The Electrocardiogram of Combined Ventricular Hypertrophy of the Heart

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SUMMARY

Combined ventricular hypertrophy was the commonest finding at autopsy in cases studied by cardiac partitioning. A large number of electrocardiographic deflections reflected left or right ventricular hypertrophy in cases with combined ventricular hypertrophy. However, no consistent electrocardiographic pattern was found, in keeping with the wide spread of combinations of left and right ventricular weights present in these cases. A division of the entire series into 6 subgroups resulted in the best correlation between the electocardiographic findings and the degree of left and right ventricular hypertrophy established at autopsy. The electrocardiograms in the cases with combined ventricular hypertrophy have been compared with those of normal subjects and those with isolated right ventricular hypertrophy.

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Relatively few studies have been made of the electrocardiogram of combined ventricular hypertrophy of the heart.[1-7] The criteria for such a diagnosis have varied in regard to both the electrocardiogram and the autopsy method of assessment. In the present study an analysis of the electrocardiogram has been made of 61 autopsied cases of combined ventricular hypertrophy. These findings have been compared with the findings in subjects without ventricular hypertrophy,[8] and with isolated right ventricular hypertrophy,[9] using normal standards which seem to have advantages over those previously described.[8]

MATERIAL AND METHODS

The method of Stofer and Hiratzka[10] was used for measuring the weight of the ventricles at autopsy. The normal range of the ventricular weights was considered to be within ±1,96 standard deviations of the average weight found in normal subjects. The degrees of both right and left ventricular hypertrophy were expressed as a ratio, designated as the ventricular weight ratio, or more concisely, as the ventricular ratio. This was obtained by subtracting the average weight of the normal ventricle from the weight of the ventricle found at autopsy, and dividing this figure by the standard deviation of the normal ventricle in question. Right or left ventricular hypertrophy was considered to be present when the ratio was equal to or exceeded 2.

The electrocardiogram had been recorded within 3 years of the autopsy, the average interval being 7 months in the subjects studied. Cases showing evidence of myocardial infarction at autopsy were excluded, as were those whose electrocardiograms had either complete right or left bundle-branch block. Subjects with autopsy findings that could lead to right ventricular hypertrophy over a relatively short period of time were also omitted. This group included cases with primary or secondary cancer of the lung, pulmonary embolic disease and significant pneumonia or lung infections. Sixty-one cases with combined ventricular hypertrophy were available for study. Three of these cases had received digitalis.

The control group consisted of 214 subjects, of whom 59 did not show ventricular hypertrophy at autopsy, and the remainder were normal on clinical and radiological assessment.[8] The degree of the emphysema was moderate or more marked in 4 of the control group, but no evidence of ventricular enlargement was present at postmortem examination. The remaining cases had little evidence of emphysema or silicosis. Thirty-four subjects with isolated right ventricular hypertrophy were used for comparison.[9]

The measurement of the electrocardiogram was made according to accepted conventions. Lead V4R had been recorded in addition to the customary 12 leads. The normal range of the various electrocardiographic deflections was based on a study of the 214 control subjects. Linear regression equations had been calculated in this group where the size of the electrocardiographic deflection was the dependent variable, and either age, mean frontal axis or the transitional point of the praecordial leads was the independent variable.[8] Linear regression equations with only one independent variable were used.[9] The normal limits were considered to be within ±1,96 standard errors of the mean regression line, or within the 2,5 and 97,5 percentile of the various electrocardiographic deflections.[8] Atrial enlargement, either isolated or combined, was diagnosed according to criteria previously described.[11] Probable atrial hypertrophy was diagnosed if some, but not all, of these criteria were fulfilled. Pointedness of the initial part of the P wave was considered to be present if it was found in more than 5 of the 13 leads.

The initial analysis was to compare (chi-square) the electrocardiographic findings in the subjects with combined ventricular hypertrophy, the control or normal group, and those with isolated right ventricular hypertrophy (Table I). Inspection of the electrocardiograms of the combined

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TABLE I. A COMPARISON OF THE ABNORMAL DEFLECTIONS IN THE NORMAL GROUP, THOSE WITH COMBINED VENTRICULAR HYPERTROPHY (L + R) AND ISOLATED RIGHT VENTRICULAR HYPERTROPHY (RV +++)

Groups	L + R v. normal		RV +++ v. L + R				RV +++ v. normal	
			RV +++		L + R			
Criteria	+	−	+	−	+	−	+	−
Q V4R - V3	++		++				++	
QV2 - V3	++							
QV4 - V6	++							
R I	++	+		++	++			++
R II		++		++				++
R III		+		++				++
R aVR			++				++	
R aVL	++			++	++			++
R aVF		++		++				++
V4R - V1			++				++	
V2 - V3	++	++		++	++			++
V4 - V6	++	++		++	++			++
S I	++		++				++	
S II	+						++	
S III	++						++	
S aVR								
S aVL			++				++	
S aVF	++						++	
V4R					++		+	
V1	++	++			++			++
V2 - V3	++	++					++	++
V4 - V6	++						++	
T I		++				++		++
T II		++				++		++
T III		++						++
TaVR	++	+			++		+	
TaVL		++						
TaVF								++
V4R	++	+		++	++			++
V1 - V3		++						++
V4 - V6		++						++
R/S V1 - V3		++		++				++
R/S V4 - V6		++		++				++

++ = significant at the 1% level or less.
+ = significant at the 5% level or less (chi square).

ventricular hypertrophy group, however, showed that a number of distinctive patterns was present, when these were related to the combinations of ventricular weights obtained at autopsy. Six subgroups of the combined ventricular hypertrophy group were established. This classification was made arbitrarily on the basis of the number of positive criteria of left and right ventricular hypertrophy present in the electrocardiogram, the grade of ST-T segment abnormality, and the weight ratios of the ventricular chambers. Overlapping was present in all these features, but their degree of distinction justified the subgrouping. Their characteristics in regard to average ventricular weights were as follows (Fig. 1):

Subgroup 1. Marked left ventricular hypertrophy (ratio 12,6), and moderate right ventricular hypertrophy (ratio 7,9), (L+++ R++).

Subgroup 2. Moderate left ventricular hypertrophy (ratio 7,8), and slight right ventricular hypertrophy (ratio 5,1), (L++ R+).

Subgroup 3. Slight left ventricular hypertrophy (ratio 3,6), and slight right ventricular hypertrophy (ratio 3,8), (L+ R+).

Subgroup 4. Slight left ventricular hypertrophy (ratio 3,6) and slight right ventricular hypertrophy (ratio 4,3), with incomplete right bundle-branch block in the electrocardiogram (L+ R+). Incomplete right bundle-branch block in the electrocardiogram was considered to be present if more than one of the following features was present:

1. An rSr[1] or rSR[1] pattern in any of the right chest leads, V4R to V2.
2. An S1, S2, S3 pattern with slurring of the S waves.
3. A prominent slurred R wave in lead aVR.
4. Prominent and slurred S waves in the left chest leads V4 to V6.

The QRS deviation was less than 0,10 s in all the cases.

Subgroup 5. Slight left ventricular hypertrophy (ratio 3,7) and marked right ventricular hypertrophy (ratio 10,0) (L+ R+++).

