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Intermediate Septal Accessory Pathways: Electrocardiographic Characteristics, Electrophysiologic Observations and Their Surgical Implications

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Intermediate septal accessory pathways are located in close proximity to the atrioventricular (AV) node and His bundle, have unique features that distinguish them from typical anterior and posterior accessory pathways and have been associated with a high risk for unsuccessful pathway division and the production of complete AV block after surgery. Between July 1986 and May 1990, 4 of 70 patients (3 men and 1 woman; mean age 33 ± 13 years) undergoing surgery for accessory pathway division were found to have an intermediate septal accessory pathway. The presenting arrhythmia was atrial fibrillation with rapid anterograde conduction over the accessory pathway in two patients and recurrent orthodromic reciprocating tachycardia in two patients.

In all patients, the delta wave on the electrocardiogram (ECG) was inverted in lead V_1, but two patterns of delta wave configuration were observed. In three patients (type 1 intermediate septal accessory pathway), the delta wave was upright in lead II, inverted in lead III and isoelectric in lead aVF; the transition from a negative to an upright delta wave occurred in lead V_2. The fourth patient exhibited a different delta wave pattern (type 2 intermediate septal accessory pathway). The delta wave was upright in each of leads II, III and aVF; the transition from a negative to an upright delta wave occurred at lead V_3.

Intraoperative electrophysiologic study localized the atrial insertion of type 1 pathways to the midpoint of Koch's triangle close to the AV node. In the one patient with a type 1 pathway in which both anterograde and retrograde accessory pathway conduction was present, preoperative catheter mapping demonstrated that earliest retrograde atrial activation occurred near the foramen ovale. Intraoperative mapping during anterograde conduction over the type 1 pathway demonstrated earliest epicardial ventricular activation to occur simultaneously at the crux and the base of the aorta. The atrial insertion of the type 2 intermediate septal accessory pathway was localized to the apex of Koch's triangle in close proximity to the bundle of His. Preoperative catheter mapping revealed that earliest retrograde atrial activation occurred on the His bundle electrogram. Intraoperative mapping during anterograde conduction over the type 2 pathway demonstrated that earliest epicardial ventricular activation occurred anteriorly at the base of the aorta.

Intraoperative ablation of the intermediate septal accessory pathway was accomplished by cooling the endocardium at the site of pathway insertion on the atrial side of the tricuspid anulus with a 5 mm cryoprobe. Patients with a type 1 intermediate septal accessory pathway had preservation of AV conduction, but the patient with the type 2 pathway did not and required permanent pacing. At late follow-up study, no patient has had return of intermediate septal accessory pathway conduction. Distinguishing an intermediate septal accessory pathway close to the AV node (type 1) from one close to the His bundle (type 2) is useful to predict both surgical success and success without the production of permanent complete AV block.

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In 1986, Gallagher et al. (1) described a unique group of patients with the Wolff-Parkinson-White syndrome whose electrocardiogram (ECG) suggested an anterior septal accessory pathway whereas retrograde atrial activation during electrophysiologic study suggested a posterior septal accessory pathway location. Such an unusual connection was termed an intermediate septal accessory pathway. Its atrial insertion was localized to the ostium of the coronary sinus and earliest ventricular activation occurred simultaneously in the anterior and posterior septum (1). Thus, although the ECG suggested that the *ventricles* were activated anteriorly, preoperative and intraoperative mapping data indicated that the *atria* were activated posteriorly. At operation, there was a high risk for unsuccessful division of these pathways and production of complete atrioventricular (AV) block (1). Electrophysiologic mapping data from an intermediate septal accessory pathway contrast with those from an anteroseptal accessory pathway that inserts in the anteromedial right atrium and activates the ventricular septum anteriorly and from a posteroseptal pathway that inserts near the ostium of the coronary sinus and activates the right and left ventricles more posteriorly (2).

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The preoperative localization and surgical treatment of an intermediate septal accessory pathway have unique features and problems that distinguish them from those of a typical anterior or posterior septal pathway. In this report, four patients with such an unusual pathway are described. The electrophysiologic properties, patterns of activation and techniques for their localization are presented together with *modifications in intraoperative mapping and ablation* techniques that allow for precise localization and ablation and leave normal AV conduction intact.

Methods

Study patients. Between July 1986 and May 1990, 70 operations for accessory pathway division were performed at the University of Alabama at Birmingham. On preoperative and intraoperative electrophysiologic study, four of these patients (three men and one woman; mean age 33 ± 13 years [range 20 to 45]) were found to have an intermediate septal accessory pathway as defined by Gallagher et al. (1). All patients gave fully informed consent before invasive procedures were performed.

