Comparative Studies on Electrocardiographic and Pathological Anatomic Findings of Ventricular Hypertrophy and Dilatation

HIROSHI MATSUBARA

Since electrocardiogram was taken into the clinical diagnosis of heart diseases by Einthoven diagnostic criteria of ventricular hypertrophy has been discussed from various points, particularly along with the development of precordial leads. However, the standard of these criteria was the increase of the weight of ventricle muscle or the increase in the thickness of ventricle walls. In this case, ventricular hypertrophy was at all a phase of cardiac enlargement and in discussing ventricular hypertrophy, ventricular dilatation cannot be overlooked. Recently, electrocardiogram is discussed from the point of ventricular dilatation, but the progress in this field is not so remarkable as compared with that of hypertrophy owing to too many factors being involved, such as difficulty of measuring ventricular volume, elongation of conduction passway in subendocardium, increase at cardiac surface, decrease of the distance between heart and chest wall, increase of the blood volume in the heart, destruction of cardiac muscle fibre etc.

Even on the criteria of ventricular hypertrophy reports discussing ventricular hypertrophy in proportion with ventricle wall thickness have not yet defined its reliability turning out the results that when positivity shows high rate, false-positivity is also high, or the positivity itself remains at low rate.

Likewise, in order to discuss the electrocardiogram of ventricular dilatation exact ventricular volume has to be measured. However, due to the difficulty of its definition report dealing electrocardiogram from the point of ventricular volume has not yet been made.

One thing which makes the definition complicated is a considerable difference in ventricular volume between systolic and diastolic phase. Determination of ventricular volume with living body is all the more difficult problem. Recently, along with the progress of angiocardiology transverse diameter of ventricle shadow is taken up as an index of ventricular dilatation in connection with blood flow, yet the report is not satisfactory as compared with that of absolute value of ventricular volume. Pathological report on measuring ventricular volume has been submitted but report discussing the problem of ventricular volume in relation with electrocardiogram does not come out yet.

Of course, autoptical ventricle volume can not be equal to that of lifetime, however, at least the approximate figure of the volume in lifetime can possibly be obtained on the basis of autoptical one. Thus, measuring the ventricular dilatation with ventricle volume plus ventricle wall thickness QRS transitional zone is studied in correlation with change of heart position. As an electrocardiographic observation in the diagnosis of ventricular hypertrophy, correlation between ventricle wall thickness and QRS high voltage, deviation of QRS axis and ventricular activation time are studied. Results are as follows.

Materials and Methods
36 cases were taken up for this study out of the
cases under autopsy, at 3rd Medical Clinic of Department of Medicine, Kyoto University, from the period of 1958 to 1964. Out of 36, 32 cases have their electrocardiograms recorded within one month before the death and the other 4 cases were within 2, 3, 4 and 5 months respectively due to decompensation or electrolyte unbalance. Therefore, these electrocardiograms do not include the cases bearing obvious electrolyte unbalance (hyperpotassium) or myocardial infarction or myocardial fibrosis. The electrocardiograms are recorded by limb leads, unipolar leads, and chest leads (V₁, V₃). A photographic electrocardiograph was used partly but mostly a heat-pen writing electrocardiograph was used. Ventricular activation time measured was: VAT (by Wilson) = time between initial point of QRS to the peak of R or R' and VAT (by Maekawa) = time between initial point of QRS to the crossing point with basic line of downward line of R or R', on the basis of chain doublet theory. QRs axis was determined according to algebraical sum of QRS surface at I, III leads.

QRS transitional zone was decided under the following items.

Type I: Sudden and high increases are seen in R/S comparison with lead before having Q wave, transitional zone is set with that point.

Type II: Cases showing gradual increase in R/S comparison with lead before having Q wave, transitional zone is determined at the point where S wave was relatively small compared with R wave.

Type III: Cases which have rs-pattern even at V₆, transitional zone is considered to be located left to V₆. This is expressed as V₆→.

The classification of these types are made in comparison with autoptical observation, which will be explained later.

Heart weight is used as index of cardiac enlargement.