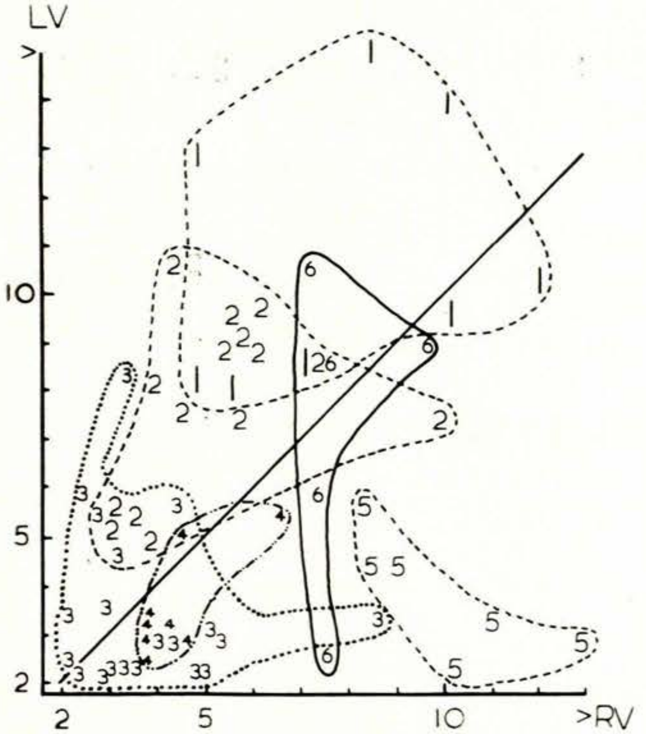

Fig. 1. The ventricular weight ratios of the left ventricle and right ventricle in subgroups 1 to 6.

Subgroup 6. Moderate left ventricular hypertrophy (ratio 7,3) and moderate right ventricular hypertrophy (ratio 7,8) (L++ R++).

A classification of the ST-T segment was made according to the shape of the ST segment and the polarity of the T wave (Fig. 2):

1(*a*). Inversion of the T wave with an upwardly convex ST segment.
(*b*). An upright T wave with an upwardly concave ST segment.
2(*a*). Inversion of the T wave with a straight descending ST segment.
(*b*). An upright T wave with a straight ascending ST segment.
3(*a*). A biphasic (−+) T wave with a straight descending ST segment.
(*b*). A biphasic (+−) T wave with a straight ascending ST segment.
4(*a*). An upright or absent T wave with a horizontal and depressed ST segment.
(*b*). An inverted or absent T wave with a horizontal and elevated ST segment.
5(*a*). An upright T wave with a horizontal and iso-electric ST segment.
(*b*). An inverted T wave with a horizontal and iso-electric ST segment.
6. An absent or iso-electric T wave and a horizontal ST segment showing no or little deviation.

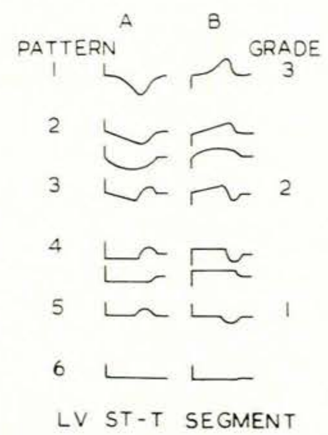

Fig. 2. A classification of the ST-T segment. The patterns listed under A and B are the inverse of each other. The arbitrary grading is indicated down the right hand side of the diagram.

An arbitrary scoring system was devised for the ST-T segment (Fig. 2). ST-T segment changes reflected the degree of left ventricular hypertrophy and were uncommon in isolated right ventricular hypertrophy. As such, they were considered to be left ventricular effects. Grade 3 left ventricular effects consisted of patterns 1 and 2 described above; grade 2 consisted of patterns 3 and 4; and grade 1 of patterns 5 and 6. A normal configuration of the ST-T segment was scored as grade 0. Right ventricular ST patterns were considered to be normal and the grading of right ventricular effects was based entirely on the T-wave inversion in the right chest leads. Grade 3 had inversion of the T wave from leads V4R to V3 and beyond, grade 2 from leads V4R to V2 and grade 1 in leads V4R and VI. Grade 0 had either inverted or upright T waves in lead V4R.

RESULTS

A large number of electrocardiographic abnormalities characterised the combined ventricular hypertrophy group and the isolated right ventricular hypertrophy group, when these were compared with the normal group (Table I). A comparison of the isolated right ventricular hypertrophy group and the combined ventricular hypertrophy group, revealed a lesser number of electrocardiographic abnormalities in each group, presumably due to the presence of right ventricular hypertrophy in both groups.

Criteria were selected from the comparison of the 3 groups studied (Table I), which favoured left ventricular hypertrophy as opposed to right ventricular hypertrophy in the electrocardiogram. In some instances a combination of a particular deflection in a number of leads was made so as to reduce the number of criteria for consideration (Table II). These combinations were made on the basis of

TABLE II. THE NUMBER AND PERCENTAGE OF ABNORMAL ELECTROCARDIOGRAPHIC SIGNS, AND COMBINATIONS OF SIGNS, FAVOURING LEFT AND RIGHT VENTRICULAR HYPERTROPHY IN SUBGROUPS 1 TO 6 (COMBINED VENTRICULAR HYPERTROPHY), THE NORMAL GROUP AND THOSE WITH ISOLATED RIGHT VENTRICULAR HYPERTROPHY

