The Electrocardiogram in Isolated Right Ventricular Hypertrophy due to Chronic Respiratory Disease

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SUMMARY

The electrocardiograms of 34 cases with isolated right ventricular hypertrophy diagnosed at autopsy have been analysed. Only subjects having chronic respiratory diseases of long duration were considered. These results have been compared with normal standards for the electrocardiogram which have advantages over those previously published. Thirty-three deflections, or combinations of deflections, of the electrocardiogram were found to characterise the isolated right ventricular hypertrophy group. Although combinations of abnormal electrocardiographic deflections could be found in some of the normal group, they did not conform to those found in the isolated right ventricular hypertrophy group in the vast majority of the cases. As such, 91% of the electrocardiograms of isolated right ventricular hypertrophy were distinctive. These results have been compared with previous reports dealing with the electrocardiographic diagnosis of right ventricular hypertrophy. Attempts at gauging the degree of right ventricular hypertrophy from the electrocardiogram have been made.

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The introduction of the Wilson extremity and chest leads (V) led to improved criteria for the electrocardiographic diagnosis of right ventricular hypertrophy.[1,2] Qualitative criteria were described in early studies,[3-4] to be superseded by quantitative standards.[5-23] There is no uniformity about the electrocardiographic criteria for the diagnosis of right ventricular hypertrophy, despite the long period over which such studies have been made. There is a similar lack of agreement in attempts to relate the electrocardiogram to the functional disturbances resulting from chronic bronchitis and emphysema.[24-30]

New standards for the normal electrocardiogram have been used in the present study[31] in order to assess the electrocardiographic changes which occur in cases having isolated right ventricular hypertrophy at autopsy resulting from chronic respiratory diseases.

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METHODS AND MATERIAL

Isolated right ventricular hypertrophy was assessed at autopsy. The method of Stofer and Hiratska was used, in which the weights of the right and the left ventricles are measured after bisecting the ventricular septum.[32] The normal range for the ventricular weight was considered to be within 1,96 standard deviations above and below the average weight found in normal subjects. The degree of right ventricular hypertrophy was expressed as a ratio (right ventricular ratio), and was estimated by dividing the difference between the average weight of the normal right ventricle and the weight of the right ventricle found at autopsy, by the standard deviation of the normal group.[36] Subjects were considered to have isolated right ventricular hypertrophy if the right ventricular weight exceeded the normal limits, and if the weight of the left ventricle fell within the normal limits. Included, however, were 3 cases in whom the left ventricular weight was below the normal limits, despite the presence of right ventricular hypertrophy.

In the cases of isolated ventricular hypertrophy selected for study the autopsy had been performed within 3 years of the recording of the electrocardiogram. The average interval was 9 months. Only those subjects were chosen in whom chronic pulmonary disease (emphysema, silicosis, etc.) was considered to have caused the right ventricular hypertrophy. Subjects having thrombo-embolic disease, primary or secondary cancer, pneumonia or myocardial infarction at autopsy were excluded. Thirty-four cases fulfilled these requirements.

The control or 'normal' 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.[31] The degree of emphysema was moderate or more in 4 of the control group, but no evidence of ventricular hypertrophy was present at post-mortem examination. The remaining cases had little evidence of emphysema or silicosis beyond a mild degree.

Linear regression equations were used as normal standards, which related the size of the electrocardiographic deflections (dependent variable) to age, mean frontal axis and the transitional point of the chest leads (independent variables, Table I). Only those equations with one independent variable were considered in the present analysis.[31] Any deflection was considered to be abnormal which deviated 2,0 or more standard errors from the mean regression line. In addition, a deflection was considered abnormal if it exceeded the 97,5 percentile, or was less than 2,5 percentile of the normal group. Only the latter criteria

