Chronic Left Complete Bundle-branch Block

Phonocardiographic and Mechanocardiographic Study of 30 Cases

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The electrocardiographic signs of left complete bundle-branch block are now well established, and in the majority of cases they correspond to total or subtotal destruction of the left bundle-branch fibres (Lenègre, 1957). However, two sorts of problems remain under discussion, namely, demonstration of the left ventricular delay in atypical cases of left bundle-branch block, for example when left bundle-branch block masquerades as right bundle-branch block (Richman and Wolff, 1954), and demonstration of the type of disturbed left intraventricular conduction, whether bundle-branch or arborization block, in typical cases with abnormal QRS prolongation (Grant and Dodge, 1956).

In a previous paper one case of intermittent left complete bundle-branch block was reported, which offered the opportunity to recall the signs of left ventricular delay, derived from the phonocardiogram and mechanocardiogram, i.e. indirect carotid pulse curve and apex cardiogram (Baragan *et al.*, 1967). The purpose of the present study was to analyse the heart sounds and the mechanocardiographic curves of a relatively large number of chronic cases of left complete bundle-branch block, with the hope that they may help to answer, in the future, the two sorts of problems mentioned above.

PATIENTS AND METHOD

The group consisted of 30 clinical cases of miscellaneous heart diseases, the electrocardiograms of which met the classical criteria for left complete bundle-branch block, namely, a QRS complex of supraventricular origin with a duration of 0.12 sec. or more, and ventricular activation times of 0.02 sec. or less in lead V1 and of 0.08

or more in lead V6. There were 20 men and 10 women with an average age of 48.5 years (range 18 to 78). The aetiological factors responsible for the heart condition associated with the pattern of left complete bundle-branch block were valvular heart disease (10 cases), ischaemic heart disease (6 cases), primary non-obstructive cardiomyopathy (6 cases), obstructive cardiomyopathy (3 cases), systemic hypertension (3 cases), and idiopathic left complete bundle-branch block (2 cases). Of these, 2 cases of left complete bundle-branch block resulted from operation, and one case, which had already a left complete bundle-branch block before operation, was aggravated by the latter. Of the 30 cases, 18 were in, or had just recovered from, cardiac failure.

The electrocardiogram, phonocardiogram, indirect carotid pulse curve, and the apex cardiogram were recorded with a photographic 4-channel Hellige Multi-cardiotest. The phonocardiogram, dissociated into two frequency bands (low from 5 to 50, and high from 50 to 250 cycles per second), was recorded simultaneously with an electrocardiographic lead, and alternatively either with an indirect carotid pulse curve (capacitance transducer Infraton-E system) or with an apex cardiogram (piezo-electric crystal), the patient lying in the left lateral position. Records were taken at a paper speed of 50 mm. per second, with the vertical lines separated by intervals of 0.02 second.

The following time intervals were measured (Fig. 1): *Q-OCP interval* (1+2) between the onset of QRS complex of the electrocardiogram (whether it started with a Q wave or not) and the onset of the carotid pulse (OCP);

electromechanical interval (EMI: 1) from the onset of the QRS complex to the onset of the systolic upstroke of the apex cardiogram;

pre-ejection period of left ventricular contraction (PEP: 2) from the onset of the systolic upstroke of the apex cardiogram to the onset of the carotid pulse: in this study this could not be measured directly but was calculated by subtracting the average electromechanical interval from the average Q-OCP interval;

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systolic ejection time (3) from the onset of the carotid pulse to its dicrotic notch;
 isometric relaxation phase (4) from the aortic component of the 2nd heart sound (A2) to the lowest diastolic point "O" of the apex cardiogram;
 ventricular filling period (5) from the point "O" to the onset of the following systolic upstroke of the apex cardiogram.

These intervals afford important landmarks for the various mechanical events of left ventricular contraction, and particularly the electromechanical interval which marks the onset of left ventricular contraction and the Q-OCP interval which marks the onset of left ventricular ejection.

All these values were an average of measurements made from four cardiac cycles, after they had been corrected for heart rate by dividing the measured value by the square root of the preceding R-R interval of the electrocardiogram. Statistical comparisons were carried out between the corresponding average corrected values of the various aetiological groups of patients, and no significant difference was found between them. In a second step, the average corrected values of the 30 cases taken *in toto* were compared with the corresponding average corrected values of 42 cases, recorded in our laboratory, of miscellaneous diseases of the heart but without electrocardiographic evidence of left intraventricular conduction disturbance. Finally, the post-operative measurements were compared to the corresponding pre-operative ones in the 3 cases in which the left intraventricular conduction disturbance either resulted from or was aggravated by operation.