Arrhythmia symptoms were present for many years in all patients. The presenting arrhythmia was atrial fibrillation with rapid anterograde conduction over the accessory pathway in two patients and recurrent orthodromic reciprocating tachycardia in two patients. No patient had evidence of heart disease other than the arrhythmia and no patient had any concomitant procedure performed at operation.

Electrophysiologic study. Electrophysiologic studies were performed using standard catheterization techniques (3,4). From the right or left femoral vein, two 6F quadripolar electrode catheters (Electro-Catheter Corporation) were positioned at the His bundle and right ventricular apex, respectively. From the same approach, a bipolar or quadripolar 6F modified atrial mapping catheter was positioned in the right atrium for recording and pacing at multiple selected sites along the right AV anulus. Finally, from the right internal jugular vein, a hexapolar catheter was advanced into the coronary sinus for pacing and recording at multiple sites from the ostium to the left atrial appendage.

During sinus rhythm, the configuration of the delta wave was noted on the standard 12 lead ECG. During reciprocating tachycardia and ventricular pacing, the sequence and timing of retrograde (ventriculoatrial [VA]) conduction were recorded. During reciprocating tachycardia, premature ventricular beats were delivered when the His bundle was refractory to establish the presence of an accessory AV connection. During differential atrial pacing (pacing at multiple sites along the right and left AV anuli, at the foramen ovale and just below the foramen ovale), the stimulus to delta wave intervals were recorded.

Intraoperative electrophysiologic study and surgical approach. All operations were performed by median sternotomy, with the electrophysiologic study carried out during normothermia. First, temporary stainless steel wire electrodes were affixed to the right atrial appendage and right ventricle for pacing, recording of the reference electrogram and postoperative electrophysiologic study. Standard ECG leads I, II, III and aVR were also recorded.

The epicardial ventricular activation sequence was mapped during atrial pacing from the right atrial appendage in all patients. In patients with retrograde accessory pathway conduction, the epicardial atrial activation sequence was also mapped during orthodromic reciprocating tachycardia and ventricular pacing (two of four patients) with use of a tripolar handheld electrode probe (2 mm interelectrode distance, Electro-Catheter Corporation). After epicardial mapping was complete, right atriotomy was performed during normothermic cardiopulmonary bypass. The right atrial endocardium was then mapped with use of the handheld electrode probe during orthodromic reciprocating tachycardia. Atrial pacing in Koch's triangle along the tricuspid anulus from the posterior limit of the septal leaflet to the anterior septum was then performed with use of the roving probe as the stimulating electrode. At each pacing site, the interval from the pacing stimulus to the onset of ventricular activation (the stimulus to delta wave interval) was then measured.

The accessory pathway was identified as intermediate septal in location by atrial mapping during orthodromic reciprocating tachycardia or by the shortest stimulus to delta wave interval on the surface ECG during atrial pacing from the probe electrode. A 0.5 cm cryoprobe (Frigitronics, Inc.) was used to selectively cool this site, first reversibly to 0°C to assess the potential for permanent injury to the AV node and then to −60°C for 2 to 3 min at a time to irreversibly ablate the accessory pathway. The atriotomy was then closed and the patient weaned from cardiopulmonary bypass. Before the patient left the operating room, incremental atrial and ventricular pacing were performed to assure absence of conduction over an accessory pathway by demonstrating Wenckebach AV and VA conduction, respectively.

Postoperative electrophysiologic study. Postoperative electrophysiologic studies were undertaken 1 week after surgery with use of the previously placed temporary wire electrodes for atrial and ventricular stimulation and recording. When AV and VA conduction were present, atrial and ventricular premature extrastimuli were introduced after a drive train of eight beats and rapid pacing to AV and VA block was performed to demonstrate the absence of inducible arrhythmia and accessory pathway conduction.

Results

Baseline ECG. All patients had pre-excitation on the baseline 12 lead ECG (Fig. 1 and 2). In all patients, the delta wave was inverted in lead V_1, but two patterns of delta wave configuration were observed. In Patients 1 to 3, the delta wave was upright in lead II, inverted in lead III and isoelectric in lead aVF and the transition from a negative to

JACC Vol. 17, No. 7
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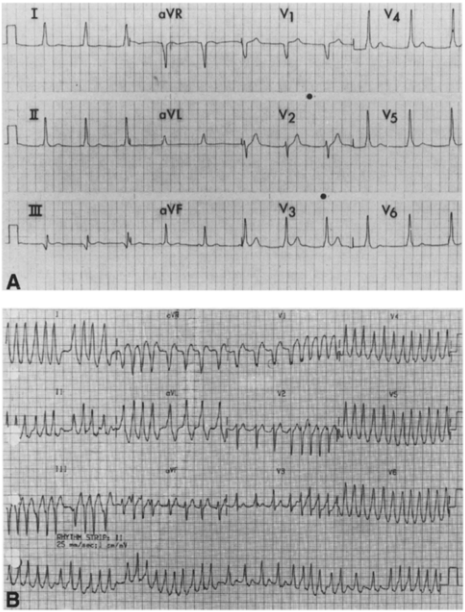