TABLE I. NORMAL STANDARDS FOR THE ELECTROCARDIOGRAM

	Regression equation (y = ax + b)	r	SEE	Percentile 2,5	Percentile 97,5
Q1	= 0,26 − 0,0025 ÂQRS	0,37	0,23	0,00	0,95
Q2	= 0,13 + 0,0024 ÂQRS	0,23	0,39	0,00	1,60
Q3	= 3,34 − 0,225 PI	0,15	0,79	0,00	3,40
QaVR	= 5,66 − 0,059 Age	0,29	3,35	0,00	10,15
QaVL	= 0,04 − 0,006 Age	0,16	0,65	0,00	2,00
QaVF	= 0,08 − 0,004 ÂQRS	0,32	0,41	0,00	1,70
QV4	= 0,64 − 0,065 T/QRS	0,29	0,40	0,00	1,45
QV5	= 0,87 − 0,064 T/QRS	0,30	0,38	0,00	1,50
QV6	= 0,84 − 0,052 T/QRS	0,23	0,41	0,00	1,50
R1	= 6,52 − 0,03 ÂQRS	0,46	2,25	1,60	12,05
R2	= 6,40 − 0,04 ÂQRS	0,43	3,26	3,50	16,25
R3	= 1,58 − 0,06 ÂQRS	0,62	2,79	0,45	12,85
RaVR	= 0,004 + 0,10 T/QRS	0,17	1,04	0,00	3,15
RaVL	= 3,83 − 0,04 ÂQRS	0,60	1,73	0,00	8,90
RaVF	= 3,17 + 0,06 ÂQRS	0,61	2,87	1,05	13,90
RV4R	= 2,28 − 0,19 T/QRS	0,30	1,09	0,00	2,00
RV1	= 3,53 − 0,04 Age	0,40	1,51	0,20	6,05
RV2	= 7,81 − 0,07 Age	0,38	2,95	0,85	12,00
RV3	= 18,97 − 1,12 T/QRS	0,48	3,80	2,35	18,00
RV4	= 29,94 − 1,49 T/QRS	0,51	4,64	5,10	24,00
RV5	= 22,77 − 0,98 T/QRS	0,37	4,50	6,00	25,15
RV6	= 16,10 − 0,57 T/QRS	0,28	3,70	4,55	18,00
S1	= 0,41 − 0,01 ÂQRS	0,35	1,02	0,00	4,00
S2	= 1,75 − 0,009 ÂQRS	0,25	1,31	0,00	4,50
S3	= 2,91 − 0,03 ÂQRS	0,64	1,41	0,00	7,00
SaVR	= 7,64 − 0,45 T/QRS	0,21	3,93	0,00	11,00
SaVL	= 0,24 − 0,03 ÂQRS	0,59	1,55	0,00	6,60
SaVF	= 1,87 − 0,02 ÂQRS	0,50	1,08	0,00	4,00
SV4R	= 0,80 − 0,09 Age	0,49	2,76	0,00	9,75
SV1	= 12,49 − 0,07 Age	0,23	5,00	2,40	22,00
SV2	= 25,93 − 0,26 Age	0,59	6,00	5,70	32,00
SV3	= 1,84 T/QRS − 6,83	0,62	4,25	3,00	23,50
SV4	= 1,31 T/QRS − 6,46	0,60	3,20	1,50	17,00
SV5	= 0,65 T/QRS − 3,10	0,47	2,31	0,00	11,00
SV6	= 0,21 T/QRS − 0,78	0,27	1,41	0,00	4.80
T1	= 3,15 − 0,03 Age	0,50	0,94	0,35	4,50
T2	= 3,53 − 0,03 Age	0,40	1,15	0,90	5,50
T3	= 0,035 ÂT − 0,94	0,78	0,62	−1,05	2,55
TaVR	= 0,032 Age − 3,43	0,50	0,94	−4,25	−0,50
TaVL	= 1,96 − 0,03 ÂT	0,69	0,67	−0,80	2.75
TaVF	= 0,58 + 0,02 ÂT	0,47	0,86	−0,30	3,40
TV4R	= 0,07 T/QRS − 0,76	0,20	0,66	−1,00	1,15
TV1	= 1,50 − 0,015 Age	0,17	1,47	−1,50	4,00
TV2	= 8,45 − 0,08 Age	0,48	2,49	1,00	11,50
TV3	= 7,83 − 0,06 Age	0,33	2,75	1,70	12,05
TV4	= 7,24 − 0,06 Age	0,36	2,54	1,20	11,00
TV5	= 5,85 − 0,049 Age	0,39	1,98	1,00	9,00
TV6	= 4,21 − 0,036 Age	0,37	1,57	0,75	6,80
R/S V4R	= 1,04 − 0,015 Age	0,16	1,56	0,00	7,75
V1	= 0,39 − 0,004 Age	0,24	0,26	0,00	1,47
V2	= 0,50 − 0,003 ÂQRS	0,37	0,27	0,04	1,52
V3	= 3,73 − 0,28 T/QRS	0,72	0,46	0,06	3.21
V4	= 13,16 − 1,03 T/QRS	0,60	2,34	0,17	14,67
V5	= 19,31 − 1,43 T/QRS	0,48	4,47	0,44	24,00
V6	= 54,12 − 3,95 T/QRS	0,35	18,06	0,88	93,50

r = correlation coefficient; SEE = standard error of the estimate; Â mean frontal electrical axis of the QRS complex and T wave; T/QRS = transitional point (null potential) of the QRS complex in the chest leads; P= ponderal index. Age in years. R/S = ratio of R to S wave. The level of significance of the F value (*P*) has been published previously.[3]

were used for the Q waves, which normally show a markedly skewed distribution, or when the regression equation for a particular deflection was not significant at the 5% level.[31]

Normal standards for the P wave have been described previously.[30] Any P wave exceeding these limits was considered to be abnormal. Features of the P wave considered to be indicative of right atrial hypertrophy in previous reports were also considered.[6,16,19,20,22,26-29]

Grouping of some of the electrocardiographic complexes was made in some instances to reduce the number of variables to be considered. The group was considered abnormal if one or more of the deflections was abnormal. The deviation from normal was indicated as a (+) if the value was above normal, and a (−) if it was below normal.

The conventions in regard to the measuring and assessing electrocardiogram have been described previously.[31]

RESULTS

Thirty-three deflections, or combination of deflections, were found to characterise the right ventricular hypertrophy group when compared with the normal group (Table II). These differences were all significant at the 1% level or less, except in 2 instances which were significant at the 5% level or less (chi-square). Arranged in decreasing degrees of sensitivity, Q V4R—V3 was the most sensitive, while T aVR (−) was the least sensitive criterion of right ventricular hypertrophy.