As regards normal value of heart weight Smith, Rossi & Roulet, and Zeek reported on European or American people and Kaneko, Sano, Oka reported on Japanese people. When compared these normal rates of European/American with Japanese the former shows considerably higher figure. We have chosen the normal rate from Oka’s standard, and divided them into cardiac enlargement and normal groups. On cardiac enlargement group further reference was made with Zeek’s normal rate, and the results revealed that except three cases having showed lower value most cases were over the normal value. But, three cases were considered to belong normal group rather than cardiac enlargement group because of their ventricle wall thickness and basic diseases. Thus 7 cases were put to normal group (hereafter called NVH-group) and 29 cases at cardiac enlargement group.

As an indication of ventricular hypertrophy the wall thickness at central part of ventricular anterior wall was used. The measurement was made only with muscle stratum excepting papillious muscles.

Reports on the normal rate of ventricle wall thickness are made by Saphir and White on European/American people, and Ishida on Japanese (Table I). As regards ventricle wall thickness not so much difference was found between European/American and Japanese. It is very difficult work to determine the abnormal value, i.e. ventricular hypertrophy on this standard. Scott states in his report: Most workers consider that in order to diagnose RVH in an adult the greatest thickness of the right ventricle must be 5 mm or more, and to diagnose LVH the greatest thickness of the left ventricle must be 13 (or 14) mm or more. The author also made the classification of right ventricular hypertrophy (hereafter called RVH-group), left ventricular hypertrophy (hereafter called LVH-group) and combined ventricular hypertrophy (hereafter called CVH-group) as follows:

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<thead>
<tr>
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<th>Right (mm)</th>
<th>Left (mm)</th>
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<tr>
<td>Saphir</td>
<td>2–3</td>
<td>8–10</td>
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<tr>
<td>White</td>
<td>3–4</td>
<td>10–12</td>
</tr>
<tr>
<td>Ishida</td>
<td>2.6–3.8</td>
<td>11.1–11.5</td>
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According to the above classification cardiac enlargement group was divided into: 4 cases at RVH group, 10 at LVH group and 15 at CVH group.

All the ventricle wall thickness of 7 cases belonging to NVH group was Wr<0.4 cm and WI>1.2 cm respectively.

Next, as an indication of ventricular dilatation, ventricle volume was measured as follows.

At the time of autopsy, the chest was opened and the heart was taken out, after being cut at vena cava, aorta, pulmonary artery and vein. An incision was put on atrium after measuring the weight of the heart. Confirming inside of the ventricle cavity watchable a small incision was made right above the valves of aorta or pulmonary artery and that part was pulled up to the same surface level formed by upper edges of mitral valves or tricuspid valves (Fig. 1. m₁-m₃ or t₁-t₃) and then water was poured through auricle (Fig. la.) till the water flows out...
from the incision part on aorta or pulmonary artery. Thus the volume of water filled in ventricle cavity can be measured, which volume is considered to represent the volume of each ventricle. Thrombus remaining in the ventricle cavity was removed after ventricle was opened and weighed. Resuming its specific gravity as 1 it is added to the ventricle volume. Although the standard is set as above, almost no thrombus was found remaining in the ventricle cavity during this study. The absolute value of ventricle volume obtained in this study is expected to fluctuate depending on whether the cardiac arrest happened in systolic or diastolic phase. According to Hochrein, right ventricle volume (hereafter called Cr) is slightly larger than the left ventricle volume (hereafter called Ci) the ratio between them is Cr/Ci = 1.13. We have adopted for our study the rate of left and right ventricle volume against

Fig. 1.

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<tr>
<th>Table II</th>
<th>Pathologic Anatomical and Electrocardiographic Data about QRS-transitional Zone</th>
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<tbody>
<tr>
<td>Group</td>
<td>Case</td>
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<td>W</td>
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IVS: Interventricular Septum  
* This indicate that transitional zone shifts leftward of V6

Japanese Circulation Journal Vol. 33, January 1969
TABLE III  Pathologic Anatomical and Electrocardiographic Data about Examined Cases