Figure 1. Patient 1. Electrocardiograms from a patient with a type 1 intermediate septal accessory pathway during sinus rhythm (A) and atrial fibrillation (B). The delta wave is negative in lead V_1 and the precordial transition occurs in lead V_2. The delta wave is positive in lead II, negative in lead III and isoelectric in lead aVF. See text for discussion.

an upright positive delta wave occurred in lead V_2. These patients were considered to have a type 1 intermediate septal accessory pathway (Fig. 1). Patient 4 was considered to have a type 2 intermediate septal accessory pathway (Fig. 2). In this patient, the delta wave was upright in leads II, III and aVF and the transition from a negative to an upright positive delta wave occurred in lead V_3.

Preoperative electrophysiologic studies (Tables 1 to 3). In Patients 1 and 2, who had atrial fibrillation and rapid anterograde conduction, the accessory pathway was capable of

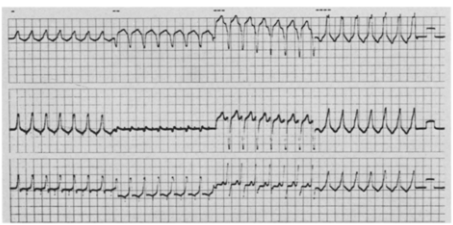


Figure 2. Patient 4. Electrocardiogram recorded during atrial pacing from a patient with a type 2 intermediate septal accessory pathway. The delta wave is negative in lead V_1 and precordial transition occurs at lead V_3. The delta wave is positive in leads II, III and aVF. See text for discussion.

Table 1. Preoperative Electrophysiologic Characteristics of the Intermediate Septal Accessory Pathway in Four Patients

	Patient 1 (AF)	Patient 2 (AF)	Patient 3 (ORT)	Patient 4 (ORT)
Anterograde effective refractory period (ms)	<270	<280	300	235
Retrograde effective refractory period (ms)	*	*	260	300
1:1 conduction (ms)	<275	<260	350	260
ORT cycle length (ms)	*	*	270	325
Shortest pre-excited RR interval in AF (ms)	160	170	320	265

*Accessory pathways conducted only in the anterograde direction. AF = atrial fibrillation; ORT = orthodromic reciprocating tachycardia.

conducting only in the anterograde direction (Table 1). In these patients, conduction over the accessory pathway was limited by refractoriness of the atrium. The shortest pre-excited RR interval during atrial fibrillation was 160 ms in Patient 1 and 170 ms in Patient 2. The intermediate septal accessory pathway was capable of both anterograde and retrograde conduction in Patients 3 and 4, both of whom had a long history of orthodromic reciprocating tachycardia.

The interval from the pacing stimulus to the onset of the delta wave on the surface ECG was measured at each of 19 selected sites around the tricuspid anulus and at 3 sites in the coronary sinus. Atrial pacing at 150 beats/min was performed at each site. In Patients 1 to 3, the shortest stimulus to delta wave interval was recorded during pacing at the coronary sinus ostium; in Patient 3, it was the same when pacing near the foramen ovale. In Patient 4, the shortest stimulus to delta wave interval also occurred when pacing near the foramen ovale. Pacing from the His bundle catheter was not performed. Pacing in the anteromedial right atrium resulted in a significantly longer interval in all patients (Table 2).

The sequence of retrograde atrial activation during orthodromic reciprocating tachycardia was mapped in the two patients with retrograde accessory pathway conduction (Table 3). In Patient 3, the region of the foramen ovale was activated before the coronary sinus ostium and the atrial deflection on the His bundle electrogram. In Patient 4, earliest atrial activation occurred on the His bundle electrogram, followed by the region of the foramen ovale and coronary sinus ostium.

Table 2. Anterograde Conduction Characteristics of the Intermediate Septal Accessory Pathway at Preoperative Electrophysiologic Study in Four Patients

	Stimulus to Delta Wave Interval (ms)			
Pacing Site	Patient 1	Patient 2	Patient 3	Patient 4
Coronary sinus ostium	75*	80*	110*	115
Foramen ovale	95	100	110*	92*
Anteromedial right atrium	115	110	125	125

*shortest stimulus to delta wave interval.