Subgroups (L & R)	1		2		3		4		5		6		Normals		Isolated right vent. h'trophy	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%				
	8	12	14	23	20	33	8	12	6	10	5	8	214		34	
Left ventricular signs																
QV4 — V6	3	37,5	2	14,3	1	5	1	12,5	0	0,0	0	0,0	4	1,9	1	3
RI, RL (+)	5	62,5	5	35,7	5	25	0	0,0	0	0,0	1	20,0	14	6,5	1	3
RV2 — V3 (−)	1	12,5	4	28,6	5	25	5+	62,5	0	0,0	1	20,0	1	0,5	14	41
RV4 — V6 (+)	5	62,5	7	50,0	3	15	0	0,0	0	0,0	1	20,0	15	7,0	0	0
SIII, SF (+)	3	37,5	6	42,8	4	20	2	25,0	0	0,0	1	20,0	17	7,5	10	29
SV4R — V1 (+)	6	75	8	57,1	6	30	1	12,5	0	0,0	2	40,0	25	11,7	1	3
T I (−)	8×	100×	5	35,7	4	20	0	0,0	0	0,0	2	40,0	1	0,5	3	9
T II (−)	8×	100×	5	35,7	3	15	0	0,0	0	0,0	3	60,0	0	0,0	5	15
T III (+)	7×	87,5×	4	28,6	3	15	0	0,0	0	0,0	2	40,0	3	1,4	+1) −7)	3) 21)
TaVR (+)	8×	100×	5	35,7	3	15	0	0,0	0	0,0	1	20,0	3	1,4	2	6
TaVF (−)	6×	75×	2	14,3	1	5	0	0,0	1	16,7	1	20,0	7	3,3	3	9
TV4R — V1 (+)	4	50	7	50,0	6	30	0	0,0	0	0,0	0	0,0	5	2,3	1	3
TV4 — V6 (−)	7	87,5	6	42,8	4	20	0	0,0	0	0,0	0	0,0	0	0,0	5	15
Right ventricular signs																
QV4R — V1	0	0,0	1	7,1	2	10	1	12,5	1	16,7	1	20,0	0	0,0	9	26
R I (−)	0	0,0	0	0	0	0	2	25,0	1	16,7	1	20,0	5	2,3	16	47
R II (−)	0	0,0	1	7,1	1	5	1	12,5	4	66,7	1	20,0	2	0,9	12	35
R III (−)	0	0,0	0	0	0	0	0	0,0	1	16,7	0	0,0	1	0,5	5	15
RaVR (+)	0	0,0	1	7,1	1	5	1	12,5	1	16,7	0	0,0	7	3,3	7	21
aVL (−)	0	0,0	0	0	0	0	0	0,0	1	16,7	0	0,0	1	0,5	4	12
aVF (−)	0	0,0	2	14,3	2	10	1	12,5	4	66,7	2	40,0	2	0,9	7	21
RV4R — V1 (+)	0	0,0	0	0	0	0	0	0,0	2	33,3	0	0,0	6	2,8	7	21
RV4 — V6 (−)	0	0,0	1	7,1	0	0	1	12,5	1	16,7	1	20,0	3	1,4	17	50
S I — S II (+)	0	0,0	1	7,1	1	5	2	25,0	4	66,7	0	0,0	14	6,5	11	32
SV4R — V1 (−)	0	0,0	1	7,1	2	10	3	37,5	4	66,7	1	20,0	2	0,9	8	24
SV4 — V6 (+)	1	12,5	4	28,6	4	20	4	50,0	6	100,0	1	20,0	24	9,4	16	47
TV4R — V3 (−)	0	0,0	1	7,1	1	5	1	12,5	6	100,0	1	20,0	6	2,8	15	44
TV4 — V6 (+)	0	0,0	0	0	2	10	0	0,0	0	0,0	2	40,0	16	7,0	2	6
Atrial enlargement																
LA (+)	2	25,0	4	28,6	4	20	0	0,0	1	16,7	1	20,0	2	0,9	0	0
LA (±)	2	25,0	5	35,7	2	10	1	12,5	0	0,0	1	20,0	3	1,4	1	3
RA (+)	0	0,0	1	7,1	0	0	0	0,0	2	33,3	1	20,0	0	0,0	4	12
RA (±)	0	0,0	1	7,1	0	0	0	0,0	0	0,0			0	0,0	8	24
LA + RA (+)	0	0,0	2	14,3	1	5	1	12,5	1	16,7	1	20,0	0	0,0	0	0
Pointed P waves	5	62,5	6	42,8	1	5	3	37,5	3	50,0	3	60,0	4	1,9	14	41
ST V6	4	50,0	5	35,7	1	5	0	0,0	0	0,0	4	80,0	4	1,9	1	3

× . . . . abnormal T waves; disregard the sign in the left-hand column; see text for discussion.
+ = positive; − = negative; LA = left atrial enlargement; RA = right atrial enlargement; LA + RA(+) = combined atrial enlargement.

TABLE III. THE PERCENTAGE INCIDENCE OF ST-T PATTERNS IN SUBGROUPS 1 TO 6 OF THE COMBINED VENTRICULAR HYPERTROPHY GROUP AND THE ISOLATED RIGHT VENTRICULAR HYPERTROPHY GROUP (RV +++)

ST-T Pattern	1A, 2A							3A							4A, 5A							6						
Subgroup / Lead	1	2	3	4	5	6	RV+++	1	2	3	4	5	6	RV+++	1	2	3	4	5	6	RV+++	1	2	3	4	5	6	RV+++
I	87	0	5	0	0	0	0	0	0	0	0	0	0	0	13	58	10	0	17	0	15	0	8	10	0	0	20	0
II	37	8	0	0	0	0	0	0	0	0	0	0	0	3	25	75	5	0	50	0	9	37	0	5	0	0	20	0
III	13	0	0	0	0	20	12	0	0	0	0	0	0	3	0	25	5	0	17	0	24	0	25	5	0	0	40	6
R	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	13	17	0	0	0	60	0
L	87	0	0	0	0	0	3	0	0	0	0	0	0	0	13	33	14	0	0	0	6	0	8	10	0	0	40	9
F	25	0	0	0	0	20	0	0	0	0	0	0	0	0	13	50	10	13	17	20	26	13	8	10	0	0	0	0
V4R	0	0	0	0	100	0	65	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
V1	0	0	0	0	100	0	44	0	0	0	0	0	0	9	0	0	0	0	0	0	9	0	0	0	0	0	0	0
V2	0	0	0	0	66	0	29	0	0	0	0	0	0	3	0	8	0	0	0	0	3	0	0	0	0	0	0	3
V3	13	0	0	0	33	0	12	0	0	0	0	0	0	6	0	17	5	13	33	0	6	0	0	0	0	0	0	0
V4	50	0	5	0	33	0	6	0	0	0	0	0	0	0	0	50	5	0	0	0	9	0	0	5	0	0	0	0
V5	87	0	5	0	17	0	3	0	8	0	0	0	0	0	0	50	14	13	0	0	6	0	8	5	0	0	0	0
V6	100	0	5	0	0	0	0	0	42	0	0	0	0	0	0	50	42	37	17	0	9		0	10	0	0	0	0
ST-T pattern	1B, 2B							3B							4B, 5B							Normal						
I	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	26	76	100	83	80	74
II	0	0	5	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	17	86	100	50	80	85
III	87	0	5	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	33	86	100	83	40	56
R	75	0	0	0	0	0	0	13	42	0	0	0	0	0	0	17	0	0	0	0	0	0	17	76	100	100	40	100
L	0	0	0	0	0	0	18	0	0	5	0	0	0	0	0	33	10	0	0	0	3	0	25	62	100	100	60	62
F	50	0	5	0	0	0	0	0	0	14	0	0	0	0	0	8	0	0	17	0	0	0	33	76	87	66	60	68
V4R	100	58	15	0	0	0	12	0	0	10	0	0	0	0	0	0	0	13	0	0	0	0	42	86	87	0	100	12
V1	100	50	0	0	0	0	24	0	0	0	0	0	0	0	0	8	0	13	0	0	0	0	42	100	87	0	100	12
V2	100	58	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	13	33	0	0	0	33	100	87	0	100	53
V3	87	58	10	0	0	0	6	0	0	0	0	0	0	0	0	0	0	13	17	0	3	0	25	81	75	17	100	68
V4	50	42	10	0	0	0	3	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	8	81	100	66	100	82
V5	0	25	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	8	76	87	66	100	88
V6	0	0	0	0	0	0	3	0	0	14	0	0	0	0	0	0	0	0	17	0	0	0	8	43	63	66	100	88

the comparisons made, as well as the electrocardiographic criteria customarily used in the diagnosis of ventricular hypertrophy. The diagnosis of combined ventricular hypertrophy required the presence of both left and right ventricular hypertrophy criteria in the electrocardiogram. The findings in subgroups 1 to 6 have been presented in Tables II to V. A comparison of these groups with the normal groups has been included in Table II, while comparisons with the isolated right ventricular hypertrophy group have been made in Tables II and III.