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age</th>
<th>Sex</th>
<th>Heart Wt. (gm)</th>
<th>Ventir. Thick. (cm)</th>
<th>Ventir. Capacity (cc) (%)</th>
<th>Tran. (sec) V1-Lead</th>
<th>V5-Lead</th>
<th>QRS (sec)</th>
<th>V.A.T. in V1 (sec)</th>
<th>V.A.T. in V5 (sec)</th>
<th>Zone R</th>
<th>S</th>
<th>R</th>
<th>S</th>
<th>Axis</th>
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<td>T.A.</td>
<td>18</td>
<td>F</td>
<td>184</td>
<td>0.3</td>
<td>1.0</td>
<td>31.0 (73)</td>
<td>10.0 (27)</td>
<td>5.3 16.0 19.0</td>
<td>0.5 + 62.0 0.06 (0.036)**</td>
<td>0.36 (0.052)</td>
<td>V2</td>
<td></td>
<td>R</td>
<td>L</td>
<td>R</td>
</tr>
<tr>
<td>U.O.</td>
<td>62</td>
<td>F</td>
<td>394</td>
<td>0.3</td>
<td>1.1</td>
<td>38.3 (77)</td>
<td>10.3 (23)</td>
<td>0.2 4.0 8.7 1.3</td>
<td>17 + 0.012 (0.020)</td>
<td>0.030 (0.046)</td>
<td>V4-5</td>
<td>0.9</td>
<td>11.6</td>
<td>11.0</td>
<td>5.5 + 78.0 0.020 (0.032)</td>
</tr>
<tr>
<td>M.J.</td>
<td>41</td>
<td>M</td>
<td>205</td>
<td>0.2</td>
<td>1.0</td>
<td>20.0 (70)</td>
<td>15.0 (30)</td>
<td>4.6 15.5 8.3 2.1</td>
<td>80 + 0.024 (0.028)</td>
<td>0.32 (0.040)</td>
<td>V3-4</td>
<td>6.1</td>
<td>9.3 16.5</td>
<td>1.4 + 49.0 0.032 (0.040)</td>
<td>0.048 (0.056)</td>
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<tr>
<td>M.K.</td>
<td>35</td>
<td>M</td>
<td>240</td>
<td>0.3</td>
<td>0.8</td>
<td>60.0 (70)</td>
<td>88.0 (59)</td>
<td>3.3 7.4 6.6 7.3</td>
<td>83 + 0.024 (0.034)</td>
<td>0.32 (0.036)</td>
<td>V3-6</td>
<td>14.0</td>
<td>10.0</td>
<td>8.2 + 84.0 0.027 (0.029)</td>
<td>0.29 (0.039)</td>
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<td>Y.N.</td>
<td>41</td>
<td>M</td>
<td>280</td>
<td>0.3</td>
<td>1.2</td>
<td>47.5 (79)</td>
<td>13.0 (21)</td>
<td>9.4 19.5 12.4</td>
<td>112 + 0.062 (0.080)</td>
<td>0.41 (0.056)</td>
<td>V6</td>
<td></td>
<td>R</td>
<td>L</td>
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</table>

**NVH-group**: Non-ventricular hypertrophic group  
**RHV-group**: Right ventricular hypertrophic group  
**LVH-group**: Left ventricular hypertrophic group  
**CVH-group**: Combined ventricular hypertrophic group  
Pt: Patient  
Heart Wt.: Heart weight  
Ventir. Thick.: Ventricular thickness  
Ventir. Capacity: Ventricular capacity  
Tran.: Transition zone  

Japanese Circulation Journal  Vol. 33, January 1969
Ventricle volumes of following cases were measured.

NVH group — 5 cases out of 7, RVH group — 1 case out of 4, LVH group — 6 cases out of 10 and CVH group — 11 cases out of 15 (total 23).

(Table III)

In order to discuss the relation between QRS transitional zone on electrocardiogram (hereafter T. Z.) and position of interventricular septum (hereafter IVC) we made the following study.

At the time of autopsy, before opening the chest wall, punctuation is made perpendicularly against the chest wall on the position corresponding to standard chest lead point of electrocardiogram, after opening the chest punctuation hall on the cardiac surface was studied from its anatomical position and electrocardiogram pattern.

The cases used for this study were: NVH group 3 out of 7, RVH group 2 out of 4, LVH group 4 out of 10, and CVH group 14 out of 16, total 23 cases (Table II).

One case out of 14 CVH group was a 12 year old female (Table II case W). This case was used only for this experiment and is not included in other studies.