Table 3. Retrograde Conduction Characteristics of the Intermediate Septal Accessory Pathway at Preoperative Electrophysiologic Study of Four Patients

	Ventriculoatrial Intervals During Orthodromic Reciprocating Tachycardia (ms)			
Recording Site	Patient 1	Patient 2	Patient 3	Patient 4
Coronary sinus ostium	NA	NA	130	122
Foramen ovale	NA	NA	110*	122
His bundle electrogram	NA	NA	135	108*

*Earliest site of retrograde atrial activation. NA = not applicable because retrograde conduction was absent.

Operative findings (Fig. 3 to 5). Epicardial ventricular mapping in Patients 1 to 3 during pre-excitation demonstrated that earliest activation occurred simultaneously at the crux of the heart posteriorly and at the base of the aorta anteriorly. In contrast, in Patient 4, epicardial ventricular activation began anteriorly at the base of the aorta 35 ms before activation at the crux.

Figure 3 shows a surgeons's view of Koch's triangle, bounded by the septal leaflet of the tricuspid valve, the tendon of Todaro and the coronary sinus ostium. The foramen ovale, membranous interventricular septum and

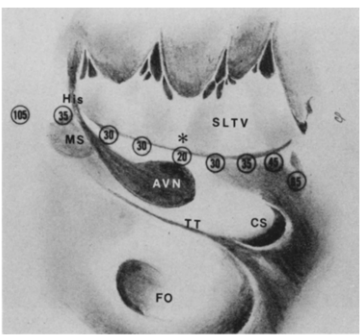


Figure 3. Patient 3, Surgeon's view of Koch's triangle. The patient's head is toward the **left** of the figure and the back is at the **bottom**. The stimulus to delta wave intervals (in milliseconds) during atrial pacing along the tricuspid valve anulus are shown. The shortest stimulus to delta wave interval (20 ms) **(asterisk)** occurred while pacing close to the AV node (AVN). This pattern of activation was remarkably consistent for Patients 1 to 3. CS = coronary sinus; FO = foramen ovale; His = His bundle; MS = membranous septum; SLTV = superior leaflet of tricuspid valve; TT = tendon of Todaro.

JACC Vol. 17, No. 7
June 1991:1570–8

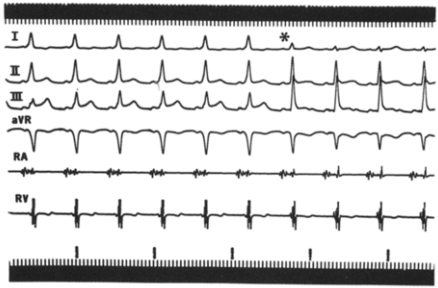
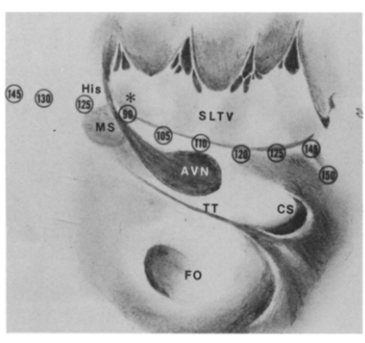


Figure 4. Patient 1. Intraoperative electrocardiogram. RA and RV identify the reference right atrial and right ventricular electrograms, respectively. The large time markers indicate seconds. The cryoprobe was applied to the site of the intermediate septal accessory pathway. When cooled to 0°C, the delta wave disappeared (asterisk). The PR interval increased from 100 to 150 ms, as measured in lead II. Even though these tracings were recorded from a patient with a type 1 intermediate septal accessory pathway, the delta wave polarity is upright rather than negative in lead III because in the operating room, ECG limb leads are placed on the patient's back and during mapping the heart is lifted and displaced in the chest, leading to variation of the electrical vector.

approximate location of the AV node and penetrating bundle of His are also illustrated as are the stimulus to delta wave intervals during atrial pacing along the tricuspid valve anulus for Patient 3. The shortest stimulus to delta wave interval (20 ms) occurred while pacing at a site close to the AV node. This pattern of activation was remarkably consistent for Patients 1 to 3. Figure 4 shows intraoperative recordings from Patient 1. While the heart was warm and beating, the site at which the shortest stimulus to delta wave was recorded was cooled to 0°C with a 5 mm cryoprobe, resulting in loss of the delta wave within seconds. This site was then frozen to a temperature of −60°C for 2 min. Cryolesions were also applied at adjacent sites.

Figure 5. Patient 4. Surgeon's view of Koch's triangle as in Figure 3, showing the sequence of retrograde atrial activation during orthodromic reciprocating tachycardia. The numbers represent ventricular to atrial activation times expressed in milliseconds. The asterisk indicates the site of earliest retrograde atrial activation (90 ms) and is adjacent to the His bundle. See text for discussion. Abbreviations as in Figure 3.



