Right Bundle-Branch Block
A Vectorcardiographic and Electrocardiographic Study of Ventricular Septal Defect Following Open-Heart Surgery

By Janet Dickens, M.D., Vladir Maranhao, M.D., and Harry Goldberg, M.D.

Confusion still exists regarding the differentiation between right bundle-branch block and right ventricular hypertrophy. Study of patients after open-heart surgery was helpful in this problem because postoperative changes in electrocardiograms and vectorcardiograms were clearly due to traumatic disturbance of the right bundle branch and not to right ventricular hypertrophy.

The differentiation between right bundle-branch block and right ventricular hypertrophy remains a difficult one in many instances. Many methods of investigation have been applied to this problem, including endocardial electrocardiography1-4 and vectorcardiography.5,6 Proponents of the latter technique have suggested that the differentiation can be made from characteristic loop appearances. An opportunity was provided to examine this proposal in patients who underwent open-heart surgery for ventricular septal defect and ventricular septal defect with pulmonic stenosis and in whom traumatic right bundle-branch block was produced.

Material and Methods
Seven patients ranging in age from 2 to 32 years who underwent open-heart surgery constitute the present series. Five had repair of an isolated ventricular septal defect and 2 had pulmonic stenosis in addition. The defect was situated in the membranous septum in all but 1 patient. Open-heart surgery was performed with the use of the sigmamotor pump and Freidland-Gemeinhardt oxygenator.7 In 5 patients the defect was repaired with Nylon sutures and in 2 with Ivalon sponges.

The pulmonic stenosis was relieved by splitting of the commissures under direct vision, by resecting the muscular ridge, or by both procedures.

A 12-lead electrocardiogram including V4R when possible was obtained before and after surgery with a polyoscillographic recorder.8 The time interval between surgery and the second electrocardiogram and vectorcardiogram varied from 14 days to 1 year.

Vectorcardiograms with both the cube system of Grishman9 and the tetrahedron system9 were obtained before and after operation. The vector loops were recorded by a Sanborn vector system and Visoscope.*

The electrocardiographic criteria for incomplete or complete right bundle-branch block were those of Barker and Valencia,10 Wilson and associates,11 and Rodriguez and Sodi-Pallares.12 Criteria for right ventricular hypertrophy were those of Sokolow and Lyon.13 The vectorcardiograms were analyzed for right bundle-branch block and right ventricular hypertrophy according to the criteria of Grishman14 as follows: Right ventricular hypertrophy—clockwise inscription of the loop in the horizontal plane; anterior and rightward position of the loop depending on the degree of hypertrophy; absence of conduction delay. Right bundle-branch block—counterclockwise inscription of the loop in the horizontal plane; terminal appendage directed to the right and anteriorly; conduction delay in the terminal appendage; orientation of the T loop opposite to the terminal appendage.

Results
Vectorcardiograms and Electrocardiograms before and after Operation. Four patients are included in this group, 2 with isolated ventricular septal defect and 2 with associated pulmonic stenosis.

The preoperative data were variable (table 1, cases 1 to 4, and fig. 1 Top). In case 1 the electrocardiogram and vectorcardiogram were
considered to be within normal limits. In case 2 the electrocardiogram was equivocal for right ventricular hypertrophy. The vectorcardiogram suggested this diagnosis in the tetrahedron system but appeared normal in the cube system. In case 3 an RSr' pattern of normal duration was present in V1. The r' was smaller than the R in V1, and the s wave in leads I and V6 was of normal duration. The RSr' pattern was thus considered to be nonspecific, but analysis of the electrocardiogram and vectorcardiogram suggested the presence of right ventricular hypertrophy. In case 4 the electrocardiogram was again problematic. An rR's was present in V1 of normal duration and with a normal intrinsicoid deflection. The S wave in leads I and V6 was likewise normal in duration. The R' was larger than the initial r, suggesting right ventricular hypertrophy. In addition the electrocardiogram met the criteria of Rodriguez and Sodi-Pallares for incomplete right bundle-branch block. The vectorcardiogram, however, showed the characteristics of right ventricular hypertrophy. Generally, the cube system of vectorcardiography appeared to be superior to the tetrahedron, particularly in regard to correlation between the vectorcardiographic loop and the precordial-lead configuration.

The postoperative electrocardiograms in all patients showed significant changes consistent with right bundle-branch block (table 1, cases 1 to 4, and fig. 2 Top). The duration of the QRS complex, the intrinsicoid deflection, and the duration of the S wave in leads I and V6 were increased in all tracings. The morphology of the V1 patterns changed in 2 patients. In cases 1 and 2 with an rS and an RS complex in V1 preoperatively, an R' of distinct magnitude appeared postoperatively. In cases 3 and 4 the r' and R' in V1 present preoperatively increased in magnitude and duration postoperatively.