TABLE IV. INCIDENCE OF QRS-T AND ST-T CRITERIA FOR BOTH LEFT (LV) AND RIGHT VENTRICULAR (RV) HYPERTROPHY IN THE 6 SUBGROUPS OF COMBINED VENTRICULAR HYPERTROPHY

Subgroup	No.	Electrocardiographic criteria (LV and RV)			
		2 or more	3 or more	4 or more	5 or more
1	8	8	8	8	8
	%	100	100	100	100
2	14	14	14	14	13
	%	100	100	100	92,8
3	20	17	11	10	4
	%	85	55	50	20
4	8	8	6	4	3
	%	100	75,0	50,0	37,5
5	6	6	6	6	6
	%	100	100	100	100
6	5	5	5	4	4
	%	100	100	80,0	80,0

Subgroup 1 (L+++ R++) presented a distinctive and consistent pattern of electrocardiographic abnormalities, indicative of left ventricular enlargement (Fig. 3). Abnormally large Q waves could be present in leads V4 to V6 (37,5%). Tall R waves were observed in leads I, aVL and V4 to V6 in over half the cases (62,5%). Large S waves were present in leads III and aVF (37,5%) and in leads V4R to V1 (75%). The axis of the T wave was abnormal with the exception of 1 case (Fig. 5). As a result, T-wave abnormality based on regression equations, with the fron-

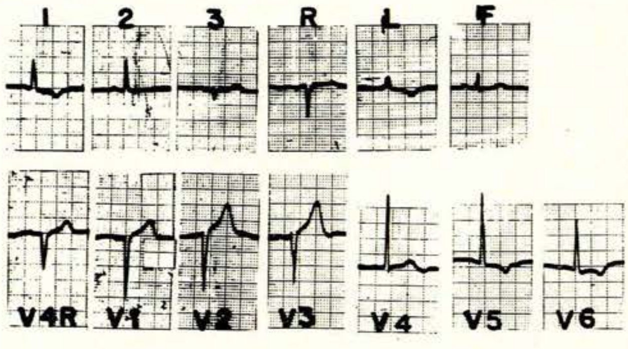

Fig. 3. An electrocardiogram representative of subgroup 1 (L+++ R+++). The T waves are abnormal in leads I, II, III, aVR and aVL. R-wave size is diminished in leads V2 and V3, and increased in lead V4. The S-wave size is increased in leads V4R and V1. The T waves are abnormally large in leads V4R to V2, and inverted in leads V5 and V6. The ST-T pattern is characteristic for this group.

TABLE V. INCIDENCE OF QRS-T AND ST-T CRITERIA FOR LEFT (LV) AND RIGHT VENTRICULAR (RV) HYPERTROPHY IN THE 6 SUBGROUPS OF COMBINED VENTRICULAR HYPERTROPHY

Subgroup	Criteria	No.	Electrocardiographic criteria: 1 or more		2 or more		3 or more	
			LV	RV	LV	RV	LV	RV
1	QRS-T	8	8 (100 %)	1 (12,5%)	8 (100 %)	0 (0%)	8 (100 %)	0 (0%)
	ST-T		8 (100 %)	0 (0%)	8 (100 %)	0 (0%)	8 (100 %)	0 (0%)
	Combined		8 (100 %)	1 (12,5%)	8 (100 %)	0 (0%)	8 (100 %)	0 (0%)
2	QRS-T	14	14 (100 %)	6 (42,8%)	14 (100 %)	4 (28,6%)	13 (92,8%)	1 (7,1%)
	ST-T		13 (92,8%)	1 (7,1%)	9 (64,2%)	0 (0%)	0 (0%)	0 (0%)
	Combined		14 (100 %)	6 (42,8%)	14 (100 %)	5 (35,7%)	13 (92,8%)	1 (7,1%)
3	QRS-T	20	16 (80 %)	9 (45,0%)	13 (65 %)	3 (15,0%)	7 (35,0%)	1 (5,0%)
	ST-T		8 (40 %)	2 (10,0%)	2 (10 %)	0 (0%)	0 (0%)	0 (0%)
	Combined		16 (80 %)	9 (45,0%)	14 (70 %)	4 (20,0%)	10 (50,0%)	1 (5%)
4	QRS-T	8	7 (87,5%)	7 (87,5%)	2 (25,0%)	4 (50,0%)	0 (0%)	3 (37,5%)
	ST-T		1 (12,5%)	1 (12,5%)	1 (12,5%)	0 (0%)	0 (0%)	0 (0%)
	Combined		7 (87,5%)	7 (87,5%)	3 (37,5%)	5 (62,5%)	2 (25,0%)	3 (37,5%)
5	QRS-T	6	2 (33,3%)	6 (100 %)	1 (16,7%)	6 (100 %)	0 (0%)	5 (83,5%)
	ST-T		1 (16,7%)	6 (100 %)	0 (0%)	6 (100 %)	0 (0%)	6 (100 %)
	Combined		3 (50,0%)	6 (100 %)	1 (16,7%)	6 (100 %)	0 (0%)	6 (100 %)
6	QRS-T	5	4 (80,0%)	4 (80,0%)	4 (80,0%)	3 (60,0%)	3 (60,0%)	2 (40,0%)
	ST-T		4 (80,0%)	3 (60,0%)	0 (0%)	1 (20,0%)	0 (0%)	1 (20,0%)
	Combined		5 (100 %)	5 (100 %)	4 (80,0%)	4 (80,0%)	4 (80,0%)	2 (40,0%)
	Total	61	53	34	44	24	37	13
		%	87	56	72	39	61	21

The number and percentage of abnormal QRS-T signs are given, while the ST-T pattern is graded from 0 to 2. The combined result is the sum of the number of abnormal QRS-T signs and the grade of ST-T pattern abnormality.

tal axis of the T wave as the independent variable, could result in a negative ratio when in fact the T wave was positive. As such, abnormalities of the T wave were considered only in relation to their actual polarity, irrespective of the sign of the ratio calculated from the regression equation. Such an approach allowed the recognition of the pattern of T-wave change, and was only applied to subgroup 1, the frontal axis of the T wave being normal or near normal in the other subgroups. The T wave was abnormal in all cases of leads I and II, in 87,5% in lead III, lead aVR and lead aVF, and in 25% in lead aVL. The pattern of the T wave, however, was predominantly negative in lead I (87,5%) and lead aVL (100%), and positive in lead III (87,5%) and lead aVR (87,5%). Positive T waves were not encountered in lead I where the T wave was iso-electric in 12,5%. Lead II had T waves which were negative (37,5%) or iso-electric (37,5%), with 25% being positive. Only 1 case in lead III (12,5%) and lead aVR (12,5%) had negative T waves. The T waves in lead aVF were negative in 25%, iso-electric in 12,5% and positive in 62,5%. The T wave in the chest leads was abnormally tall in leads V4R - V1 in 50% of cases, and inverted in leads V4 - V6 in 87,5% of cases. Only one electrocardiographic sign of right ventricular enlargement was present (12,5%), where the S waves were large in leads V4 - V6.