RESULTS

Heart Sounds. A fourth heart sound was distinctly recorded in all the 29 cases with sinus rhythm; one case was in atrial fibrillation.

The first heart sound was prolonged (more than 0.09 sec.) in 20 cases and was considered soft in 17. In the 3 cases in which a notch on the systolic upstroke of the apex cardiogram was recorded—indicating mitral valve closure and making it possible to identify with reasonable safety the mitral closure sound—it was possible to show that the mitral closure sound followed instead of preceding the tricuspid closure sound: reversed splitting of the first heart sound (see Fig. 4).

The second heart sound was found split in 16 cases, with an aortic closure sound following the pulmonary one (A2 after P2): reversed splitting of the second heart sound (see Fig. 6). However, in 14 cases the second heart sound was single.

Morphological Patterns of Apex Cardiogram. Two main patterns were encountered: (1) prominent "a" waves, with an increased average amplitude of 15.4 per cent of the maximum amplitude of the apex cardiogram (see Fig. 5), and (2) bifid systolic apex impulse in 10 cases (33%).

FIG. 1.—Diagram of sequence of left ventricular activation and ejection in the normal heart. LI: electrocardiogram lead I. CP: indirect carotid pulse. ACG: apex cardiogram (N is notch on the ascending systolic limb indicating mitral valve closure; "O" is the lowest diastolic point indicating mitral valve opening). PCG: phonocardiogram (showing left-sided valvar components only: M1 is mitral closure sound; A2 is aortic closure sound).

1: electromechanical interval; 2: pre-ejection period (eventually divided into two components by N when present and/or M1); 3: systolic ejection period; 4: isometric relaxation phase; 5: ventricular filling period. The interval Q-onset of the carotid pulse is the sum of 1 + 2.

Prolonged (30 cases) versus Normal (42 cases) Left Intraventricular Conduction (Table I). Except for the corrected systolic ejection time, all the other corrected intervals were significantly different from one group to the other. In the group with left complete bundle-branch block the following corrected intervals were increased: Q-onset of the carotid pulse, electromechanical, pre-ejection period, isometric relaxation; the corrected ventricular filling interval was shorter.

Post-operative versus Pre-operative Measurements in 3 Cases of Left Complete Bundle-branch Block Resulting from or Aggravated by Operation (Table II). When compared with pre-operative tracings, the post-operative records showed an increase of the corrected Q-onset of the carotid pulse, electromechanical, pre-ejection period, and isometric relaxation intervals, and a decrease of the corrected ventricular filling interval. The corrected systolic ejection time was unmodified in 2 and shortened in one.

In conclusion, when the cases of left complete

TABLE I
PROLONGED VERSUS NORMAL LEFT INTRAVENTRICULAR CONDUCTION*

	Absent left bundle-branch block (42 cases)	Left bundle-branch block (30 cases)	Significance (p value)
QRS interval	75 ± 1.2	142 ± 2.5	0.001
Q-onset carotid pulse interval	139 ± 21	192 ± 35	0.001
Electromechanical interval	32 ± 13	57 ± 19	0.001
Pre-ejection period	107 ± 21	134 ± 35	0.001
Systolic ejection time	306 ± 39	309 ± 45	N.S.
Isometric relaxation	105 ± 31	135 ± 31	0.001
Ventricular filling	389 ± 88	331 ± 112	0.02

* Note: All values are an average of measurements made from four cardiac cycles, after they had been corrected for heart rate (except for QRS) by dividing the measured value by the square root of the preceding R-R interval of the electrocardiogram.

TABLE II
POST-OPERATIVE VERSUS PRE-OPERATIVE MEASUREMENTS IN CASES OF LEFT INTRAVENTRICULAR CONDUCTION RESULTING FROM OPERATION*

	Case 1			Case 2			Case 3		
	Pre-op.	Post-op.	Difference	Pre-op.	Post-op.	Difference	Pre-op.	Post-op.	Difference
QRS interval	90	120	+ 30	90	120	+ 30	120	170	+ 50
Q-onset carotid pulse interval	135	210	+ 75	121	188	+ 67	121	222	+ 101
Electromechanical interval	27	54	+ 27	33	68	+ 35	35	60	+ 25
Pre-ejection period	108	156	+ 48	88	120	+ 32	86	162	+ 76
Systolic ejection time	366	349	- 17	357	355	- 2	396	279	- 117
Isometric relaxation	73	104	+ 31	158	160	+ 2	121	147	+ 26
Ventricular filling	382	330	- 52	337	150	- 187	474	263	- 211

* Note: All values are average corrected values from four cardiac cycles (see Table I).

bundle-branch block were considered together, left ventricular ejection was found to be delayed (increased average Q-onset of the carotid pulse interval). This delay resulted from both a late onset (increased average electromechanical interval) and a prolonged pre-ejection period of left ventricular contraction. In addition, the isometric relaxation period was prolonged, the ventricular filling period shortened, and the systolic ejection time was unmodified.