The sequence of retrograde atrial activation during orthodromic reciprocating tachycardia for Patient 4 is shown in Figure 5. During orthodromic reciprocating tachycardia, earliest retrograde atrial activation (90 ms) occurred at the apex of Koch's triangle directly over the region of the His bundle at the caudal extent of the membranous interventricular septum. Cooling to 0°C resulted in prompt loss of both pre-excitation and normal conduction. Because of the proximity of this pathway to the His bundle, an incision was made along the tricuspid anulus with the heart warm and beating, with sharp dissection of the posterior pyramidal space up to the central fibrous body; the delta wave persisted. A standard anteroseptal dissection also failed to ablate accessory pathway conduction, leaving an isthmus of 4 to 5 mm directly over the central fibrous body and membranous septum. Because it was clear that this pathway could not be divided without producing complete heart block, it was elected to complete the dissection and later implant a permanent dual chamber (DDD) pacemaker.

Postoperative electrophysiologic findings. The three patients with a type 1 intermediate septal accessory pathway, all without AV block, had no postoperative evidence of accessory pathway conduction and no inducible arrhythmia. Each of these patients has had complete ablation of the accessory pathway with intact AV conduction over a follow-up period of 12 to 21 months. The patient with the type 2 intermediate septal accessory pathway who developed complete AV block during the operation underwent implantation of a DDD pacemaker.

Discussion

Features of intermediate septal pathways. In 1986, Gallagher et al. (1) described the intermediate septal accessory pathway. The 12 lead ECG had a delta wave configuration

Table 4. Features of Intermediate Septal Accessory Pathways

	Type 1	Type 2
Localization (intraoperative)	Midpoint of Koch's triangle	Apex of Koch's triangle
Delta wave polarity (ECG lead)	II (positive) III (negative) aVF (isoelectric)	II (positive) III (positive) aVF (positive)
Retrograde atrial activation (preoperative)	Foramen ovale and coronary sinus (Ref. 1)	His bundle electrogram and foramen ovale
Epicardial ventricular activation (intraoperative)	Base of aorta and crux	Base of aorta

that suggested anterograde ventricular activation in the anterior septum but retrograde atrial activation in the posterior septum. The present study confirms and extends the initial observations of Gallagher et al. (1) by describing in greater detail the electrophysiologic characteristics of these connections and techniques that facilitate their identification, localization and intraoperative ablation.

Although there is likely to be a continuum of septal accessory pathway locations, the features of an intermediate septal accessory pathway can be divided into two functional types (Table 4). Type 1 pathways are located near the midpoint of Koch's triangle in close proximity to the AV node. The delta wave pattern is positive in ECG lead II, negative in lead III and isoelectric in lead aVF. These ECG features are similar to those described by Gallagher et al. (1). Preoperative mapping in the patient with intact retrograde accessory pathway conduction demonstrated earliest retrograde atrial activation near the foramen ovale. Although the foramen ovale is posterior to Koch's triangle and seemingly distant from the point of earliest atrial activation at intraoperative study (anterior to the AV node), the latter site was not mapped at preoperative study. The His bundle catheter usually records electrograms more proximally, near the apex of Koch's triangle. If a recording catheter had been positioned closer to the midpoint of Koch's triangle, earliest activation might have been recorded at this location. Intraoperative mapping during anterograde conduction by way of a type 1 intermediate septal accessory pathway demonstrates that earliest epicardial ventricular activation occurs simultaneously at the base of the aorta and the crux. A type 2 pathway is located at the apex of Koch's triangle in close proximity to the bundle of His. The delta wave polarity is upright in ECG leads II, III and aVF. Preoperative catheter mapping reveals that earliest retrograde atrial activation occurs on the His bundle electrogram. Intraoperative mapping during conduction by way of a type 2 pathway demonstrates earliest epicardial ventricular activation to occur anteriorly at the base of the aorta.

Anatomic considerations. During fetal cardiogenesis, there is physical and by implication electrical continuity between the primitive atrial and ventricular tissues. During gestation, the anulus fibrosus develops and separates the physical and electrical continuity of the atria and ventricles except in the location of the bundle of His (5,6). Accessory muscular connections and histologically distinct cholinesterase-positive specialized tissue may persist on the right side of the heart as a result of defects in the anulus fibrosus, leading to both subepicardial and subendocardial AV connections, respectively (7,8). On the left side of the heart around the mitral anulus, accessory connections are not associated with defects in the anulus fibrosus and are usually subepicardial in location (8). Finally, septal accessory AV connections may traverse the AV groove in the fat that fills the paraseptal spaces (2) or in the atrial septum (9,10). It is not possible to ascertain whether an intermediate septal accessory pathway is composed of atrial muscle or specialized conducting tissue.