TABLE II. ABNORMAL DEFLECTIONS AND COMBINATIONS OF DEFLECTIONS IN DECREASING DEGREES OF SENSITIVITY IN THE DIAGNOSIS OF ISOLATED RIGHT VENTRICULAR HYPERTROPHY

1. QV4R − V3 (+)
2. RV2 − V3 (−)
3. R/S V4 − V6 (−)
4. R/S V1 − V3 (−)
5. SV4R − V3 (+) / V4 − V6 (+)
6. R II (−)
7. RV4 − V6 (−)
8. TV4R − V3 (−) / V4 − V6 (−)
9. R I (−)
10. R III (−)
11. S V1 (−)
12. R aVF (−)
13. T III (−)
14. T V1 − V3 (−)
15. R aVL (−)
16. SaVF (+)
17. T I (−)
18. T II (−)
19. SV4 − V6 (+)
20. SaVL (+)
21. S I (+)
22. SV2 − V3 (+)
23. TaVF (−)
24. TV4R (−)
25. RaVR (+)
26. SV4R − V3 (−) / V4 − V6 (+)
27. S V2 − V3 (−)
28. S II (+) (P)
29. SV4R − V3 (−)
30. RV4R − V1 (+)
31. S III (+)
32. S V4R (+)
33. TaVR (−)

A normal electrocardiogram was recorded in 1 case of the isolated right ventricular hypertrophy group. The right ventricular weight was only slightly above the normal limits (ratio 2,0), and the electrocardiogram had been recorded 36 months before the autopsy. One case had one abnormality in the electrocardiogram (SV2 − V3 (−)), and this had occurred 6 times in the normal group. Two cases had 2 abnormal electrocardiographic findings (SV4 − V6 (+), T3 (−)), and similar abnormalities had been observed in 2 subjects of the normal series. The remaining 31 cases of the isolated right ventricular hypertrophy group (91%) had from 2 to 29 abnormal electrocardiographic deflections or combinations of deflections. These combinations of abnormal deflections were not observed in the normal series, despite the fact that 36 out of 214 cases had 2 or more abnormal deflections (17%). Two cases had 7 electrocardiographic abnormalities, 2 cases had 5, 6 cases had 4, 8 cases had 3 and 18 cases had 2 electrocardiographic abnormalities (Table III). A comparison of the abnormal electrocardiographic deflections in the isolated right ventricular hypertrophy group, and the 36 normal cases with 2 or more abnormal findings, showed that S-wave abnormalities were approximately equal in both groups, while R- and T-wave abnormalities and abnormally small R:S ratios in the chest leads, strongly favoured right ventricular hypertrophy (Fig. 1).

Four of the normal or control series had moderate or more marked emphysema at autopsy, without evidence of

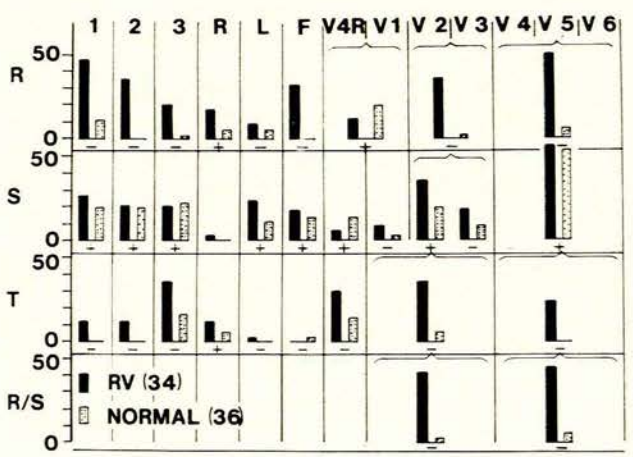

Fig. 1. The percentage incidence of electrocardiographic criteria of right ventricular enlargement or hypertrophy in 34 cases with isolated right ventricular hypertrophy, and 36 cases of the 214 control or normal series who had 2 or more such findings. The sign of the electrocardiographic criterion is given below each column. See text for discussion.

right ventricular hypertrophy. Two of these cases had 7 electrocardiographic abnormalities, 1 case had 4 such changes and 1 case had 3 electrocardiographic abnormalities.

The number of abnormal findings in the right ventricular group correlated very poorly with the right ventricular weight at autopsy. It was apparent, however, that certain signs or combinations of signs related to mild, moderate or marked right ventricular hypertrophy. Arbitrarily, mild was scored as 1, moderate as 2 and marked as 3. In most instances it was found necessary to enter each item into the mild and moderate category, or the moderate and marked category (Table IV). The total score for each electrocardiographic deflection or combination of deflections was divided by the number of entries. For example, if the entries against the abnormal signs were 2,3 for R1 (−) and 1,2 for R2 (−), the score was 2,0 (8/4). Regression equations relating score (Sc) and the right ventricular weight ratio (RVR) in the 34 cases of the right ventricular hypertrophy resulted in RVR = 2,56 Sc − 0,0825 (r 0,43, $P<0{,}02$) and Sc = 0,072 RVR + 1,573 (r 0,43, $P<0{,}02$) (Fig. 2). The correlation coefficient was markedly improved if only those cases were used in whom an autopsy had been done within 1 year of the electrocardiogram (Figs. 3 and 4). The linear regression equations in these 14 cases were: RVR = 11,416 Sc − 18,1 (r 0,77, $P<0{,}01$) and Sc = 0,0525 RVR + 1,77 (r 0,77, $P<0{,}01$).