Criteria of left ventricular enlargement occurred less frequently in subgroup 2 (14% to 57%) and less so in subgroup 3 (5% to 30%) (Table II). Many of the criteria of right ventricular enlargement were present in both groups, the incidence varying from 10% to 30% in regard to individual criteria. T-wave abnormalities in the chest leads, however, were approximately twice as common in subgroup 2 as compared with subgroup 3.

Subgroup 4 (L+ R+) was characterised by incomplete right bundle-branch block. The incidence of positive right ventricular signs was greater than in subgroup 3, despite a similar distribution of right ventricular weights in both groups (Table II). A feature of note was the presence of abnormally tall R waves in leads V2 and V3 (63%).

Subgroup 5 (L+ R+++) was devoid of signs of left ventricular enlargement with one exception, and signs of right ventricular enlargement were frequently present (Table II). All cases had large S waves in leads V4 and V6 and negative T waves in leads V4R - V3 (100%). Subgroup 6 (L++ R++) had both left and right ventricular signs in almost equal numbers.

The ST-T pattern was abnormal in all cases of subgroup 1 (L+++ R++), with type 1a and 1b predominating (Table III, Fig. 4). A low evidence of type 5a was present in the limb leads. Approximately one third of the ST-T patterns were normal in subgroup 2 (L++ R+), except for the left chest leads, where normal patterns were present in only 8% of cases. Patterns 3a and 4a predominated in these leads. The limb leads were chiefly characterised by patterns 4a, 5a, 5b and 6. The ST-T pattern in subgroups 3 and 4 (L+ R+) was normal in most leads, with the 4a and 5a patterns predominating in the left chest leads. The inversion of the T waves in leads V4R to V3 in subgroup 5 (R+++ L+) resulted in a high incidence of type 1a pattern (65% in V4R). The ST-T pattern was normal

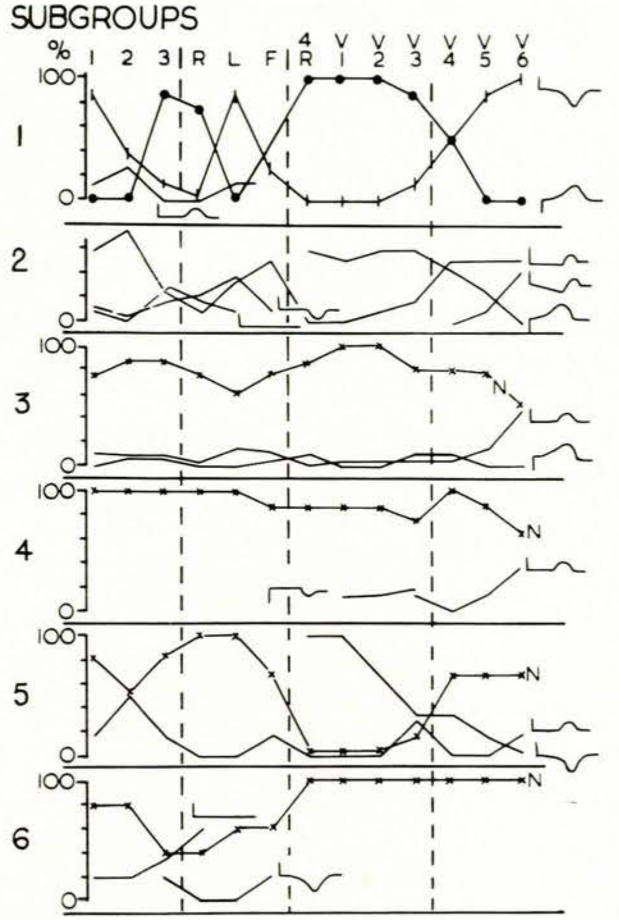

Fig. 4. The predominant ST-T patterns in the subgroups 1 to 6 are demonstrated from data given in more detail in Table III.

in the majority of the remaining leads, except for a low incidence of type 5a. Despite moderate enlargement of both the left and right ventricles in subgroup 6 (L++ R++), a high incidence of normal ST-T patterns was observed, ranging from 40% in leads III and aVR to 100% in the chest leads.

Left atrial enlargement and probable left atrial enlargement was present in approximately half the cases of subgroups 1 and 2, and to a lesser extent in subgroup 3 (30%) and subgroup 4 (13%) (Table II). Even in the predominantly right ventricular hypertrophy group (subgroup 5), 17% of cases demonstrated left atrial enlargement. A 40% incidence of left atrial enlargement (actual and probable) was observed in subgroup 6. Right atrial enlargement was absent or infrequent in subgroups 1 to 4, and was present in 33% of subgroups 5 and 6. Combined atrial hypertrophy was infrequent. The incidence of pointed P waves in 6 or more leads was high, and its presence appeared to reflect the degree of right ventricular hypertrophy.

The axis of the P wave did not exceed the 2,5 and 97,5 percentiles in any of the subgroups (Fig. 5). The mean

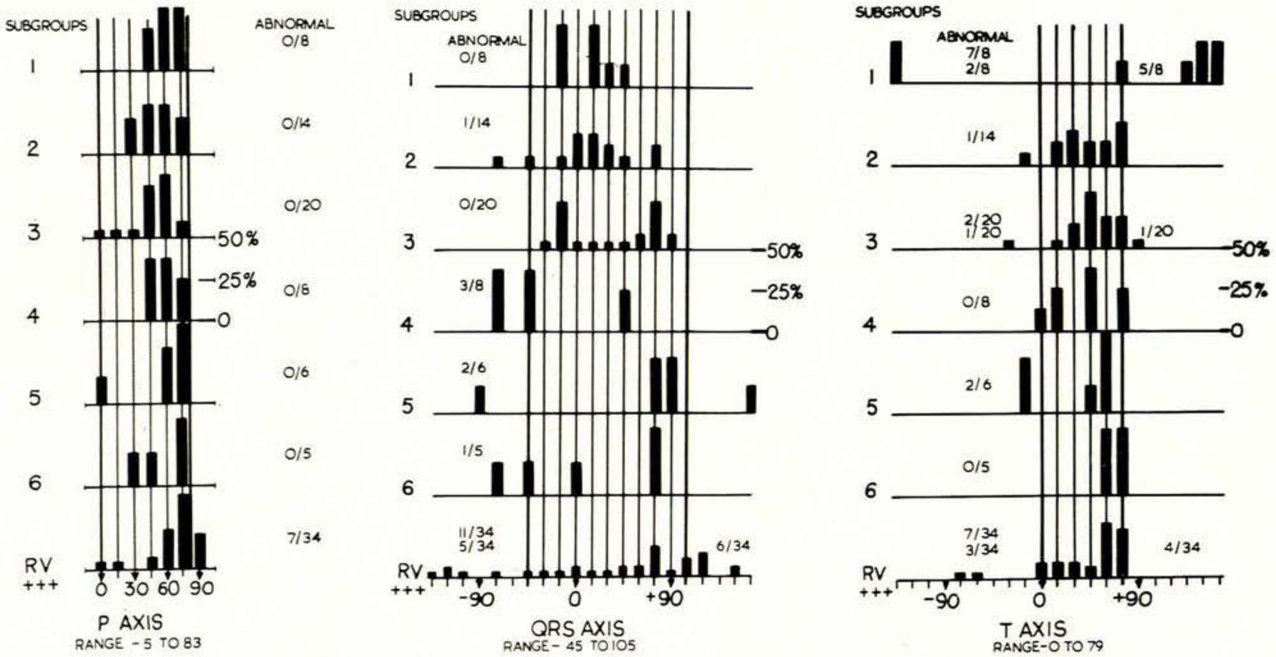

Fig. 5. The distribution of the mean frontal electrical axis of the P wave, QRS complex and the T wave is represented for subgroups 1 to 6 and the isolated right ventricular hypertrophy group (RV +++). The normal limits are indicated by the heavier vertical lines. The number of cases exceeding the limits of normality are given under the heading 'abnormal'.