RESULTS OF EXAMINATION

1. Relation between transitional zone (T. Z.) and anatomical position of interventricular septum (IVS).

Correlation between T. Z. on electrocardiogram and anatomical position of IVS was re-examined. Wilson² interprets T. Z. as "complexes that are intermediate in form or represent a combination of the deflection obtained at point further to the right and those obtained at point further to the left". Many literatures¹⁵,¹⁴,¹² published after Wilson define that the height of R wave is equal to the depth of S wave. However, according to Wilson's definition at T. Z. the height of R wave may equal to the depth of S wave but conversely the zone of R wave equal S wave in amplitude is considered not usually equal to transitional zone. Intermediate form on electrocardiogram is reported¹⁶,²⁴,⁴³,⁴⁴ to meet with anatomical IVS but recent report⁴⁵ says this does not necessarily meet with.

This study on all through the 23 cases, with only one exception, revealed that Q wave could be seen on the lead further left to the lead point corresponding IVS.

According to the study of Barbatò⁴⁶, on direct cardiac surface lead rS-pattern is seen on right ventricular side of IVS, and qRs-pattern is seen left side of IVS, and quite rapid change is seen on transition. Body surface lead does not reflect directly that of direct cardiac surface lead because of the distance between the chest wall and the heart due to the existence of lung, but quite a number of electrocardiograms show not unfrequently similar patterns. We classified this pattern as Type I. 12 cases out of total 23 cases (52%) belong to this type as shown on Table II.

Electrocardiograms showing the pattern of slow change in R/S ratio on its transition from right ventricular lead to left ventricular lead is classified as Type II (Fig. 2). Among the cases belonging to this type one of chest leads at cases B. J. M. O. (Table II) is upon IVS and their R/S ratios are 0.83, 1.26, 1.45 and 1.10 respectively. While on cases C. H. O. (Table II) two chest leads are seen closely at both sides of IVS and their R/S ratios are 0.45–0.88, 1.37–3.14 and 2.07–3.52 respectively. All of the cases suggest that R/S ratio corresponding to T. Z. is not necessarily equal to 1. With T. Z. equivalent lead, R/S ratio rather tends to be larger than 1. Considering from the ratio of right ventricle muscles and left this tendency is acceptable. Therefore, on the electrocardiograms of this pattern T. Z. is set on the point where S wave is comparatively smaller than R wave, i.e. R/S ratio >1 on the lead before Q wave being appeared.

Further with cases D. E. and U. (Table II) where the position of IVS is located at V₅–V₆ or further left, the electrocardiogram showed rS-pattern even at V₅–V₆. These cases are identified as Type III (Fig. 2) and expressed as V₆→, considering T. Z. is further left than V₆.

Case L (Table II) has complete right bundle branch block and does not belong to any of the abovementioned types. T. Z. is determined to belong V₆→ in view of anatomical position of IVS, Q wave of electrocardiogram, and other data. Criteria of classification of T. Z. were decided as above.

A certain physical constitutional changes caused by death cannot be overlooked when comparing electrocardiogram pattern in lifetime and findings of autopsy, but these changes will not be of so serious problem, as Rosen-
BURG\textsuperscript{43} reported.

Classification of T.Z. is decided as above. Comparing T.Z. with IVS position, 2 cases showed T.Z. further right of IVS, 8 cases showed perfect coincidence and 3 cases showed deviation of T.Z. with 1/2 distance of 2 chest lead points toward IVS (for example, T.Z. exists between V\textsubscript{3} and V\textsubscript{4} while IVS at V\textsubscript{3}), 5 cases have the deviation of 1 chest lead distance, 3 showed 1-1/2 and 2 showed 2 chest lead distance. Except the two cases which showed the deviation of T.Z. right toward IVS the remaining 21 cases are either T.Z. and IVS correspond or T.Z. deviates left to IVS. This fact indicates that T.Z. may easily be affected than anatomical heart position. However, admitting the

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Fig. 2. The arrow indicates the position of interventricular septum.
allowance of 1/2 chest lead distance, with 11 cases (48%), or admitting the allowance of 1 chest lead distance as made by Rosenburg, with 16 cases (70%), T.Z. correspond with IVS. This may mean that a considerable correlation be between T.Z. and IVS.

Out of 2 cases which showed deviation of T.Z. right toward IVS (Table II Case A.F.), Case A belongs to NVH group and the electrocardiogram of this case shows the Q wave already at the body surface lead corresponding to IVS, as shown in Fig. 2 Case I. While, the electrocardiogram of Case B which belongs also to NVH group shows almost same pattern at V₃, V₄ and V₅, as shown in Fig. 2 Case II. This outcome in NVH-group is supposed to have been caused by a considerably long distance between heart and chest wall.