The mean frontal axis of the P wave exceeded the 97,5 percentile of +83 degrees in 7 cases (21%) (Fig. 5). The mean frontal axis of the QRS complex exceeded the 97,5 percentile of +105 degrees in 11 cases (32%), while 2 cases had left axis deviation beyond −30 degrees (6%). The normal range of the mean frontal T wave axis was exceeded in 7 cases (21%), with 4 cases beyond +79 degrees (12%) and 3 cases less than 2 degrees (9%).

TABLE III. COMBINATIONS OF TWO OF MORE ELECTROCARDIOGRAPHIC CRITERIA OF RIGHT VENTRICULAR HYPERTROPHY (RV) IN 214 SUBJECTS WITHOUT EVIDENCE OF VENTRICULAR ENLARGEMENT (NORMAL SERIES)

R – WAVE									S – WAVE										T – WAVE									R/S RATIO		No. RV Signs
1	2	3	R	L	F	V4R, V1	V2 3	V4 5 6	1	2	3	R	L	F	V4R	V1 2 3	V2 3	V4 5 6	1	2	3	R	L	F	V4R	V1 2 3	V4 5 6	V1 2 3	V4 5 6	
−	−	−	+	−	−	+	−	−	+	+	+		+	+	+	− −	+	+	−	−	−	+	−	−	−	−	−	−	−	
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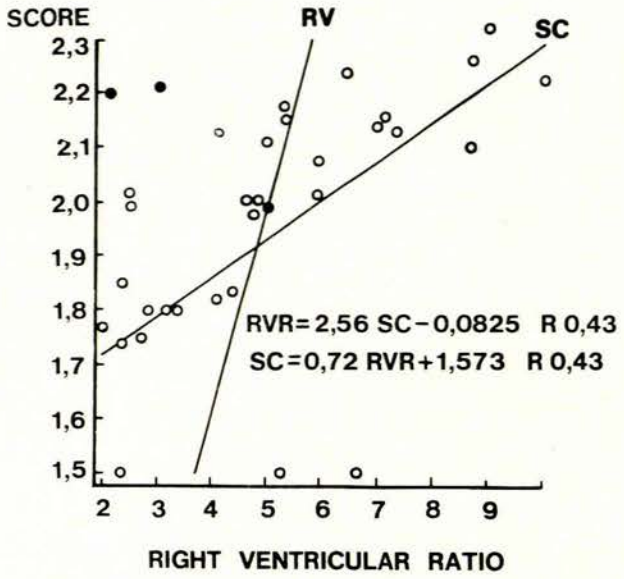

Fig. 2. Regression lines for the equations relating the right ventricular weight ratio (RVR) to the electrocardiographic score (Sc) in 34 cases of isolated right ventricular hypertrophy. The right ventricular ratio is the independent variable in the second equation. The score is the independent variable in the first equation and the dependent variable in the second equation. The solid circles (●) represent 3 cases with left ventricular atrophy and the right ventricular hypertrophy, while the open circles (o) are cases of isolated right ventricular hypertrophy. See text for discussion. r = multiple correlation coefficient.

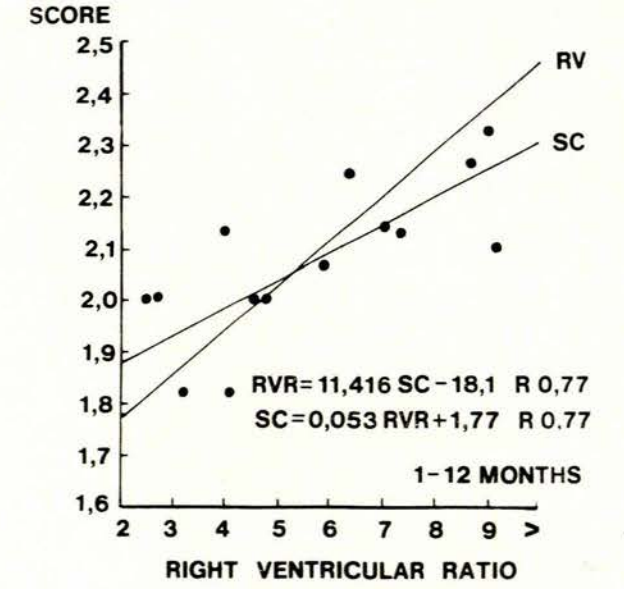

Fig. 3. Regression lines for equations relating the right ventricular weight ratio (RVR) and the electrocardiographic score (Sc), for 14 cases of isolated right ventricular hypertrophy, in which an electrocardiogram had been recorded within 1 year before autopsy. Cases with left ventricular atrophy and right ventricular enlargement were not included as they were in Fig. 2. See text for discussion. r = multiple correlation coefficient.

