Analysis of Surgically-induced Right Bundle Branch Block Pattern Using Intracardiac Recording Techniques

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SUMMARY Using intracardiac recording techniques, His bundle (H) and right ventricular apical (RVA) electrograms were recorded in 16 patients with a postoperative electrocardiographic pattern of right bundle branch block (RBBB). Their ages ranged from 5 to 12 years (mean 6.9 years) at surgery and the follow-up period was 1 to 7 years (mean 2.7 years). All were asymptomatic and in sinus rhythm at the time of study. The P-A interval was normal in all and the A-H, H-V, and V-RVA intervals were prolonged in one, one, and six patients, respectively. The V-RVA interval was normal (≤30 msec) in ten out of the 11 patients (91%) without associated left anterior hemiblock (LAH), indicating a physiologically intact main right bundle branch, and was abnormally lengthened (45-62 msec) in all five patients (100%) with associated LAH. These findings suggest that there are two subgroups of patients with surgically-induced RBBB pattern and the measurement of the V-RVA interval in conjunction with the H-V interval may be of ultimate importance in understanding the long-term prognostic implication of surgically-induced RBBB pattern with or without LAH.

THE FREQUENT DEVELOPMENT of the electrocardiographic pattern of right bundle branch block (RBBB) following surgical correction of tetralogy of Fallot (TF) and ventricular septal defect (VSD) is well recognized. The mechanism by which this RBBB pattern occurs has been attributed to operative trauma of the main right bundle branch during surgical repair of the septal defect or to disruption of the subendocardial Purkinje network secondary to a vertical right ventriculotomy. Differentiation as to the site of conduction disturbance is of prognostic importance since complete heart block may complicate the former, but not the latter when left bundle branch block develops in later life. It is appreciated that the scalar electrocardiograms, under these circumstances, are of limited value in differentiating main right bundle branch injury from distal Purkinje fiber disruption.

Recording of the His bundle and the right ventricular apical (RVA) electrograms has been used to approximate conduction time from the level of the His bundle along the right bundle branch to the site of earliest activation in the right ventricle at the apical region. Therefore, it can be assumed that activation of the RVA would be delayed in the presence of conduction disturbance within the main right bundle branch. Using this concept, we recorded the His bundle and the RVA electrograms in 16 patients who had acquired RBBB pattern following total surgical repair of TF and VSD. The analysis of the electrophysiological data provided information which may be of ultimate importance in understanding the clinical implication of this surgically-induced RBBB pattern.

Material and Methods

Sixteen patients, of whom 11 had TF and five had isolated membranous VSD (table 1), constituted the study population. Surgically-induced RBBB pattern was confirmed in each by comparing serial preoperative and postoperative electrocardiograms. Five of them had also acquired left anterior hemiblock (LAH) by Rosenbaum's criteria. The age at surgery ranged from 5 to 12 years (mean 6.9 years), and the follow-up period since surgery had been from 1 to 7 years (mean 2.7 years). Operative records were analyzed and there was no evident difference in the surgical correction of these patients; all had undergone a vertical right ventriculotomy (3-5 cm) followed by closure of VSD during their operative procedures.

An informed consent was obtained from the parents in each case. In each patient, the study was performed in the postabsorptive basal state following demerol and phenergan sedation. None of them were receiving a cardiotonic or antiarrhythmic drug. A bipolar electrode catheter was placed in the right atrium and positioned across the septal leaflet of the tricuspid valve to obtain His bundle electrograms (HBE). An additional bipolar electrode catheter was placed in the right ventricle at the apical region to record RVA electrograms. The position of the catheter at the RVA was confirmed by its anterior location in the lateral view. The HBE and RVA electrograms, filtered with settings of 40–500 Hz and 120–500 Hz respectively, were displayed simultaneously with two or three surface ECG leads on a multichannel oscilloscopic photographic recorder (Electronics for Medicine, DR-8, White Plains, New York). The purpose of using 120 Hz as the low limit of the filter setting for recording RVA electrograms was to obtain sharp as well as narrow electrogram deflections (fig. 1). Recording and measurement were made at a paper speed of 100 mm/sec with a vernier device having an accuracy of ±1 msec.

The P-A, A-H, and H-V intervals were measured as conventionally described. Normal values in pediatric patients over five years of age in our laboratory are 0–35, 50–115, and 30–45 msec respectively. The V-RVA interval was measured from the earliest onset of QRS complex to the onset of first rapid moving deflection on the RVA electrogram. In order to obtain control values for the V-RVA interval, we have recorded RVA electrograms in 12 patients with mild aortic stenosis, in whom the surface electrocardiograms and the right heart hemodynamics were normal (partly presented in our previous communication). The
V-RVA intervals in these patients served as control values and ranged between 5 and 30 msec (fig. 1). The reason for utilizing the V-RVA interval instead of H-RVA interval was to more accurately localize the site of conduction abnormality occurring within the main right bundle branch, since an isolated intra-Hisian conduction disturbance would prolong the H-RVA interval, but not the V-RVA interval. Patients (91%) indicating a physiologically intact main right branch (figs. 2 and 3), and was abnormally lengthened (50 msec) in only one patient (case 4) indicating the presence of