The vectorcardiograms likewise showed striking changes postoperatively (fig. 2 Top). In the horizontal plane in all cases the loops in both the cube and tetrahedron systems were directed counterclockwise, changing from the clockwise direction seen preoperatively in 3 patients. This uniformity in direction of inscription was not seen in the sagittal and frontal planes. The loops which were previously mostly anterior in position were now
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Fig. 1. Top. Preoperative tracings in cases 1 to 4. Only the horizontal plane vectorcardiograms are shown. The vector loops of cases 3 and 4 are indicative of right ventricular hypertrophy. The tetrahedron loop of case 2 is also consistent with right ventricular hypertrophy. Bottom. Preoperative electrocardiograms in cases 5 to 7. No vectorcardiograms were obtained in this group.

found to be mainly to the left in the cube system and to the left and somewhat posterior in the tetrahedron. Of particular importance was the new appearance of a terminal appendage of distinct magnitude in all cases, directed to the right and anteriorly. Conduction delay was noted in the terminal appendage in the form of crowding of the time markings and irregularity of the loop. The T loop was directed opposite to the terminal appendage.

No Preoperative Vectorcardiograms. Three patients are included in this group (table 1,
Fig. 2. Top. Postoperative data in cases 1 to 4. Note the similarity between the electrocardiograms and vectorcardiograms and in particular the anteriorly directed terminal appendage. Horizontal plane vectorcardiograms are shown. Bottom. Postoperative data in cases 5 to 7. The vectorcardiograms of cases 5 and 6 are indicative of right bundle-branch block while that of case 7 is normal. Only the horizontal plane loops are shown. Two exposures of the tetrahedron loops are present in cases 5 and 6.

cases 5 to 7, fig. 1 Bottom). The preoperative electrocardiogram was normal in 1 case (case 7) and consistent with right ventricular hypertrophy in 2 (cases 5 and 6). Postoperatively in the 2 latter patients right bundle-branch block was produced (table 1 and fig. 2 Bottom, cases 5 and 6) as noted in the electrocardiogram by the striking changes in the patterns and durations of the complexes. The postoperative vectorcardiograms showed findings simi-
lar to the previous group, that is, counterclockwise rotation of the body of the loops, and a huge terminal appendage with conduction delay directed anterior and rightward. In case 7 there was little change in the postoperative electrocardiogram. The V_1 r' which appeared postoperatively was present in V_2 preoperatively. This finding can be explained by change in electrode positions. The postoperative vectorcardiogram showed counterclockwise direction of the loop with a very small terminal appendage without conduction delay, which was within the normal variation.

**DISCUSSION**

The location of the cardiac conduction system in relation to defects of the membranous ventricular septum has been extensively investigated by Truex and Bishop. The position of the common bundle of His in the posterior margin of the defect exposes it to injury by suturing during surgery. The right bundle branch may be injured in particular, because of the great variability in both the branching of the common bundle at the posteroinferior angle of the defect and in the course of the right bundle branch in the interventricular septum. The right bundle may descend either posterior or anterior to the defect and in the form of one or several fascicles. Thus, there may be injury to the right bundle, as in 1 of our cases, during repair of a defect situated in the muscular septum. In 1 case reported by Truex periarterial conduction tissue was dissected about a transposed pulmonary artery. This observation raises the question of possible injury to the conduction tissue during the performance of the pulmonary valvotomy in the cases of tetralogy of Fallot in this series. In addition to injury to the conduction tissue hemorrhage within the atrioventricular node and bundle branches was noted at postmortem examination in some cases.

On the basis of these studies the postoperative right bundle-branch block, which developed in the patients presented here, was presumed to be traumatic in origin, resulting from the inadvertent placement of sutures at surgery; indeed, the abnormal conduction was noted to occur during the operative procedure, as the sutures were being placed within the septum. This event has been noted also by other groups reporting on the repair of ventricular septal defects by open-heart surgery. When right bundle-branch block does not occur following surgery, as in 1 patient in our group, it can be postulated that the area of the conduction tissue was avoided during the operative procedure.

The production of right bundle-branch block was accompanied by striking changes in the electrocardiogram. The duration of the QRS complex and ventricular activation time was markedly increased. An RSR' pattern appeared in those patients in whom it was not present preoperatively and became more significant in those in whom it was noted before surgery. Of greater importance was the increase in duration of the R' in V_1 and the S wave in leads I and V_6. The latter findings appear to be much more significant than the morphology of the QRS complex alone.