TABLE IV. ELECTROCARDIOGRAPHIC DEFLECTIONS OR COMBINATION OF DEFLECTIONS ARRANGED ACCORDING TO THE DEGREE OF RIGHT VENTRICULAR HYPERTROPHY (SEE TEXT)

Right ventricular hypertrophy		
Mild (score 1)	Moderate (score 2)	Marked (score 3)
—	Qq Rr	Q S
—	R I (−)	R I (−)
R II (−)	R II (−)	—
R III (−)	R III (+ or −)	RIII (+)
—	R_R (+)	R_R (+)
—	R_L (−)	R_L (−)
RF (−)	R_F (−)	R_F (+)
—	RV4R − V3 (+)	—
—	RV2 − V3 (−)	RV2 − V3 (−)
—	RV4 − V6 (−)	RV4 − V6 (−)
—	S I (+)	S I (+)
S II (+)	S II (+)	—
S III (+)	S III (+)	—
SL (+)	SL (+)	—
—	SF (+)	SF (+)
—	SV4R (+)	—
S V1 (−)	SV1 (−)	—
SV2 − V3 (−)	SV2 − V3 (−)	—
—	SV2 − V3 (+)	SV2 − V3 (+)
SV4 − V6 (+)	SV4 − V6 (+)	SV4 − V6 (+)
TI (−)	T I (−)	—
T II (−)	T II (−)	—
T III (−)	T III (−)	—
TR (+)	T_R (+)	—
—	TV4R (−)	TV4R (−)
—	TV1 − V3 (−)	TV1 − V3 (−)
TV4 − V6 (−)	TV4 − V6 (−)	—
—	R/S V1 − V3 (−)	R/S V1 − V3 (−)
—	R/S V4 − V6 (−)	R/S V4 − V6 (−)

The transitional point of the praecordial leads exceeded the normal range in 12 instances (35%). It was situated at lead V6 or to the left in 3 cases (9%), or at V1 or to the right in 9 cases (26%).

The mean frontal axis of the P wave, transitional point of the P wave, QRS complex and the T wave in the praecordial leads, correlated poorly with the right ventricular weight. The mean frontal axis of the QRS complex (ÂQRS) correlated well with the right ventricular ratio (RVR). A linear regression equation was RVR = 0,018 ÂQRS + 3,41 ± 1,89 (r 0,62, $P<0,001$) (Fig. 6). The correlation between the right ventricular ratio and the mean frontal axis of the T wave (ÂT) was less than that found for the mean frontal axis of the QRS complex. The linear regression equation was RVR = 0,0206 ÂT + 3,92 (r 0,33, $P<0,10$).

P wave abnormalities were present in 22 (65%) of the 34 cases of right ventricular hypertrophy. They were never unassociated with abnormalities of the Q, R, S and T waves and the R:S ratio. Abnormal P waves correlated poorly with the right ventricular ratio or weight (Fig. 5). The total number of peaked P waves never exceeded 5 out of the 13 leads in the normal subjects, while this figure

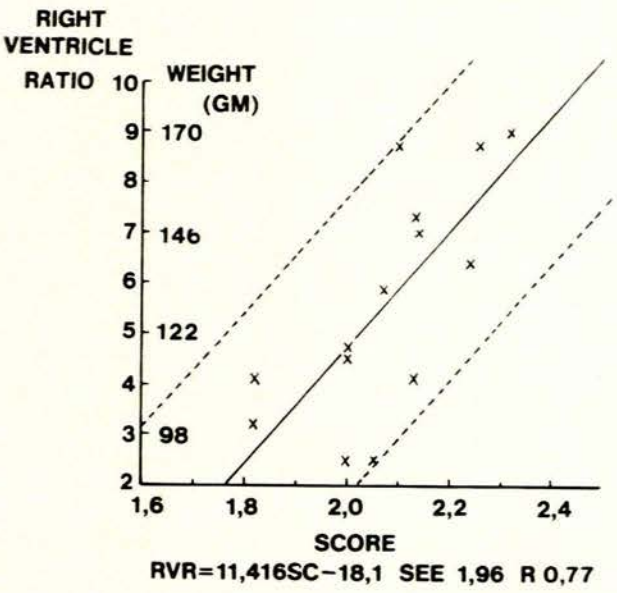

Fig. 4. The mean regression line and limits at 1,96 standard errors of the estimate, for the linear regression equation relating the right ventricular weight ratio (RVR) as the dependent variable, and the electrocardiographic score (Sc) as the independent variable. The 14 cases had isolated right ventricular hypertrophy. The 3 cases with a similar finding, but with left ventricular atrophy included in Fig. 2, were excluded. See text for discussion.