frontal axis of the QRS complex was normal in subgroups 1 to 3 with a single exception that showed a left axis deviation of left anterior hemiblock type (Fig. 5). A left axis of −45 degrees or more was present in 38% of subgroup 4 due to the effects of incomplete right bundle-branch block on this calculation. An abnormal axis deviation (ÂQRS) was present in 33% of subgroup 5, and 20% in subgroup 6. The mean frontal axis of the T wave was abnormal in 88% of subgroup 1. Only isolated abnormalities of the T-wave axis were observed in the remaining subgroups, except for subgroup 6 in which a left axis of −15 degrees was observed in 33% of the cases.

The incidence of individual electrocardiographic deflections exceeding the normal limits in the control group was low.[8] Among the criteria chosen for the diagnosis of left and right ventricular hypertrophy, certain deflections had been grouped into a single criterion. The incidence of such combinations in the control group could be high, in particular R I, R L (+) 6,5%, R V4 - R V6 (+) 7,0%, S I, S II (+) 6,5%, S III, S aVF (+) 7,5%, S V4R, S V1 (+) 11,7% and S V4 - V6 (+) 9,4% (Table II). Combinations of electrocardiographic criteria for left and right ventricular hypertrophy were present in the control series. Six cases had one of each of these criteria. A further 9 cases had the following combinations of left (LV) and right (RV) ventricular hypertrophy criteria: 2 cases LV 2, RV 1; 1 case LV 2, RV 2; 3 cases LV 1, RV 3; 1 case LV 3, RV 1; 1 case LV 3, RV 3; 1 case LV 1, RV 4. As such 8% of the normal cases had one or more electrocardiographic signs of both left and right ventricular hypertrophy.

The number of positive electrocardiographic criteria of both left and right ventricular hypertrophy was 5 or more in all the cases of subgroups 1 and 5 (Table IV, Fig. 6). Four such signs were present in all the cases of subgroup 2, 3 such signs were present in all the cases of subgroup 6, and 2 such signs in all the cases of subgroup 4. Subgroup 3 had the lowest incidence of positive electrocardiographic signs, in that 85% of cases have two criteria of ventricular hypertrophy.

A consideration of the number of electrocardiographic criteria of left and right ventricular hypertrophy independently, and the grade of ST-T segment pattern, probably represents the most accurate description of left and right ventricular effects in combined ventricular hypertrophy (Table V). The incidence of QRS-T signs and ST-T grade have been given independently and combined in Table V. The incidence of the combined QRS-T criteria and ST-T grade could exceed the incidence of these criteria independently in some instances. For example, if one QRS-T sign and a grade 1 ST-T pattern occurred in the individual case, the combination of the electrocardiographic criteria was 2. The ST-T pattern of right ventricular hypertrophy (T-wave inversion in the right chest leads) can be observed in normal subjects for grade 1 and 2. This pattern was only considered to be significant if there were additional signs of right and/or left ventricular hypertrophy, based on QRS-T signs.

A value of 2 for the QRS-T signs and ST-T grade for both left ventricular hypertrophy (LV) and right ventricular hypertrophy (RV) was as folows (Table V): Subgroup 1, LV 100%, RV 0%; subgroup 2, LV 100%, RV 35,7%; subgroup 3, LV 70,0%, RV 20,0%; subgroup 4, LV 37,5%, RV 62,5%; subgroup 5, LV 16,7%, RV 100%; subgroup 6, LV 80,0%, RV 80,0%. For the total series, 72,0% had a

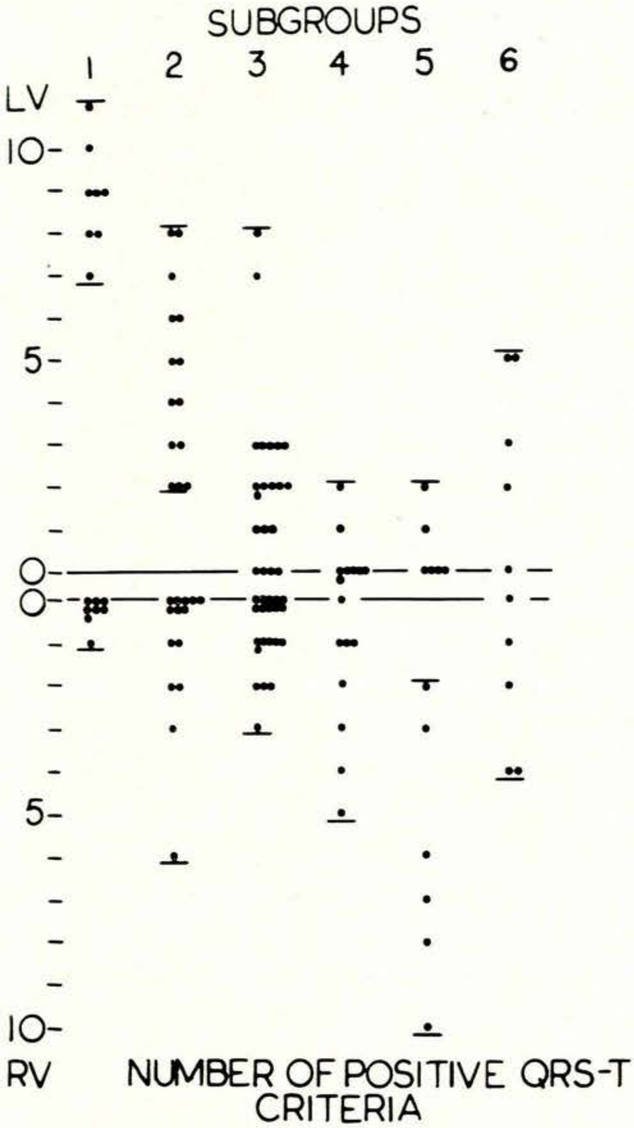

Fig. 6. The number of positive electrocardiographic criteria (QRS-T) for left ventricular enlargement and right ventricular enlargement in subgroups 1 to 6. The electrocardiographic criteria are those listed in Table II.

value of 2 for left ventricular enlargement, and a value of 2 for right ventricular enlargement was achieved in 39% of the cases. The incidence in the control group was low, when a combination of 2 or more electrocardiographic criteria of both left and right ventricular hypertrophy were required to establish a diagnosis of combined ventricular hypertrophy. Such findings only occurred in 2 cases of the control group and their combination of left ventricular signs was not present in the cases with combined ventricular hypertrophy. When a value of 3 or more for both left and right ventricular hypertrophy was required, only 1 case in the control series had such a finding, and this particular combination was not observed in the cases with combined ventricular hypertrophy. Whether a value of 1 for QRS-T signs and ST-T grade can be considered diagnostic of combined ventricular hypertrophy, is debatable. Sixteen normal cases (8%) had such a combination of signs or more, which would indicate that normal subjects would have 1 in 12,5 chances of producing such a result. The yield, however, in regard to the diagnosis of combined ventricular hypertrophy would be greater than it would if a value of 2 or 3 were required for such a diagnosis (Table V).