In the description of the surgical approach to septal accessory pathways by Sealy and Gallagher (2), posterior septal accessory pathways were found between the right fibrous trigone and coronary sinus in 12 patients, in close proximity to the His bundle in 6 patients, at the crux in 5 patients, in the left atrium in 1 patient and at unknown sites in 7 patients. Only two of the six accessory connections coursing with the His bundle were successfully divided (2). Anterior septal accessory pathways were located adjacent to the right fibrous trigone in eight patients, between the atrial septum and right free wall in four patients and at unknown sites in two patients (2).

Because accessory pathways are found not only at multiple free wall locations along the mitral and tricuspid anuli, but also in the anterior and posterior septal spaces, the occurrence of accessory pathways in Koch's triangle should not be unexpected. This is the location of intermediate septal accessory pathways. In the four patients identified prospectively by Gallagher et al. (1) and in three of our four patients described here, mapping confirmed the pathway to be located anterior to the foramen ovale and tendon of Todaro, inferior but close to the AV node and cephalad to the orifice of the coronary sinus (type 1 pathway, Fig. 3). Although such a pathway is located within the posterior pyramidal space, its close proximity to the AV node distinguishes it from a posteroseptal accessory pathway. In our fourth patient, the intermediate septal accessory pathway was located at the apex of Koch's triangle in close proximity to the His bundle (type 2 pathway, Fig. 5). Although the mapping data suggest a very close association with the His bundle, definitive localization anterior or posterior to the central fibrous body is not possible. It is likely that pathways with similar functional characteristics may in fact be located either anterior or posterior to the His bundle. Finally, although our classification of intermediate septal accessory pathways is dichotomous, the anatomic location of such pathways is likely to be a continuum from the anterior to the posterior septum and their functional properties have important clinical implications for the likelihood of successful operation without the production of AV block.

Table 5. Differentiation of Type 1 Intermediate Septal From Posteroseptal Accessory Pathways

Characteristics of a Type 1 Intermediate Accessory Pathway
1. There is an abrupt transition of delta wave polarity from negative in lead V_1 to positive in lead V_2. The delta wave is positive in lead II, negative in lead III and isoelectric in lead aVF. In contrast, posteroseptal accessory pathways have negative delta waves in these three leads.
2. Earliest retrograde atrial activation occurs near the foramen ovale during retrograde conduction. In contrast, during retrograde conduction over a posteroseptal accessory pathway, earliest atrial activation occurs at the ostium of the coronary sinus.
3. Earliest ventricular activation occurs when pacing at the ostium of the coronary sinus. An identical stimulus to delta wave interval may be measured when pacing near the foramen ovale, but it is never shorter than that obtained when pacing at the ostium of the coronary sinus. In contrast, when a posteroseptal accessory pathway is present, the shortest stimulus to delta wave interval is always recorded when pacing at the ostium of the coronary sinus.
4. There is simultaneous epicardial activation of the ventricles during pre-excitation at the crux and the base of the aorta. In contrast, a posteroseptal accessory pathway activates the ventricles earliest at the crux.
5. It is located close to the atrioventricular node at the level of the limbus of the foramen ovale and probably inserts into the muscular interventricular septum. In contrast, a posteroseptal accessory pathway inserts into the more posterior portions of the right and left ventricles, including the posterosuperior process.

Table 6. Differentiation of Type 2 Intermediate Septal From Anteroseptal Accessory Pathways

Characteristics of a Type 2 Intermediate Accessory Pathway
1. The delta wave pattern is similar to that of a typical anteroseptal accessory pathway.
2. Earliest retrograde atrial activation occurs at the site of the His bundle recording during retrograde conduction. In contrast, during retrograde conduction over an anteroseptal accessory pathway, earliest retrograde atrial activation occurs at the anteromedial right atrium.
3. Earliest ventricular activation occurs when pacing near the foramen ovale. In contrast, when an anteroseptal accessory pathway is present, the shortest stimulus to delta wave interval is recorded when pacing at the anteromedial right atrium.
4. The ventricles are activated at the apex of Koch's triangle at the caudal extent of the membranous interventricular septum. In contrast, when there is an anteroseptal accessory pathway, the ventricles are activated more cephalad and anterior to the membranous septum.
5. The location is para-Hisian, close to the membranous interventricular septum. In contrast, a typical anteroseptal accessory pathway is more cephalad and distinct from the bundle of His.