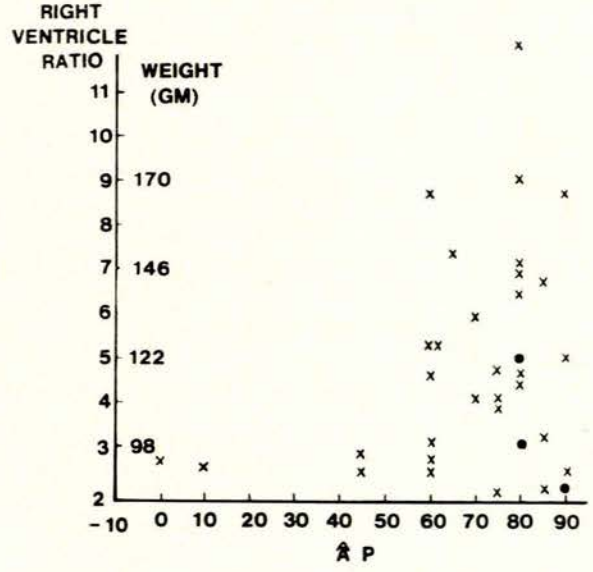

Fig. 5. A plot of the mean frontal electrical axis of the P wave (Â P) and the right ventricular ratio or weight, for 34 cases of isolated right ventricular hypertrophy. The solid circles (●) represent 3 cases with left ventricular atrophy and right ventricular hypertrophy. See text for discussion.

was exceeded in 5 (15%) of the right ventricular hypertrophy group.

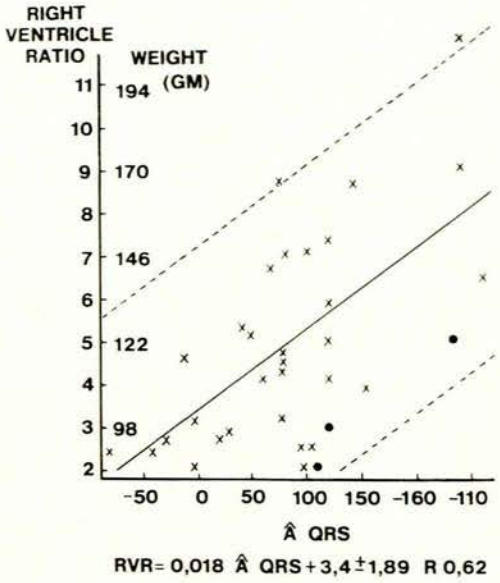

Fig. 6. The mean regression line and limits at 1,96 standard errors of the estimate, for the linear regression equation relating the right ventricular weight ratio (RVR) as the dependent variable, and the mean frontal electrical axis of the QRS complex (ÂQRS) as the independent variable. The solid circles (●) represent 3 cases of left ventricular atrophy and right ventricular hypertrophy.

Lead V1 is commonly singled out in the diagnosis of right ventricular hypertrophy, where an R:S ratio of 1,0 and above is regarded as a criterion for such a diagnosis (Table V). Twenty-eight cases had both an R and S wave in lead V1 and the R:S ratio was less than 1,0 in 27 cases (96%). Six electrocardiograms had a QS complex (3 cases) or a QR complex (3 cases) in which an R:S ratio could not be calculated. Six electrocardiograms showed a QRS complex, in only 1 of which did the R:S ratio exceed 1,0. Only 2 cases (6%) in the total group had an R:S ratio 1,0 or greater. In only 3 cases (9%) did the R wave in lead V1 exceed 5 mm and in each instance a Q wave was present. The R wave in V4R was taller than that in lead V1 in 2 instances (6%).

An RSR^1 wave in V4R or V1 was present in 2 cases (6%), and was present in V3 in 1 case (3%). A notched R or S wave in leads V4R or V1 was present in 2 cases (6%), while splintering of the QRS complex (embryonic rsR^1), with the total complex being largely below the baseline, was present in 2 cases (6%). An rSr^1 was present in aVR in 7 cases (21%) of which 4 cases (11%) did not show this pattern in leads V4R and V1. The predominant pattern in lead aVR was a Qr or QR, with only 2 cases showing an rS pattern.

The S-T segments were normal in most instances and flat S-T segments were uncommon. In lead V6 a rising concave S-T segment was found in 25 cases (74%), while a flat but not depressed S-T segment was present in 9 cases (26%). Two cases (6%) showed depression of the 'J' points in leads II, III and aVF, with flat S-T segments and inverted T waves. One instance (3%) of significant depression

TABLE V. ELECTROCARDIOGRAPHIC CRITERIA OF VARIOUS AUTHORS FOR THE DIAGNOSIS OF RIGHT VENTRICULAR HYPERTROPHY

Reference	4	6	7	8	9	11	13	15	16	17	19	20	22	23	Total	+ %
QV4R, V1	+			+	+			+							4	28,6
RaVR (+)	+	+	+					+	+			+			6	42,9
RV4R (+)	+		+	+				+							4	28,6
RV1 (+)		+		+	+			+	+			+	+	+	8	57,1
RI-3, aVL, aVF (−)												+			1	7,1
RV5 – V6 (−)		+							+			+			3	21,4
SI – 3 (+)												+			1	7,1
SaVL aVF (+)									+						1	7,1
SV4R (+)			±												1	7,1
SV1 (+)							+								1	7,1
SV2 – V3 (+)							+								1	7,1
SV4 (+)															0	0
SV5 – V6 (+)	+	+	+	+				+	+			+		+	8	57,1
SV1 (−)		+							+			+			3	21,4
T1, T2, aVF (−)		aVL													1	7,1
T3 (−)		+		+											2	14,3
TaVR (+)															0	0
TV4R (−)				+											1	7,1
TV1 – V3 (−)	+	+		+				+	+				+		6	42,9
R/S V4R – V1 (+)	+		+		+	+*			+	+			+		7	50,0
R/S V1 – V3 (−)										+		+			2	14,2
R/S V4 – V6 (−)	+	+	+						+		+	+			6	42,9
RAD		+		+		+				+		+	+	+	7	50,0
RSR'				+	+				+						3	21,4
P pulmonale		+		+	+				+		+	+		+	7	50,0
RV1 + SV5 (+)		+							+			+			3	21,4
R/S V5 – R/S V1 (−)		+							+						2	14,2
Intrinsicoid time (RV)		(+)														
		+	+		+				+				+		5	35,7
Ventricular gradient											+				1	7,1
Total	7	14	7	10	6	2	2	6	14	3	3	12	5	4		