Another case showing deviation of T.Z. right toward IVS is Case F, which belongs to LVH group and its deviation is 1 chest lead distance. This may also be the results of the distance between heart and chest wall, but the definite cause is hard to explain since it does not so often happen with ventricular hypertrophy group. However, if 1 chest lead distance is admitted as mentioned above this case can also be included in the group where T.Z. and IVS correspond with.

Next, Case R, belonging CVH group, as mentioned in Fig. 2 Case III, IVS is seen at V₃-4 and according to the above classification T.Z. is at V₅-6. The case which shows large deviation between T.Z. and IVS (at least 1-1/2 lead or above) is considered to have obvious decompensation at the time of recording electrocardiogram (especially right) and this right ventricular dilatation due to overload seems to be lightened or relieved at the time of autopsy, having IVS been shifted to right. Besides Case R, Cases J.P. and U. (Table II) are under the same classification. Especially both Cases J and P, of which ventricle volume could be measured at the time of autopsy show the right ventricular dilatation (Table III), which confirms the above supposition.

Further, relation of the position between each lead point and anatomical longitudinal heart axis or various part of heart are shown in Table IV and V. 21 cases out of 23 on which cardiac punctuations were made disclosed the relation between lead points and longitudinal axis as follows. In relation with orthogonal projection to front chest wall V₁, in all cases, and V₂ in most cases, were located at lower part of longitudinal axis, and half of the V₃ and most of V₄ were at the point of axis, V₅ and V₆ were in most cases located upper part of longitudinal axis. As to the relation with various parts of heart of all the 23 cases V₁ was at right auricle and V₂ in most cases at right ventricle excepting a few at right auricle, V₃ mostly at right ventricle, V₄ at both left and right ventricles having ventricular septum in the center, and V₅ and V₆ are located mainly at left ventricles. (Table VI).

Table IV Distribution of Transitional Zone in Each Group

<table>
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<tr>
<th>Group</th>
<th>V2</th>
<th>V2-3</th>
<th>V3</th>
<th>V3-4</th>
<th>V4</th>
<th>V4-5</th>
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<th>V5-6</th>
<th>V6</th>
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<td>LVH (10)</td>
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<td>CVH (15)</td>
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</tbody>
</table>

* Number of cases

Table V Correlation between Anatomical Longitudinal Axis and Position of Precordial Lead

<table>
<thead>
<tr>
<th></th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower part of L.A.</td>
<td>21</td>
<td>13</td>
<td>11</td>
<td>2</td>
<td>2</td>
<td>—</td>
</tr>
<tr>
<td>Part of L.A.</td>
<td>—</td>
<td>8</td>
<td>10</td>
<td>13</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Upper part of L.A.</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>6</td>
<td>15</td>
</tr>
</tbody>
</table>

L.A.: Longitudinal axis

Japanese Circulation Journal Vol. 33, January 1969
TABLE VI  CORRELATION BETWEEN EACH PART OF THE HEART AND POSITION OF PRECORDIAL LEAD

<table>
<thead>
<tr>
<th></th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
<th>V4</th>
<th>V5</th>
<th>V6</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>20</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RV</td>
<td>3</td>
<td>21</td>
<td>20</td>
<td>12</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>IVS</td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>LV</td>
<td></td>
<td></td>
<td>9</td>
<td>20</td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>

RA: Right atrium  
RV: Right ventricle  
IVS: Interventricular septum  
LV: Left ventricle

2. Location of T.Z. on Normal Heart and Hypertrophied Heart (Table IV).  
As shown in Table IV T.Z.s of NVH groups are distributed from V₂ to V₅₋₆. With all LVH groups T.Z.s are located right hand of V₅.

Though only 4 cases belong to RVH group, their T.Z.s are located at V₆ or further left to V₆. In CVH groups 2 cases (14%) are at V₃₋₄ and other 17 cases (86%) are at further left to V₄.

3. Wr and T.Z. (Fig. 3)  
On all the 36 cases correlation between right chest wall thickness and transitional zone was examined.