The origin and interpretation of the RSR' patterns has long been a subject of contention. It can be said however, that in the presence of an RSR' complex the differentiation between right ventricular hypertrophy and right bundle-branch block often cannot be made electrocardiographically. In particular, in the presence of an RSR' complex of normal duration and with a normal intrinsicsoid deflection, the differentiation between incomplete right bundle-branch block and a normal variant may be impossible. Although some investigators attribute the presence of 2 positive deflections (R and R') exclusively to right bundle-branch block, it has been demonstrated by endocardial electrocardiography that an RSR' pattern can be recorded from the right ventricle of patients with right ventricular hypertrophy or right bundle-branch block and from normal persons. Grisham and associates also obtained 2 different vectorcardiographic loops in patients with similar RSR' patterns in V_1. Criteria were then proposed by these workers.
for the vectorcardiographic diagnosis and differentiation of right ventricular hypertrophy and right bundle-branch block. Since the diagnosis of right bundle-branch block could be confirmed in the present group of patients, an ideal situation was presented to evaluate these proposed criteria. The results obtained support the differentiation between these entities by vectorcardiography.

The vectorcardiograms of the patients who developed traumatic right bundle-branch block following surgery present the loop characteristics described by Grishman and associates and attributed by them to clinical right bundle-branch block. The postoperative changes in the vectorcardiograms were striking and uniform, particularly in the horizontal plane. Distinct reversal of the loop to a counterclockwise direction occurred in the patients in whom a clockwise direction in the horizontal plane was present preoperatively. The position of the loop likewise was markedly changed. Preoperatively the loops were mostly anterior in both systems, while postoperatively they were mainly to the left in the cube and to the left and somewhat posterior in the tetrahedron. A terminal appendage, which appeared postoperatively, corresponded with the broad R' of V_{1} and the S wave of leads I and V_{a}. Thus, the vectorcardiogram appeared to be superior in demonstrating the mechanism of right bundle-branch block.

In this study as in others\textsuperscript{5, 18} the differentiation between right ventricular hypertrophy, right bundle-branch block, and a normal variant often cannot be made electrocardiographically in the presence of an RSR' pattern in V_{1}. In addition, different types of vectorcardiographic loops may be recorded in the presence of similar RSR' patterns in V_{1}. However, after the production of right bundle-branch block by surgery characteristic changes in the vectorcardiographic loops were recorded in all patients. This observation suggests that these specific loop characteristics, when encountered in clinical vectorcardiography, may be attributed to right bundle-branch block. In some of our patients reexamined in the early postoperative period who developed right bundle-branch block, it cannot be presumed that right ventricular hypertrophy was relieved immediately by surgery. Thus, when the clinical picture suggests that both right bundle-branch block and right ventricular hypertrophy may coexist, the vectorcardiogram appears to demonstrate the predominant lesion only.

**Summary**

Seven patients who underwent open-heart surgery for repair of ventricular septal defect were studied by electrocardiograms and vectorcardiograms before and after operation. Traumatic right bundle-branch block was produced by the operative procedure. In association with this abnormality in conduction, characteristic changes occurred in the vectorcardiographic loops. The vector loop features may be applied in the differentiation between right bundle-branch block and right ventricular hypertrophy in the presence of an equivalent electrocardiogram.

**Summario in Interlingua**

Septe patientes, subjicite a chirurgia a corde aperte pro le reparo de defectos ventriculo-septal, esseva studiate electro- e vectorecardiographicamente ante e post le operation. Traumatic bloco de branca dextere esseva producita per le intervention chirurgie. In association con iste anormalitate del conduction, alteraciones caracteristic occurreva in le ansas vectocardiographique. Le caracteristicas note in le ansas potre esser utilizate in le differentiation inter bloco de branca dextere e hypertrophia dextero-ventricular in casos in que le electrocardiogramma es equivoc.

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In very many, and almost all kinds of Insects, by reason of the smallness of their Corpulency, we cannot rightly discern; yet in Bees, flies and wasps we may by the help of a perspective glass. You may likewise see something beat in lice, in which moreover you may clearly see the passage of the nourishment through the intestines (this Animal being transparent) like a black spot, by help of this multiplying glass. But in those that have no blood and are colder, as in Snails, Shell-fish, Crusted-Shrimps, and the like, there is a little part which beats (like a little bladder, or an ear) without a heart, making its contraction and pulse seldom, and such a one as you cannot discern but in summer, or in a hot season.—WILLIAM HARVEY. De Motu Cordis, 1628.
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JANET DICKENS, VLADIR MARANHAO and HARRY GOLDBERG

Circulation. 1959;20:201-207
doi: 10.1161/01.CIR.20.2.201

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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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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