### Results

#### Postoperative ECG Changes (table 1)

Of the total 16 patients, one (case 4) developed first degree atioventricular (A-V) block (P-R interval lengthened from 140 to 240 msec) which had been persistent since surgery. The QRS duration ranged from 60 to 90 msec (mean 75 ± 8 msec) preoperatively and from 120 to 165 msec (mean 131 ± 16 msec) postoperatively. The postoperative prolongation of the QRS duration was statistically significant (P < 0.001). The maximal frontal QRS axis lay between +90° to +150° preoperatively and between +140° to −60° postoperatively. Five patients (cases 12–16) had postoperative ECG changes compatible with the electrocardiographic criteria for the diagnosis of LAH, in which the maximal frontal QRS axis shifted to between −30° and −60°, with the initial 0.02 second vector being displaced inferiorly and to the right.

#### Electrophysiological Data

The measurements of the P-A, A-H, H-V, and V-RVA intervals are tabulated in table 2. The P-A interval was normal in all patients; the A-H interval was normal except for the patient (case 4) who had developed first degree A-V block following surgery (A-H interval of 180 msec); and the H-V interval was prolonged (56 msec) in one (case 12) of the five patients who had associated LAH (figs. 2–5).

In order to delineate the difference in electrophysiological findings of the V-RVA interval, the total 16 patients were divided into two groups (table 2): group I, 11 patients (cases 1–11) without associated LAH, and group II, 5 patients (cases 12–16), with associated LAH. In the former group, the V-RVA interval was normal (≤30 msec) in ten

![Figure 1](http://circ.ahajournals.org/) The His bundle electrogram (HBE) and right ventricular apex (RVA) electrogram recorded simultaneously with leads I, II, and V1. In this and figures 3, 5, and 7, the broken line demarcates the earliest onset of the QRS complex and the arrow points to the onset of rapid deflection in RVA electrogram. H = His bundle deflection. The filter settings for HBE and RVA electrograms are 40–500 Hz and 120–500 Hz respectively. Note the relatively sharp and narrow RVA electrogram. The intervals are expressed in milliseconds.
conduction disturbance within the main right bundle branch. In the latter group, all five patients had prolonged V-RVA interval (45-62 msec) suggesting the presence of main right bundle branch injury (figs. 4-7); one (case 12) of them had additionally prolonged H-V interval (56 msec) indicating the presence of a trifascicular disease and/or His bundle involvement distal to its recording site (figs. 4 and 5).

Clinical Follow-up

During the immediate postoperative period none of these 16 patients developed transient complete heart block. All of them had been followed for a period ranging from 1 to 7 years (mean 2.7 years) and late development of second degree or complete heart block was not observed. All were asymptomatic and in sinus rhythm at the time of study.

Discussion

Studies on the A-V conduction system associated with TF and VSD have demonstrated that the His bundle and the right bundle branch are intimately related to the posteroinferior aspect of the defect.7, 14-17 Therefore, these structures may be traumatized during surgical repair of the septal defect. In a series of 13 patients who succumbed after surgical correction of TF and VSD, Titus et al.8 have found a high incidence (92%) of operative trauma to the A-V conduction system — the His bundle, the right bundle branch, and to a lesser degree, the left bundle branch. Nevertheless, using epicardial mapping technique, Gelband et al.,9 as well as Krongrad et al.,10 have demonstrated that a RBBB pattern commonly occurs following a vertical right ventriculotomy as a result of disruption of the subendocardial Purkinje network. Further, in canine heart experiments, Watt and Pruitt18 and Krongrad et al.19 have also shown that a discrete lesion in the distal (branching) portion of the His bundle can induce a RBBB-LAH pattern. From these observations, it would appear that operative trauma at three different levels of the conduction system — the distal portion of the His bundle, the main right bundle branch and the right ventricular subendocardial Purkinje fibers can produce electrocardiographic patterns of RBBB that are indistinguishable.

In patients with surgically-induced RBBB pattern, it has been repeatedly emphasized that the prognostic implication depends upon identification of the site of block within the right bundle branch.4-10 If a main right bundle branch lesion is present, the development of left bundle branch block in later life may herald the onset of complete A-V block. Okoroma et al.20 analyzed the vectorial orientation of the QRS loop from the Frank electrocardiograms as well as scalar electrocardiograms taken at 50 mm per second speed, and concluded that main right bundle injury, but not distal Purkinje fiber disruption, would induce an anterior-to-posterior shift of the initial 0.02 second electrovectorcardiographic forces. Unfortunately, these changes, in general, are too subtle to be appreciated, and are subject to error caused by minimal ECG lead displacement.

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Preoperative (A) and seven years' postoperative (B) electrocardiograms in a 6-year-old girl (case 1) with tetralogy of Fallot. Note postoperative development of complete right bundle branch block pattern without left anterior hemiblock.