DISCUSSION

Heart Sounds. The presence of a distinct fourth heart sound, recorded in all the 29 cases with a co-ordinate atrial activity, together with the presence of large "a" waves on the apex cardiogram, supports the assumption of a forceful left atrial contraction in these cases of left bundle-branch block, which are usually associated with a diseased left ventricle (Haber and Leatham, 1965).

Increased duration of the first heart sound was due to dissociation of three of its valvar components, the aortic opening sound being carried away from the atrioventricular closure sounds, as a consequence of the late left ventricular ejection (Baragan *et al.*, 1967). In the 3 cases in which closure of the mitral valve was indicated by a notch

on the systolic ascending limb of the apex cardiogram (Tafur, Cohen, and Levine, 1964), the mitral closure sound was found to occur after the tricuspid closure sound (Contro and Luisada, 1952; McKusick *et al.*, 1955; Gray, 1956; Levine and Harvey, 1959; Dalla-Volta, Battaglia and Vincenzi, 1962; Burch, 1963). This reversed splitting of the first heart sound may occur in spite of a left ventricular contraction starting within normal time limits (Baragan *et al.*, 1967). Dissociation of the valvar components of the first heart sound, powerful atrial contraction, and probably also semi-closure of the mitral valve (Haber and Leatham, 1965), all contribute to the softening of the first heart sound.

Reversed splitting of the second heart sound was found in 16 cases, resulting from the late onset and termination of left ventricular ejection (Wolferth and Margolies, 1935; Gray, 1956; Haber and Leatham, 1965). However, in 14 cases no splitting of the second heart sound could be demonstrated, either because P2 was too soft to be recorded, or because A2 was little delayed and coincided with P2, or because both A2 and P2 were delayed and coincided with each other (bilateral bundle-branch block).

Sequence of Mechanical Events of Left Ventricular Contraction. Since the demonstration by Wolferth

and Margolies (1935) of a delayed left ventricular ejection in left complete bundle-branch block, opinions have differed as to the cause of such a delay. Gray (1956), using phonocardiographic arguments, assumed that it was due to late activation of the left ventricle, but the great majority of others found a normal activation time contrasting with a prolonged pre-ejection period of left ventricular contraction (Wolferth and Margolies, 1935; Segers and Hendrickx, 1951; Braunwald and Morrow, 1957; Luisada, 1959; Lev, 1961; Polis, 1961; Bourassa, Boiteau, and Allenstein, 1962; Haber and Leatham, 1965; Baragan *et al.*, 1967).

In the present study, when the whole group of 30 cases of left complete bundle-branch block was considered together, the late left ventricular ejection was found to result both from a late onset and from a prolonged pre-ejection period of left ventricular contraction. These findings were confirmed by the comparison between the pre-operative and post-operative data of the 3 cases in which left bundle-branch block either appeared after or was aggravated by operation. Nevertheless, when the 30 cases were considered individually, one or other interval was found to be within normal limits.

The upper limits of "normal" in our 42 cases with heart disease but without electrocardiographic evidence of prolonged left intraventricular conduction were determined in such a way as to include 95 per cent of these 42 "control" cases, and were found to be 0.052 sec. for the corrected electromechanical interval, 0.135 sec. for the corrected pre-ejection period, and 0.175 sec. for the corrected Q-onset of the carotid pulse interval. These limits are probably too high, as any of these intervals may be increased for some other reason than intraventricular conduction disturbance, and particularly the pre-ejection period in cases of cardiac failure (Warembourg *et al.*, 1964). However, if they are accepted, our 30 cases of left complete bundle-branch block might be subdivided in the following way (Fig. 2): normal electromechanical interval and pre-ejection period (Group A, 6 cases); normal electromechanical interval but prolonged pre-ejection period (Group B, 8 cases), increased electromechanical interval but normal pre-ejection period (Group C, 11 cases); and increased electromechanical interval and pre-ejection period (Group D, 5 cases). If one excludes Group A (6 cases, 20%), which according to our very strict standards has no unquestionable mechanocardiographic evidence of left complete bundle-branch block (Fig. 3), and if one assumes that prolongation of the electromechanical interval results from bundle-branch lesion and prolongation of the pre-ejection period from arborization lesion, the 8 cases of Group B may represent arborization

FIG. 2.—Diagram of the various types of left intraventricular conduction disturbance in 30 cases with an electrical pattern of "left complete bundle-branch block" (LBBB). a: onset of ventricular depolarization. a-b: maximum normal corrected electromechanical interval (EMI), b-c: maximum normal corrected pre-ejection period (PEP) in 42 cases without electrical evidence of LBBB. These intervals are respectively of 0.052 and 0.135 sec.