* = R5 mm.
+ = The incidence (percentage) of the particular electrocardiographic criterion of right ventricular hypertrophy occurring in the 14 publications.

of the 'J' point was found in the chest leads, and this occurred in the presence of inverted T waves.

The T wave configuration was normal in most of the tracings. In fact, many of the T waves, whether upright or inverted, were sharp with a tendency towards equal afferent and efferent limbs. This was found in 17 cases (50%) in lead V6, was possibly present in a further 5 cases (15%), while the T wave was normal (longer afferent limb) in the remaining 12 cases (35%).

The R:S ratios were abnormal in 15 cases (44%). An increase in the R:S ratio in one or more of the leads from V1 to V3 occurred in 6 cases (18%). Seven cases (21%) had decreased R:S ratios only, ranging from V2 to V6. One case (3%) showed this only in lead V6, while 4 cases (11%) had increased R:S ratios over the right chest leads up to lead V3, and decreased R:S ratios over the left chest leads. However, an abnormality of the R:S ratio on its own was never found, and the number of associated abnormalities ranged from 5 to 29, with an average of 20 deviations from normal per case. In this respect the R:S ratio was not an early finding in right ventricular hypertrophy, nor on its own was it an indication of the degree of hypertrophy of the right ventricle.

No QRS complex exceeded 0,10 sec by exclusion. The P-R intervals were all within normal limits and the Q-T time corrected for rate was within normal limits.

DISCUSSION

The reported criteria for the electrocardiographic diagnosis of isolated right ventricular hypertrophy have varied markedly (Table V), from as few as 2 criteria[11] to as many as 14 criteria.[5] In addition, no agreement exists about electrocardiographic criteria for the diagnosis of right ventricular hypertrophy (Table V). The present study indicates that in a comparison of subjects without ventricular enlargement and those with isolated right ventricular hypertrophy at autopsy, 33 deflections or combinations of deflections characterised the right ventricular hypertrophy group at a statistically significant level (Tables II and IV).

Where clinical, radiological and pulmonary function tests were used to gauge the degree of right ventricular hypertrophy, the electrocardiographic record was considered to be consistent with this diagnosis in from 63% to 75%.[12,13,14] The electrocardiogram has also been shown

to reflect the degree of obstructive lung disease[28,30] in cases studied by pulmonary function tests, without regard to the degree of right ventricular hypertrophy.

Elevation of the pulmonary artery pressure at cardiac catheterisation has shown electrocardiographic evidence of right ventricular hypertrophy in from 54% to 70% of the cases.[7,9,25,26] In addition, the degree of right ventricular hypertrophy in the electrocardiogram increased as the pulmonary artery pressure became higher.[7,13]

The estimation of right ventricular hypertrophy from the right ventricular wall thickness at autopsy has been used in a number of studies.[10,11,14,29,20] The electrocardiographic record was consistent with right ventricular hypertrophy in from 23% to 75% of the subjects studied.

Myers and associates[4] found no direct correlation between cardiac weight, ventricular ratio or thickness of the right ventricular wall, and the electrocardiographic pattern.[4] A fairly good correlation between right ventricular wall thickness and the degree of right ventricular hypertrophy in the electrocardiogram was found by Goodwin and Abdin.[15] Chronic lung disease, however, was only present in 16 of the 117 cases studied. The same electrocardiographic and anatomical criteria were used by Caird and Wilcken[18] in cases with chronic lung disease, and no correlation was found between the degree of hypertrophy and the electrocardiographic grade. Millard confirmed the lack of association between the degree of right ventricular hypertrophy at autopsy and the Goodwin and Abdin electrocardiographic grade, in a study of 40 patients with chronic lung disease, without associated myocardial involvement.[23]

The diagnosis of isolated right ventricular hypertrophy from ventricular partitioning at autopsy resulted in an electrocardiographic diagnosis in from 0 to 80% of the cases studied.[4,21,23] In the present investigation the electrocardiogram showed changes in 91% of the cases, utilising 33 diagnostic criteria. In this respect, Mazzoleni *et al.*[21] found no positive evidence of right ventricular hypertrophy in the electrocardiogram of 7 cases that came to autopsy. Millard found that 80% of 20 cases of isolated right ventricular hypertrophy had an axis beyond +90 degrees, and that other features of the electrocardiogram made no further contribution.[23]

It is surprising that in the reported literature up to as many as 70% of cases of right ventricular hypertrophy could be diagnosed, when the means of selecting such cases and the diversity of the criteria used for the diagnosis are considered. A further complicating factor appears to be the diversity of diseases studied, which can cause right ventricular hypertrophy.