![Figure 3](https://example.com/figure3.png)

**Figure 3.** His bundle electrogram (HBE) and right ventricular apex (RVA) electrogram recorded simultaneously with leads I and V, in the same patient as in figure 2. Note normal P-A, A-H, H-V, and V-RVA intervals.
When an impulse is being propagated through the His-Purkinje system reaching the ventricular myocardium, the exact myocardial site to be first depolarized in the human heart remains to be determined. However, the beginning of the QRS complex delineates the onset of that event. Prolongation of the H-V interval generally indicates a trifascicular disease and/or His bundle involvement distal to its recording site. One one (case 12) of our 16 patients had such a finding (figs. 4 and 5). In an attempt to define the prognostic implication of acquired RBBB and LAH in patients who had undergone surgical correction of TF and VSD, Godman et al. and Pahlajani et al. noted that 50% and 22% of their patients respectively had prolonged H-V intervals, but they failed to specifically identify the incidence of conduction disturbance within the main right bundle branch. Besides, some of these patients could have conduction through an intact postero-inferior division of the left bundle branch to reach the myocardium, even in the presence of a main right bundle branch lesion, and hence would have a normal H-V interval as measured electrophysiologically (for example, see our case 14, figs. 6 and 7).

The measurement of V-RVA interval depicts the difference in time of the onset of activation at two different ventricular sites, i.e., the area to be first depolarized and the RVA. It is assumed that RVA activation occurs following an impulse propagated from the His bundle level along the right bundle branch to reach the RVA myocardium. An injury to the main right bundle branch would, therefore, delay impulse transmission through the right bundle branch to the RVA or result in RVA myocardium to be activated trans-septally from the left bundle branch. In both situations, the V-RVA interval would be expected to be longer. Indeed, the V-RVA interval has been shown to be significantly prolonged in the presence of functional and permanent RBBB unrelated to surgery. In this study, the finding of normal V-RVA interval ($\leq$30 msec) in the majority of patients with surgically-induced RBBB without associated LAH (10 out of 11 patients, 91%) (table 2 and figs. 2 and 3), further confirms that surgically-induced RBBB pattern is principally related to disruption of the right ventricular sub-endocardial Purkinje fibers secondary to a vertical right ventriculotomy. The V-RVA interval was significantly lengthened (45-62 msec) in all five patients (cases 12-16) with RBBB-LAH pattern (table 2 and figs. 4-7). A combined lesion in the proximal right bundle branch and the anterosuperior division of left bundle branch in these five patients seems likely, if one remembers that these structures are adjacent to each other and are in proximity to the septal defect. However, it should be emphasized that anatomical variations of the A-V conduction system in patients with TF and VSD do exist. Therefore, an isolated lesion in the anterosuperior division of the left bundle branch due to VSD

![Figure 5](https://example.com/figure5.png)

**FIGURE 5.** His bundle electrogram (HBE) and right ventricular apex (RVA) electrogram simultaneously recorded with leads I and II in the same patient as in figure 4. Note prolongation of both H-V and V-RVA intervals, indicating the presence of His bundle conduction disturbance distal to its recording site or a trifascicular disease and main right bundle branch injury.
repair may occur in conjunction with peripheral disruption of subendocardial Purkinje fibers related to right ventriculotomy. The scalar electrocardiograms of the above composite would be identical to that of a combined lesion in the main right bundle branch and the anterosuperior division of left bundle branch with or without distal Purkinje fiber disruption. Measurement of the V-RVA interval is useful in differentiating these two different types of ECG complexities, as the V-RVA interval would be normal in the former and abnormally lengthened in the latter.

The etiology of unexpected cardiac arrest and sudden death in patients who have had surgical correction of TF remains to be determined. Both complete heart block and ventricular arrhythmias have been implicated as possible causes.26-27 Wolff et al.28 reported that surgically-induced bifascicular block — RBBB and LAH — was associated with a high incidence of late complete heart block and sudden death. However, others1, 29, 30, 31 reported that surgically-induced bifascicular block had a rather benign prognosis. Steeg et al.,1 first suggested that inhomogeneous patient populations which could not be differentiated by the scalar electrocardiogram might have accounted for such marked differences in the long-term clinical evaluation of patients with surgically-induced bifascicular block. Although one cannot draw a definitive conclusion from a small number of patients with a relatively short-term follow-up presented herein, our findings have demonstrated that, indeed, there are two subgroups of patients with surgically-induced RBBB pattern, as indicated by the differences in the V-RVA interval. We believe, therefore, that measurement of the V-RVA interval as well as the H-V interval may be of ultimate importance in understanding the long-term prognostic implication of surgically-induced RBBB pattern with or without LAH.

Figure 7. His bundle electrogram (HBE) and right ventricular apex (RVA) electrogram simultaneously recorded with leads I, II, and III in the same patient as in figure 6. Note normal H-V interval and prolonged V-RVA interval, indicating a physiologically intact postero-inferior division of the left bundle branch in the presence of main right bundle branch injury and left anterior hemiblock.

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*Circulation*. 1976;54:442-446
doi: 10.1161/01.CIR.54.3.442

*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1976 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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