The combination of the number of abnormal QRS-T signs of ventricular enlargement and the grade of ST-T pattern increased the number of positive criteria over and above those found when these items were considered individually (Table V). The increase was slight in most instances, indicating a rough parallelism between the number of QRS-T abnormalities and the grade of ST-T abnormality (Table V). The grade of ST-T abnormality was less than the number of QRS-T abnormalities in each subgroup, with the exception of subgroup 1, where they were equal. For subgroups 2 to 4, the difference between the QRS-T criteria and grade of ST-T deviation became more marked, with the former having a higher incidence of abnormality than the grade of ST-T segment deviation. Subgroup 6 was of interest in that ST-T abnormalities indicative of left ventricular enlargement did not occur, and were only found for 20% of the cases at a level of grade 2 for right ventricular enlargement. This was surprising in view of the degree of left and right ventricular hypertrophy present in this group (LV ratio 7,3, RV ratio 7,8). In 2 cases electrocardiographic QRS-T criteria for left ventricular hypertrophy were associated with abnormally negative T waves in the right chest leads consistent with a grade 2 to 3 right ventricular ST-T pattern.

DISCUSSION

The electrocardiographic abnormalities in combined ventricular hypertrophy cover a wide spectrum, in keeping with the wide spread of combinations of ventricular weights which were observed. In conformity with other reports, it was found that no single electrocardiographic pattern exists in the entire group.[1-7] However, subgroups exist where the electrocardiographic pattern and ventricular weights are sufficiently consistent to justify the subdivisions.

The electrocardiographic pattern of subgroup 1 (L+++ R++) was distinctive and consistent, with left ventricular QRS-T criteria occurring exclusively with one exception, and a grade 3 ST-T pattern being consistently present (Fig. 3). The only suggestion of right heart involvement was the presence of deep S waves in the left chest leads in 1 case, and pointedness of the initial part of the P wave (Table II). This pattern has universally been referred to as 'marked left ventricular hypertrophy and strain' in the medical literature, despite the invariable presence of moderate right ventricular hypertrophy in the present series.[12] This easily recognisable electrocardiogram is thus one of combined ventricular hypertrophy with marked left and moderate right ventricular hypertrophy.

The degree of left ventricular hypertrophy decreased from subgroup 1 to subgroup 3, with a parallel decrease in the incidence of the number of abnormally large R and S waves, and abnormal S-T segments and T waves (Tables II, III). The genesis of the increased voltage of the QRS complex is poorly understood in left ventricular hypertrophy. It probably results from delayed activation (or depolarisation) of the hypertrophied left ventricular base, a region of the heart which is normally activated late.[13] At this time, delay in the depolarisation of the hypertrophied left ventricular base is not subject to the cancellation effects of the right and residual left ventricular effects, as occur normally, and large voltages are generated. It is highly likely that the T-wave changes are secondary to the altered left ventricular depolarisation in the typical and consistent electrocardiographic pattern of subgroup 1. In effect, this electrocardiogram is one of left ventricular parietal (basal) block with secondary S-T and T-wave changes. To what extent the lesser grades of ST-T segment change are secondary to voltage increases of the QRS complexes remains a matter of conjecture. The rough parallelism between the grade of ST-T segment abnormality and the incidence of abnormally large R and S waves, suggests that the ST-T changes of lesser degree could be secondary to the voltage changes. Factors responsible for primary T-wave changes in left ventricular hypertrophy have appeared to be over-estimated.

The electrocardiographic diagnosis of left ventricular hypertrophy was possible in all the cases of subgroup 2, and in about one-third of the cases of right ventricular hypertrophy, if a figure of 2 or more QRS-T criteria and ST-T grades was required for the diagnosis of both left and right ventricular hypertrophy (Table V). The ST-T pattern was grade 2 or more in more than half the cases. A lower incidence of left ventricular enlargement could be diagnosed in subgroup 3 (70%), while right ventricular hypertrophy was present in about one-fifth of the cases, and ST-T abnormalities were much less common. These findings are consistent with the lesser degree of left and right ventricular hypertrophy in subgroup 3 as compared with subgroup 2. They differ from the findings in subgroup 1, where an almost negligible incidence of signs of right ventricular hypertrophy was found. In subgroups 2, 3 and 4 it would appear that the degree of left ventricular hypertrophy was not sufficiently marked to cancel the electrocardiographic right ventricular manifestations, as it did in subgroup 1. Electrocardiographic manifestations of right ventricular hypertrophy were more common.

Subgroup 4 (L+ R+) was distinguished by the presence of incomplete right bundle-branch block. The incidence of left ventricular QRS-T signs was less, and of right ventricular hypertrophy more numerous than that found in subgroup 3 (L+ R+), despite almost similar ventricular weights in the 2 groups (Table V). The differences in the 2 groups were primarily due to accentuation of right ventricular signs in subgroup 4, such as accentuation of the S waves in the limb and left chest leads, a decrease in the size of the S waves in the right chest leads, and a decrease in the size of the R waves in the left chest leads (Table II). These findings can be attributed to the effects of incomplete right bundle-branch block rather than to right ventricular hypertrophy, and point to the need for separate standards for normal subjects showing this electrocardiographic pattern. An unexpected finding was the presence of R (+) in leads V2 and V3 in 63% of subgroup 4. It is possible that this finding is a valid criterion of combined ventricular hypertrophy in this group, despite its explanation being unknown.

Right ventricular hypertrophy could be diagnosed in all cases of subgroup 5 (+ R+++), and evidence of left ventricular hypertrophy was minimal (Table V). The influence of left ventricular hypertrophy in this group (LV ratio 3,7, RV ratio 10,0) can be assessed by comparing it with 8 of the extreme cases of isolated ventricular hypertrophy (LV ratio 0,4; RV ratio 8,3). The features which appeared to favour associated mild left ventricular hypertrophy in the presence of moderate or more marked right ventricular hypertrophy, were a lesser incidence of R I (−) and R V4 - V6 (−), while the incidence of R2 (−) and possibly R F (−) was increased. The incidence of S V1 (+) and S V5 - V6 (+) was increased, while abnormal S waves in aVL and aVF were not found (Fig. 7). As such, these features suggest mild left ventricular hypertrophy in the presence of moderate or more marked right ventricular hypertrophy. The incidence of T inversion in the chest leads was more common in leads