The present results, however, indicate that the electrocardiogram does reflect the degree of right ventricular hypertrophy. Arbitrary scoring resulted in a correlation coefficient of 0,43 between the right ventricular ratio (or weight) and the electrocardiographic criteria. The correlation coefficient was 0,77 when cases were chosen in which the electrocardiogram had been recorded within one year before autopsy; 50% of the variation in the observed right ventricular ratios (or weight) could be explained by the electrocardiographic criteria used in scoring.

Right axis deviation has frequently been used as an indication of right ventricular hypertrophy. An axis to the right of +100 degrees has most often been used,[6,11,12,15,17,20,22] while others have suggested an axis to the right of +120[16] or +90 degrees as an indication of right ventricular hypertrophy.[8,23] An axis of +105 degrees was situated at the 97,5 percentile in our control subjects. Millard[23] reported that 80% of his autopsy material with right ventricular hypertrophy exceeded +90 degrees, whereas 33% exceeded +105 degrees in the present study. Left axis deviation has been present in subjects with right ventricular hypertrophy.[6] The 2 subjects who exceeded −30 degrees in the present series both had slight enlargement of the right ventricle at autopsy, and the pattern of the tracing was consistent with left anterior hemiblock.

A linear regression analysis with the right ventricular ratio (RVR) or right ventricular weight (RV) as the dependent variable, and the mean frontal axis (ÂQRS) as the independent variable was:

$RVR = 0{,}0182\ \hat{A}QRS + 3{,}4 \pm 1{,}89$ (r 0,62 $P<0{,}001$)
$RV = 0{,}2186\ \hat{A}QRS + 102{,}90 \pm 22{,}83$ (r 0,62, $P<0{,}001$).

A similar calculation done on the data of Millard[23] was:

$RV = 0{,}4457\ \hat{A}QRS + 46{,}54 \pm 35{,}5$ (r 0,57, $P<0{,}001$).

The linear regression of the combination of the present results and those of Millard was:

$RV = 0{,}2893\ \hat{A}QRS + 78{,}54 \pm 35{,}8$ (r 0,49, $P<0{,}001$).

These results indicate that right axis deviation reflects the degree of right ventricular hypertrophy. However, only 38% of the variation in the right ventricular ratio (or weight) could be explained by the mean frontal axis in our results, 32% in the series of Millard, and 24% when both groups were combined.

Widimsky *et al.*[16] have shown a significant correlation between the mean frontal axis of the QRS complex and the mean pulmonary artery pressure and pulmonary resistance, the correlation coefficients being 0,29 ($P<0{,}02$) and 0,37 ($P<0{,}01$) respectively. The mean frontal axis of the QRS complex reflected the degree of right ventricular hypertrophy at autopsy more closely than it did the pulmonary haemodynamics.

Right axis deviation is undoubtedly of value in the diagnosis of right ventricular hypertrophy. Its value is, however, diminished by the small number of cases that exceed the normal upper limits. The regression analysis indicates that considerable right ventricular hypertrophy can still exist in cases falling within the normal range.

Additional features of the electrocardiogram have been stressed in the diagnosis of right ventricular hypertrophy, but have been shown to be of limited value in the present study. Evidence of right atrial hypertrophy was often present, but it never occurred on its own and is correlated poorly with the degree of right ventricular hypertrophy. In addition to the many features of the P wave that have been described as occurring in right atrial hypertrophy,[6,16,19,20,22,26-29,33] the number of pointed P waves in the 13 lead electrocardiogram need be added. In normal subjects, recording by means of a direct writing electrocardiograph, the number did not exceed 5, while this number was exceeded in 6 (17%) of the right ventricular hypertrophy cases studied.

A pattern of incomplete right bundle-branch block with an rSr^1 in lead V1 (or lead V4R or lead V2) has been advocated as diagnostic of right ventricular hypertrophy.[7,8,16] Such findings were uncommon in our series and did not correlate with the degree of right ventricular hypertrophy, even when a similar pattern in lead aVR was included.

The pattern of the S-T segments and shape of the T wave was of interest in the right ventricular hypertrophy group. By and large, both the S-T segments and the T waves showed a normal configuration, especially in those leads where the T waves were large. Depression of the 'J' point did occur, but only with inversion of the T wave of large degree. Flat S-T segments were uncommon, the vast majority of cases showing a normal bowing. The T waves tended to be peaked with equal afferent and efferent limbs. The findings in regard to the S-T segments and the T waves are thus significantly different from the patterns seen in the left ventricular hypertrophy and combined ventricular hypertrophy where the left ventricle predominates.

The material studied in the present analysis did not allow any estimate of the degree to which chronic bronchitis and emphysema and/or silicosis affected the electrocardiogram in the absence of right ventricular hypertrophy. In 4 cases in the control series, with moderate or more marked emphysema at autopsy, the incidence of electrocardiographic abnormalities was sufficiently high (7, 7, 5 and 3) to suggest that the influence could be marked. In addition, the electrocardiogram of right ventricular hypertrophy in chronic lung disease differs in many respects from that found in other diseases which cause right ventricular hypertrophy. These differences could be ascribed to the effects of chronic lung disease, hyperinflation and emphysema in particular.

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