Group A: no mechanical evidence of left ventricular delay. Group B: arborization block. Group C: bundle-branch block. Group D: combined arborization and bundle-branch block.

block (Fig. 4), the 11 cases of Group C bundle-branch block (Fig. 5), and the remaining 5 cases of Group D combined arborization and bundle-branch block (Fig. 6). It may thus be said that left bundle-branch block accounted for 16 of 24 cases (67%), either alone or in combination with arborization block. Arborization block may be considered in 8 of 24 cases (33%).

Except for the surgical cases which all fell within the group of combined bundle-branch and arborization block (they resulted from incision of the interventricular septum for obstructive cardiomyopathy in two cases and from insertion of a Starr-Edwards prosthetic ball valve for calcific aortic valvular disease in one case), there were no obvious differences in aetiology between the various groups.

Finally, these results are not very dissimilar to those of a histological study of the interventricular septum of 25 cases with typical electrocardiograms of left complete bundle-branch block, in which

FIG. 3.—One example of Group A: aortic incompetence in a man of 24. LI, LII, LIII: standard electrocardiogram leads. LF and HF: respectively low and high frequency phonocardiogram. CP: indirect carotid pulse. ACG: apex cardiogram. 1 and 2: first and second heart sounds; 4: fourth heart sound; sm: systolic murmur; dm: diastolic murmur. Paper speed 50 mm. per sec. with 0.02 sec. intervals between the vertical lines.

Left: electrocardiogram. *Middle:* carotid pulse with phonocardiogram from the aortic area (—: Q-onset of the carotid pulse interval, Q-OCP). *Right:* apex cardiogram with phonocardiogram from the mesocardiac area (—: electromechanical interval, EMI). Corrected Q-OCP interval 0.164 sec., corrected EMI 0.044 sec., corrected PEP 0.120 sec.

FIG. 4.—One example of Group B: idiopathic "left bundle-branch block" in a man of 32. Same abbreviations and presentation as in Fig. 3. Corrected Q-OCP interval 0.228 sec., corrected EMI 0.044 sec., corrected PEP 0.184 sec. Note that N (mitral valve closure) corresponds to the second group of vibrations M of the first heart sound (reversed splitting of the first heart sound).

FIG. 5.—One example of Group C: non-obstructive cardiomyopathy in a man of 60. Same abbreviations and presentation as in Fig. 3. 3+4: summation of third and fourth heart sounds. Corrected Q-OCP interval 0.179 sec., corrected EMI 0.060 sec., corrected PEP 0.119 sec. Note the prominent "a" wave of atrial contraction and the physiological splitting of the second heart sound (P after A).

total or subtotal destruction of the bundle-branch fibres was found in 76 per cent of the cases (Lenègre, 1957).

SUMMARY AND CONCLUSIONS

The phonocardiographic and mechanocardiographic signs of left complete bundle-branch block were assessed in 30 patients in whom the electrocardiograms corresponded to the classical criteria.

The well-known modifications of the heart sounds (widening and softening of the first sound, inverted splitting of the second sound, and accentuation of the fourth sound) were all commonly encountered, but not constantly so.

Comparison between the group of 30 cases with, and a group of 42 cases without, electrocardiographic evidence of left complete bundle-branch block showed that in the former group, left ventricular

FIG. 6.—One example of Group D: non-obstructive cardiomyopathy in a woman of 42. Same abbreviations and presentation as in Fig. 5. Corrected Q-OCP interval 0.222 sec., corrected EMI 0.083 sec., corrected PEP 0.139 sec. Note reversed splitting of the second heart sound (A after P).

ejection was on the average delayed, from both a late onset and a prolonged pre-ejection period of left ventricular contraction. These results were confirmed in the three surgically-induced cases, when post-operative tracings were compared to the pre-operative ones.

The occasional presence of a normal electro-mechanical interval or a normal pre-ejection period made it possible to subdivide the 30 cases with left intraventricular conduction disturbance into four groups: Group A (6 cases), with no mechanical evidence of left ventricular delay; Group B (8 cases), suggestive of arborization block; Group C (11 cases), suggestive of bundle-branch block; and Group D (5 cases), suggestive of combined arborization and bundle-branch block. These suggestions, though difficult to prove, are not unlike the results of one histological study of 25 cases with left complete bundle-branch block.

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