead>
<tr>
<th>Dog #</th>
<th>Time post surgery</th>
<th>Location in conduction system</th>
<th>Pre-AVN</th>
<th>AVN</th>
<th>Penetrating HB</th>
<th>Branching HB &amp; proximal LB</th>
<th>Degenerative changes</th>
<th>NE</th>
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<tbody>
<tr>
<td>123</td>
<td>1 week</td>
<td></td>
<td>NE</td>
<td></td>
<td>Granulation tissue</td>
<td>Granulation tissue</td>
<td>Degenerative changes</td>
<td>NE</td>
</tr>
<tr>
<td>6942</td>
<td>1 week</td>
<td>Granulation tissue</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>6993</td>
<td>1 week</td>
<td>Necrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>6990</td>
<td>1 week</td>
<td>Necrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>2616</td>
<td>2 weeks</td>
<td>Hemorrhage and necrosis, early granulation tissue and fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>6555</td>
<td>23/4 weeks</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>12432</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
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<tr>
<td>7601</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
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<tr>
<td>7610</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
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<tr>
<td>7613</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
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<tr>
<td>7680</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
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<td>NPD</td>
<td>NE</td>
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<tr>
<td>7554</td>
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<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
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<td>NPD</td>
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<tr>
<td>7697</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
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<td>NPD</td>
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<tr>
<td>2906</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
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<tr>
<td>2619</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
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<td>NE</td>
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<tr>
<td>12432</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
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<tr>
<td>7042</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
<td>NE</td>
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<tr>
<td>7895</td>
<td>1 month</td>
<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
<td>NPD</td>
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<tr>
<td>6810</td>
<td>2 months</td>
<td>Fibrosis</td>
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<td>Fibrosis</td>
<td>NPD</td>
<td>NPD</td>
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<td>NPD</td>
<td>NE</td>
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</table>

Abbreviations: HB = His bundle; LB = left branch; NPD = no pathological diagnosis; RB = right branch; NE = not examined.
B. Clinical Studies

Case Report 1

A 26-year-old female with recurrent SVT was referred to this medical center in November 1975. She had been well until 18 years of age. During a routine appendectomy, she suddenly went into atrial fibrillation with a rate over 200/min. Since that time, she had experienced recurrent SVT uncontrolled by treatment with digoxin (0.75 mg/day), propranolol (up to 1200 mg daily), quinidine sulfate (400 mg every 4 hours), procainamide (500 mg every 3 hours), and diphenylhydantoin (400 mg daily). Because of recurrent arrhythmia and a questionable heart murmur, she underwent cardiac catheterization including coronary arteriography in 1968 which was entirely normal. During the four years prior to admission she experienced 1-2 episodes of syncope per week associated with heart rates over 200/min. SVT was accompanied by dyspnea, aching and numbness in the left arm, and light-headedness. In March 1975 she underwent a jejunooileal bypass for obesity, resulting in a 100 pound weight loss. Although the latter may have resulted in malabsorption of drugs, the frequency of arrhythmia was not substantially altered by surgery. Holter monitors recorded prior to admission demonstrated numerous episodes of SVT with ventricular responses ranging from 100-200/min. On admission for electrophysiologic evaluation, her cardiac exam was unremarkable. The chest X-ray was within normal limits. A resting electrocardiogram off medication demonstrated a P-R interval of 0.16 with normal morphology of the P, QRS, and T complexes. Electrophysiologic study failed to demonstrate evidence of preexcitation. The P-R interval (0.17 sec) was comprised of a P-A interval of 55 msec (normal 24-45), an A-H interval of 65 msec (normal 160-120), and an H-V interval of 50 msec (normal 30-55). During right atrial pacing, a Wenckebach phenomenon proximal to the His deflection occurred at a cycle length of 500 msec. Pacing of the right atrium or coronary sinus at cycle lengths less than or equal to 400 msec resulted in a re-entrant atrial rhythm with a variable cycle length of 325-410 msec arising in the low right atrium (fig. 4). This was generally associated with A-V Wenckebach and periods of 2:1 A-V block, but sustained periods of 1:1 A-V conduction at cycle length 410 msec were observed. She was taken to surgery on 12/5/75 and following median sternotomy, an attempt was made to induce SVT by programmed stimulation in the hope that an intervention directed at the site of atrial re-entry might be undertaken. A sustained episode of SVT could not be elicited. She was therefore placed on cardiopulmonary bypass under normothermic conditions. The right atrium was opened and the His bundle localized by mapping. The cryo-probe was applied to this area and the area was cooled to 0°C for 30 seconds with prompt production of complete A-V block. Within 30 seconds after rewarming, she returned to normal conduction. The probe was then set to −60°C and two 90 second coolings were carried out. A third freeze was carried out slightly proximal to the first lesion and nearer the coronary sinus orifice. A rate adjustable pacemaker (Medtronic Xytron Model 5954) was connected to two Medtronic screw-in wires in the left ventricle and set at 70/min. She tolerated the procedure well and initially demonstrated a junctional rhythm at a rate of 82/min. On December 16, 1975, her programmable pacemaker was tested at a rate of 30/min and she demonstrated a regular escape rhythm at 40-50/min with a normal QRS complex, despite the presence of atrial tachycardia at a rate of 150/min (fig. 5).