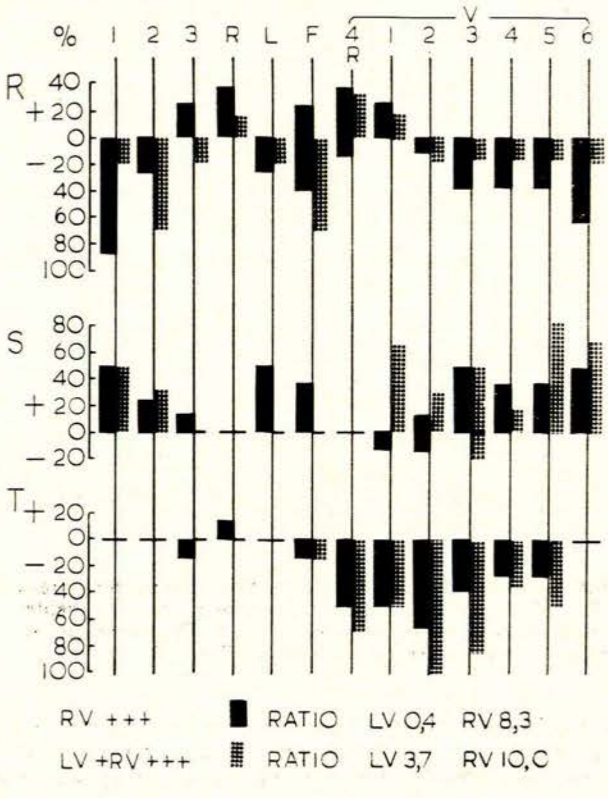

Fig. 7. The percentage incidence of abnormal R, S, T complexes has been compared in 8 of the extreme cases of the isolated right ventricular hypertrophy group (RV +++), and subgroup 5, which comprises cases of combined ventricular hypertrophy with marked predominance of right ventricular hypertrophy and mild left ventricular hypertrophy (L+ R+++).

V2 - V6 in subgroup 5, and was probably due to the heavier right ventricle in this group (RV ratio 10,0), as compared with the isolated right ventricular hypertrophy group (RV ratio 8,3).

Subgroup 6 (L++ R++) presented a surprisingly nondescript pattern of the electrocardiogram including a high incidence of normal ST-T segments, considering the presence of moderate left ventricular (ratio 7,3) and right ventricular (ratio 7,8) hypertrophy. The group occupied a unique position in regard to the ventricular weights, sandwiched between the left and right ventricular preponderant groups (Fig. 1). The electrocardiogram was of no distinctive pattern due to cancellation of the left and right ventricular effects.[2] Where abnormalities of the QRS-T complex did occur, these were approximately equally distributed between the left and right ventricular criteria in the individual cases.

Two cases presented with QRS abnormalities of left ventricular hypertrophy and abnormal inversion of the T waves in the right chest leads, indicative of right ventricular ST-T abnormalities. The combination was unique, in that combined ventricular hypertrophy was based on QRS abnormalities for the diagnosis of left ventricular hypertrophy, and T-wave abnormalities for the diagnosis of right ventricular hypertrophy. Such a combination for the diagnosis of combined ventricular hypertrophy has previously been stressed by Pagnoni and Goodwin.[3] While T-wave inversion in the right chest leads can occur normally, it can be indicative of associated right ventricular hypertrophy if the electrocardiogram shows evidence of predominant left ventricular hypertrophy. Lesser grades of ST-T pattern deviation in the right chest leads need further study in the presence of electrocardiographic evidence of left ventricular hypertrophy. In particular this applies to an upwardly convex ST segment in the right chest leads, with or without terminal dipping of the T wave. Commonly in left ventricular enlargement the ST-T pattern in the right chest leads has an upwardly concave ST segment and an upright T wave, which differs quite markedly from the pattern described above.

The P-wave axis did not exceed the normal limits in any of the 6 subgroups of combined ventricular strain, whereas it did so in 21% of the cases of isolated right ventricular hypertrophy (Fig. 5). A P wave to the right of the upper limits of normal would favour the latter diagnosis. A mean frontal axis of the QRS complex to the right of 105 degrees did not occur in subgroups 1 - 4 and 6. Such a degree of right axis deviation was only observed in the isolated right ventricular hypertrophy group (18%) and subgroup 5 (17%). A superior or left axis deviation was due to left anterior hemiblock in subgroups 2 to 3, or was due to incomplete right bundle-branch block in subgroup 4, some cases of subgroups 5 and 6, and the isolated right ventricular hypertrophy group. Extreme right axis deviation (−90 degrees to −180 degrees) characterised the isolated right ventricular hypertrophy group. The mean frontal axis of the T wave was abnormal with one exception in subgroup 1, being normal in most cases of subgroups 2 - 6. When an abnormal axis deviation did occur it was to the left in 7,5%, and to the right in 2%, of the 53 cases in subgroups 2 - 6. A right axis of the T wave beyond +80 degrees favoured isolated right ventricular hypertrophy, but the deviation beyond this limit was only marginal.

Left, right or combined atrial hypertrophy did not appreciably add to the frequency with which the associated ventricular hypertrophy could be diagnosed. In addition atrial hypertrophy did not reflect the degree of associated ventricular hypertrophy. Pointedness of the initial part of the P wave, however, appeared to show some relationship to the degree of right ventricular hypertrophy. The lack of relationship between ventricular weight and atrial hypertrophy has been commented on previously.[4,7] The findings are contrary to those of Morris *et al.*,[14] who pointed out that electrocardiographic evidence of left atrial enlargement is a useful criterion for left ventricular hypertrophy. This study, however, was made on subjects with valvular heart disease, and would not necessarily apply to ventricular hypertrophy in the absence of valvular heart disease.

The accuracy of the electrocardiographic diagnosis of combined ventricular hypertrophy in previous publications has varied from extremely low to 26% of cases.[1-7] In most of these studies chamber enlargement of the heart was assessed by autopsy criteria. An over-all accuracy of 30% was achieved in the individual cases of the present study at a figure of 2 for the number of QRS-T abnormalities and the grade of ST-T segment deviation. This figure was reduced to 28% of subgroup 1 was eliminated, where combined ventricular hypertrophy was inferred from the electrocardiogram pattern, because of its variable association with combined ventricular hypertrophy at autopsy. If the criteria of Pagnoni and Goodwin[3] were applied to the present series 6% of the cases had one criterion of left ventricular and right ventricular enlargement, and none had 2 or more such criteria. In their own series of cases, however, these authors were able to diagnose 26% of cases of combined ventricular hypertrophy. It is apparent that the limited number of criteria used by these authors and others accounts for low incidence of positive diagnoses achieved, in addition to the arbitrary limits of normality adopted in these studies.[1-7]

Combined ventricular hypertrophy was by far the commonest finding in our study of 116 cases at autopsy. Thompson and White[15] had observed the common finding of right ventricular hypertrophy in the presence of left ventricular hypertrophy. Isolated left ventricular hypertrophy was in present only 5 cases, combined ventricular hypertrophy in 61 cases, isolated right ventricular hypertrophy in 34 cases, and left ventricular atrophy in 16 cases. It is possible that the above findings depend partly on the method of study at autopsy, the normal standards being based on the results of Stofer and Hiratzka.[10] The latter authors' study was conducted at an altitude close to sea-level, whereas it is highly likely that the right ventricle normally weighs slightly more at the altitude at which the present study was conducted (1 763 m). Despite these reservations, it is apparent that isolated left ventricular hypertrophy is uncommon, and consideration should be given to associated right ventricular hypertrophy where the electrocardiogram shows evidence of predominant left ventricular hypertrophy.

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