ECG observations. In patients with anterograde conduction over an intermediate septal accessory pathway, detailed analysis of the standard 12 lead ECG can help to distinguish it from accessory pathways in other locations. In all patients, pre-excitation was present on the baseline ECG and the delta wave in lead V_1 had a negative polarity (Fig. 1 and 2). Although both posteroseptal and type 1 intermediate septal accessory pathways have abrupt transition of delta wave polarity from negative in lead V_1 to positive in lead V_2, the delta wave polarity in the inferior leads distinguishes these two accessory connections (Table 5). A type 1 intermediate septal accessory pathway has a positive delta wave in lead II, a negative delta wave in lead III and an isoelectric delta wave in lead aVF. In contrast, a posteroseptal accessory pathway has negative delta waves in these three leads. A type 2 intermediate septal accessory pathway also has negative delta waves in lead V_1, but the transition from negative to positive occurs between leads V_2 and V_3 and the delta wave polarity in leads II, III and aVF is positive. Because both anteroseptal and type 2 intermediate septal accessory pathways have positive delta waves in the inferior leads with biphasic or predominantly negative delta waves in leads V_1 and V_2 (Table 6), the 12 lead ECG alone may not distinguish a type 2 pathway from a typical anteroseptal accessory pathway. Finally, differentiation from accessory connections in the left and right free walls is less difficult because the former have strongly positive delta waves in the precordial leads and the latter have more gradual transitions from a negative to a positive delta wave polarity in the precordial leads (3).

The delta wave configuration on the standard 12 lead ECG that results from an intermediate septal accessory pathway can be explained by considering the direction in which the cardiac mass is depolarized. Typical anteroseptal and right free wall accessory pathways activate both the right and left ventricles in the anterior to posterior direction. Typical posteroseptal and left free wall accessory pathways activate both ventricles in the posterior to anterior direction. Intermediate septal accessory pathways activate the ventricles in a more complex manner. During type 1 intermediate septal accessory pathway conduction, the left ventricle is activated in the posterior to anterior direction as when a posteroseptal accessory pathway is present, and the right ventricle is activated in the reverse direction, beginning anteriorly at the base of the aorta as when an anteroseptal accessory pathway is present. During conduction over a type 2 intermediate septal accessory pathway, left ventricular activation occurs more anteriorly than during conduction over a type 1 pathway, but not as anteriorly as when a typical anteroseptal accessory pathway is present.

Intraoperative mapping during pre-excitation shows earliest epicardial breakthrough to occur simultaneously at the base of the aorta and at the crux during type 1 intermediate septal accessory pathway conduction and anteriorly at the base of the aorta during type 2 conduction. Parallel fibers of the crista supraventricularis may be responsible for carrying the wave front of activation to the anterior right ventricle at the base of the aorta in both instances. The ECG reflects these unusual sequences of ventricular activation by an abrupt transition from a negative to a positive delta wave polarity in leads V_2 or V_3 and by exhibiting features characteristic of both anteroseptal and posteroseptal activation.

Differentiation of intermediate septal from posteroseptal and anteroseptal accessory pathways. The anatomic substrate for the electrophysiologic findings observed in our patients and described by Gallagher et al. (1) is an accessory

pathway near the AV node (type 1 intermediate septal accessory pathway) or His bundle (type 2 intermediate septal accessory pathway) distinct from typical posteroseptal and anteroseptal accessory pathway locations.

By careful measurement of the stimulus to delta intervals during pacing at different sites along the AV ring (differential pacing), an intermediate septal accessory pathway can be recognized preoperatively. When the shortest stimulus to delta interval occurs during pacing near the AV node, at the ostium of the coronary sinus or near the foramen ovale, an intermediate septal accessory pathway should be suspected (Table 2). The shortest stimulus to delta interval indicates the approximate location of the accessory pathway and, as in the two patients in this study who lacked retrograde accessory pathway conduction, differential pacing may be the only way to localize the accessory connection in the electrophysiology laboratory.

It may be difficult to differentiate intermediate septal from posteroseptal and anteroseptal accessory pathways (Tables 5 and 6). At preoperative electrophysiologic study, retrograde atrial activation by the type 1 pathway with retrograde conduction occurred at the foramen ovale (Table 3). In contrast, the ostium of the coronary sinus is activated earliest when retrograde conduction occurs over a posteroseptal accessory pathway. During differential atrial pacing at preoperative electrophysiologic study, the shortest stimulus to delta wave interval occurs when pacing at the ostium of the coronary sinus for both type 1 intermediate septal accessory and posteroseptal accessory pathways. However, at intraoperative electrophysiologic study, a type 1 intermediate septal accessory pathway causes simultaneous epicardial ventricular activation of the crux and the base of the aorta in contrast to a posteroseptal accessory pathway that activates the ventricles earliest at the crux. A type 1 intermediate septal accessory pathway occurs in close proximity to the AV node below the level of the limbus of the foramen ovale and probably inserts into the muscular interventricular septum rather than into more posterior portions of the right and left ventricles, including the posterosuperior process of the left ventricle, as does a posteroseptal accessory pathway.