![Figure 4](http://circ.ahajournals.org/)

**FIGURE 4.** Top) Preoperative electrocardiogram of patient I during supraventricular tachycardia. Standard ECG leads I-III are shown. Bottom) Intracavitary tracings during supraventricular tachycardia. Recordings are standard ECG lead V1, and bipolar electrograms from the right ventricular apex (RV), the right atrium (RA), the His bundle electrogram (HBE), and the coronary sinus (CS). A = atrial electrogram, H = His deflection, V = ventricular electrogram. Atrial tachycardia is present with variable A-V conduction. The nonconducted atrial impulses block proximal to the His bundle.

![Figure 5](http://circ.ahajournals.org/)

**FIGURE 5.** Postoperative electrogram demonstrating persistent atrial tachycardia with complete heart block. A junctional rhythm with a normal QRS with a 1400 msec cycle length. The atrial cycle length was 360 msec. P indicates P wave. The abnormal T waves are due to resolving postoperative pericarditis.
She has continued to do well with her pacemaker set on demand at 70/min. Currently, she has no compromising cardiac dysrhythmias and takes no medications.

Case Report 2

Patient 2 was a 52-year-old male who first noted onset of tachyarrhythmia, associated with presyncope, at age 22 during exercise. Because of recurrent episodes of tachycardia and bradycardia he had been severely disabled since January 1975. A quinidine sulfate level of 11 mg% was ineffective in controlling dysrhythmia and was associated with gastrointestinal upset. A combination of quinidine and procainamide was likewise ineffective. Propranolol resulted in sinus rates of 30/min and yet allowed ventricular responses of 160/min during atrial fibrillation. It also caused depression and extreme lethargy. Musculoskeletal pains were associated with administration of procainamide. Digoxin alone or in combination with the above regimens was ineffective. Syncope occurred on two occasions. Analysis of all the clinical regimens tried suggested that optimal medical therapy would require large doses of multiple antiarrhythmic agents in combination with a permanent pacemaker and would be attended by unacceptable side effects. He was therefore admitted for elective ablation of his conduction system. On admission his cardiac exam and chest film were unremarkable. Resting electrocardiogram was normal with a P-R interval of 0.18 sec. An atrial tachyarrhythmia with features of atrial flutter and fibrillation was observed in the hospital with a variable ventricular response up to 160/min. Preoperative electrophysiologic study confirmed the absence of pre-excitation. The P-A interval was 45 mseg, the A-H interval was 90 mseg and the H-V interval was 45 mseg. Atrial fibrillation was again observed spontaneously (fig. 6) and could be induced readily with rapid atrial stimulation. During right atrial pacing, the Wenckebach phenomenon occurred proximal to the His bundle at a cycle length of 380 mseg. Figure 7 is a recording during right atrial pacing at cycle length 400 mseg demonstrating normal conduction with an H-V interval of 45 mseg. This was validated by His bundle pacing. A prolonged corrected sinus node recovery time of 965 mseg was noted with right atrial pacing at cycle length 600 mseg (normal 260 ± 95 mseg).24

On January 21, 1976, he was taken to the operating room. A median sternotomy was performed and cardiopulmonary bypass initiated. The His bundle was recorded by intracardiac mapping, confirming the H-V value of 45 mseg (fig. 8). Local cooling of this area to 0°C created reversible complete heart block. Two freezes to −60°C for 90 seconds each were carried over the His bundle and two additional freezes more proximal to the coronary sinus were performed. Screw-in ventricular epicardial electrodes were inserted in the left ventricle and connected to a Medtronic 5954 pacemaker. Bypass was terminated uneventfully.

On the ninth postoperative day, he was restudied electrophysiologically. After introduction of catheters to record and pace the atrium, His bundle, and right ventricle, the pacemaker was programmed to a rate of 30/min. An escape rhythm appeared with a cycle length of 1135 mseg, associated with a normal QRS. All complexes were preceded by a His deflection at an H-V interval of 35 mseg (fig. 9). Complete antegrade and retrograde block was present. Table 3 demonstrates the response to two minutes of overdrive ventricular pacing. The study suggested that the escape rhythm was depressed with paced rates faster than cycle length 875 mseg, and the permanent pacemaker was therefore programmed for this rate. Similar data were obtained during restudy six months postoperatively. He is currently working, feels well, and takes no drugs.

Case Report 3

A 42-year-old male was referred to Duke University Hospital for evaluation of persistent tachyarrhythmias and cardiomyopathy. He was well all of his adult life until December 1974 when he experienced his first episode of tachycardia. During the ensuing 14 months he had several episodes of tachycardia, some clearly of supraventricular origin, others of unknown origin, with rates up to 220/min. Resting electrocardiogram at that time showed a nonspecific intraventricular conduction defect of the left bundle branch block type with a P-R interval of 0.18 sec. Study revealed an A-H interval of 98 mseg and H-V interval of 53 mseg. Corrected sinus recovery time during right atrial pacing at cycle length 600 mseg was 1200 mseg. Cardiac catheterization revealed no coronary artery disease, slight left ventricular enlargement, generalized decreased contrac-

**Figure 6.** Preoperative electrocardiogram of patient 2 demonstrating atrial flutter-fibrillation with a variable ventricular response. Some conducted beats show left bundle branch block aberration.

**Figure 7.** Intracavitary recording during atrial pacing preoperatively. $S =$ stimulus. During atrial pacing (cycle length 400 mseg) 1:1 A-V conduction is present associated with an A-H of 112 mseg and H-V of 45 mseg and a normal QRS.
A-V of the 45 diomegaly and mild conduction disturbance cardiogram tility with an ejection fraction of .47. He was given quinidine which produced cinchonism. He then was given procanamide but subsequently developed agranulocytosis. Propranolol (240 mg/day) resulted in symptoms of congestive heart failure. On April 1, 1976, the patient had an episode of ventricular tachycardia and ventricular fibrillation requiring cardioversion. He was referred to Duke University Medical Center for repeat electrophysiologic studies.

On admission, physical exam and chest film revealed cardiomegaly and mild congestive failure. Resting electrocardiogram on digoxin therapy showed the intraventricular conduction disturbance with a P-R of 0.20 sec. Continuous monitoring showed numerous episodes of atrial fibrillation with rapid ventricular responses of 150-180/min, associated with marked hypotension.

On April 20, 1976, electrophysiologic study demonstrated a wide variety of abnormalities of impulse formation and conduction. The P-A interval was 55 msec, the A-H interval was 62 msec, and the H-V interval was 85 msec. A-V nodal conduction was well preserved, with the Wenckebach phenomenon appearing proximal to the His bundle at a cycle length of 300 msec. Termination of atrial pacing at a cycle length of 500 msec was followed by a 3.8 sec period of asystole. In addition, a re-entrant ventricular tachycardia comparable to two spontaneous events observed in hospital was induced. The ventricular cycle length in tachycardia was 300 msec and there was ventriculo-atrial dissociation. The onset of ventricular tachycardia was not directly related to rapid conduction of supraventricular impulses, but was thought to be engendered possibly by repeated hemodynamic collapses attending the latter.

Because of progressive deterioration in myocardial function in the face of intractable supraventricular arrhythmias, we elected to surgically interrupt A-V conduction. It was hoped that this might also ameliorate the problem of ventricular tachycardia.

The patient was taken to the operating room, anesthetized, subjected to a median sternotomy and placed on cardiopulmonary bypass. Intracardiac mapping was carried out to localize the His bundle. This region was cooled to 0°C for 30 seconds with production of complete heart block which readily reversed with rewarming. The A-V node was then cooled to -60°C for two 90 second periods. Complete heart block was produced. The patient tolerated the procedure well and demonstrated a junctional rhythm at 45 beats per minute. Two Medtronic screw-in electrodes were attached to the lateral wall of the left ventricle and connected to a Medtronic 5955 pacemaker set at 70/min.