A type 2 intermediate septal accessory pathway is paraHisian in close proximity to the membranous septum and electrophysiologic mapping is necessary to differentiate it from a typical anteroseptal accessory pathway (Table 6). An anteroseptal accessory pathway activates the ventricles anterior to the membranous septum in contrast to a type 2 intermediate septal accessory pathway, which activates the ventricles at the apex of Koch's triangle at the caudal extent of the membranous interventricular septum. At preoperative electrophysiologic study, an anteroseptal accessory pathway has earliest retrograde activation at the anteromedial right atrium. The different location of a type 2 intermediate septal accessory pathway is manifested by earliest retrograde atrial activation at the site of His bundle electrogram recording (Table 3). Finally, during pacing along the AV ring at preoperative electrophysiologic study, the shortest stimulus to delta wave interval occurs when pacing near the foramen ovale when a type 2 intermediate septal accessory pathway is present (Table 2), but it occurs when pacing the anteromedial right atrium when a typical anteroseptal accessory pathway is present.

Surgical considerations. Two patterns of activation mapping and anatomic localization were observed and had correlates with delta wave configuration on the surface ECG. Intraoperative mapping localized the type 1 intermediate septal accessory pathway to the midpoint of Koch's triangle cephalad to the coronary sinus but caudal to the His bundle. This type of accessory pathway leads to simultaneous epicardial ventricular activation at the crux and the base of the aorta, as described by Gallagher et al. (1). A type 2 intermediate septal accessory pathway is located at the apex of Koch's triangle adjacent to the bundle of His and activates the ventricles earliest anteriorly at the base of the aorta.

Two aspects of our operative technique warrant special mention. First, the location of an intermediate septal accessory pathway may be identified despite the inability to map the atrial side of the anulus during either AV reciprocating tachycardia or ventricular pacing. Differential atrial pacing in Koch's triangle along the tricuspid anulus and on-line measurement of the stimulus to delta wave intervals provide immediate identification of the location of the pathway. Intraoperative mapping localizes a type 1 intermediate septal accessory pathway to the midpoint of Koch's triangle just anterior to a line that connects the inferior AV node to the anterior ostium of the coronary sinus (Fig. 3). In the patient with a type 2 intermediate septal accessory pathway, the pathway was located adjacent to the bundle of His, making it impossible to selectively ablate the former without interrupting normal AV conduction (Fig. 5).

The second operative technique of special importance was the use of cryothermia, which greatly facilitated selective intermediate septal accessory pathway ablation. Our approach combines the techniques of epicardial cryoablation for interrupting free wall accessory pathways promoted by Guiraudon et al. (11–13) and of endocardial cryoablation for treatment of AV node reentrant tachycardia as described by Cox et al. (14). In the description of intermediate septal accessory pathways by Gallagher et al. (1), two of four patients prospectively identified had successful accessory pathway division without developing complete heart block, whereas the other two patients had immediate complete heart block after cooling to 0°C. Localization of the accessory connection to a position distinct from the His bundle enabled us to use a 5 mm flat-faced cryoprobe to verify the location of the accessory pathway by cooling to 0°C and observe loss of the delta wave. This was followed by cryoablation at −60°C for 2 to 3 min to permanently interrupt the accessory pathway without causing complete heart block and without surgical dissection. Furthermore, loss of the delta wave within seconds of initiating cooling to 0°C (Fig. 4)

suggests that an intermediate septal accessory pathway may be located subendocardially rather than deep in the fat of the posterior pyramidal space. This location is distinctly different from the left-sided location of "atypical" posteroseptal accessory pathways reported by Guiraudon et al. (15) but is within the spectrum of anteroseptal accessory pathway locations described as para-Hisian by the same group (9).

Conclusions. A type 1 intermediate septal accessory pathway is located near the midpoint of Koch's triangle and may be cryoablated over the right atrial endocardial surface without permanent damage to the normal AV conduction system. A type 2 intermediate septal accessory pathway is located at the apex of Koch's triangle in close proximity to the His bundle and may be divided with a high risk of AV block. Successful surgical ablation of an intermediate septal accessory pathway can be accomplished without disrupting AV node and His-Purkinje conduction by meticulous mapping and cryoablation.

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