On the ninth day after surgery, the patient was studied in the electrophysiology laboratory to determine the nature of his intrinsic pacemaker rhythm. The escape rhythm had a cycle length of 1500 msec, associated with a QRS configuration identical to that observed preoperatively during sinus rhythm. Atropine (2 mg) effected a rhythm with a 1154 msec cycle length. The underlying atrial rhythm during this entire observation was atrial flutter (cycle length 200 msec). In three months of follow-up he has remained free of arrhythmias and is well compensated on digoxin (0.25 mg) and furosemide (40 mg) daily.

Discussion

Hass et al.25-28 described a hypothermal method for producing quantitative injury to cardiac, neural and other tissues in 1948. Utilizing carbon dioxide, they demonstrated the ability of hypothermia to produce a homogeneous, sharply demarcated lesion. Of particular interest was the resumption of normal function by epicardial vessels within minutes after removal of the freezing instrument from the epicardium. They also noted their ability to produce transmural lesions in any cardiac chamber, without danger of rupture, aneurysmal dilatation or intracardiac thrombosis. The marked resistance of vascular elements to freezing has been observed by others.27-28 A particularly attractive feature of cryogenic lesions is the resistance of collagen and fibroblasts to hypothermal injury. This characteristic may be responsible for the absence of rupture or aneurysm formation in lesions after freezing.

The cryogenic method offers considerable advantage over previous methods. Experimental approaches have utilized injection of formalin into the A-V node area21,22 and attempts at incision,24 suture ligation,25 cautery,28,29 mech-

![Figure 8](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.85.3.389)

**Figure 8.** Intraoperative recordings are standard ECG lead I, and bipolar electrograms from the right ventricular apex and region of the His bundle. During atrial pacing (cycle length 500 msec) 1:1 A-V conduction is present associated with an A-H of 71 and an H-V of 45 msec.

**Figure 9.** Postoperative His bundle recording during right atrial pacing (cycle length 400 msec). Complete heart block is present. A junctional rhythm is present at a cycle length of 1100 msec, associated with normal H-V intervals of 45 msec and normal QRS complexes.

| Table 3. Effects of Ventricular Pacing on Escape Time (HH 03892) |
|-------------------|------------------|-------------------|
| CL (msec) | Rate (beats/min) | Time to first normal beat |
| 500 | 120 | 15 sec |
| 600 | 100 | 13 sec |
| 666 | 90 | 7 sec |
| 750 | 80 | 4 sec |
| 875 | 70 | 1285 msec |
| 1000 | 60 | 1185 msec |
anical crushing,14,15 and septal infarction14 of the A-V node-His bundle area. Previously reported clinical efforts have advocated cautery,3,45 suture ligation,3,4,6,7 and incision of the A-V node-His bundle area.5,8 The use of cautery has some obvious disadvantages in that heat denatures collagen, destroys fibroblasts and cannot be applied to effect a reproducible and reversible state of dysfunction. Methods using suture ligation have been associated with a high incidence of return to normal sinus rhythm in both experimental and clinical studies.6 Suture ligation, incision and cautery are all associated with risk of inducing tricuspid insufficiency, ventricular septal defects, and aneurysms and fistulae of the aortic sinus of Valsalva. The major advantage of the cryosurgical method of effecting A-V block is the reversible nature of the technique; it is possible to identify the appropriate area and observe the functional effect of conduction block prior to production of an irreversible state of A-V block.

It is of interest that in the three clinical cases, the escape rhythm suggested a block proximal to the branching portion of the His bundle. In the second case, the postoperative studies suggested the block might be intra-His. This patient’s response to atropine was similar to that reported in patients with intra-His block,23 namely little or no change in the escape cycle length. In contrast to the clinical studies, many of the animals demonstrated wider and slower escape rhythms. Histological examination of the animal conduction system frequently demonstrated extension of the lesion to the level of the branching fibers of the His bundle. It appears that the smaller system of the dogs’ septal structures relative to the size of the ice ball accounts for the more extensive changes noted.

We cannot exclude long-term progression of some process of cicatrization to the branching fibers of the His bundle by this method. For this reason, these patients will return at regular intervals for follow-up of the spontaneous escape rhythms with their pacemakers turned off.

Although this procedure is relatively simple, and in these three cases was easily applied to produce A-V block, a word of caution is essential: only patients who suffer life-threatening, debilitating arrhythmias resistant to medical therapy should be considered for cryoablation of their His bundles. Each patient must be subjected to a thorough electrophysiological study prior to surgery. While the three patients described here are currently well, and free from compromising cardiac dysrhythmias, long-term safety of cryoablation of the His bundle has not yet been established.

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