With NVH and LVH groups no significant correlation was found between Wr and T.Z., and RVH group had too few cases to discuss with their correlation. Only on CVH group statistically positive correlation of r = 0.57, P < 0.05 was obtained.

4. T.Z. and Cr/CrL (Fig. 4)  
Studies were made on each group of the 23 cases, on the ratio of right ventricle volume against the total volume of right and left ventricles.

Except a considerably large figure of negative correlation was obtained with LVH group (r = -0.91, P < 0.05), no significant correlation was observed on NVH and CVH groups. Having only 1 case RVH group was not entitled as the subject of this study.

5. T.Z. and Wr × Cr/CrL (Fig. 5)  
As an index representing ventricular hypertrophy together with ventricular dilatation Wr

This sketch shows a projective figure of the heart to the chest wall.  
L.A.: Longitudinal axis

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Fig. 3~19  ● NVH-group, □ RVH-group, ▲ LVH-group, ○ CVH-group.

Japanese Circulation Journal  Vol. 33, January 1969
Comparison of Ventricular Hypertrophy and Dilatation

$\times Cr/Crl$ was used, on which the correlation with T.Z. was studied. No significant correlation was found with NVH group. LVH group showed a considerably large negative correlation ($r = -0.67$) but in view of large risk ($P < 0.2$) this correlation was considered insignificant. With CVH group higher positive correlation ($r = 0.73$, $P < 0.02$) than that between simple Wr and T.Z. (mentioned in (3)) was obtained. Here again RVH group was out of the question having only 1 case included.

6. Wr and R Wave (hereafter RV$_1$) and Ventricular Activation Time (hereafter VAT V$_1$) at V$_1$ (Fig. 6, 7, 8)

The correlation between Wr and RV$_1$ or VAT V$_1$ was examined, the latter being representative criteria$^{4,5,8,11,12}$ of the diagnosis of right ventricular hypertrophy.

As to RV$_1$ on 33 cases, excepting 3 cases of CVH group which showed complete or incomplete right bundle branch block, correlation with Wr was traced on each group but no

Fig. 6. RV-thickness (Wr) and height of RV$_1$.

Fig. 7. RV-thickness (Wr) and VATV$_1$ (Wilson).

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*Japanese Circulation Journal Vol. 33, January 1969*
significant correlation was obtained with any case. Here again RVH group was not included because the cases were few to be considered as subject of this study.

Out of the total 33 cases the cases which showed $RV_1$ higher than 0.7 mV\textsuperscript{10} are 3 out of 4 with RVH group (75%), and 1 out of 12 with CVH group (8%). 3 cases of CVH group which have right bundle branch block being excluded. Cases with $RV_1$ more than 0.5 mV\textsuperscript{11} were:

2 cases out of 7 with NVH group (29%)
3 cases out of 4 with RVH group (75%)  
1 cases out of 10 with LVH group (10%)  
1 cases out of 12 with CVH group (8%)  

Only 2 cases out of 3 with RVH group showed deviation to right axis. 3 cases of RVH group showed R/S ratio > 1.

No significant correlation between $W_r$ and VAT\textsubscript{vi} on total 33 cases.

7. $RV_1$ and $W_r/W_l$ (Fig. 9)

Correlation between $RV_1$ and right ventricle chest wall thickness to left ventricle chest wall thickness were traced but no significant correlation was seen similar to the case of $W_r$.

8. Distribution of QRS axis with Normal Heart and Hypertrophied Heart (Fig. 10)

Distribution of QRS axis in each group was studied with 35 cases. Mostly distribution was in the normal range except 4 cases of RVH group which showed a slight deviation toward right axis.

9. T.Z. and Wl (Fig. 2)

On total 36 cases correlation between transitional zone and left ventricle wall thickness was studied in each group, however, no significant relation was obtained.

10. T.Z. and Cl/Crl (Fig. 12)

With 23 cases of which ratio of left ventricle volume against total right and left ventricle volume were measured and the correlation between T.Z. in each group was studied. A considerably high positive correlation was obtained with LVH group ($r=0.92$, $P<0.01$) but with

![Fig. 9. RV-thickness ($W_r$) and height of $R_{V_1}$](image)

![Fig. 10.](image)
the other groups particular significance was not found. RVH group was not discussed due to the case belonging was only one.

11. T.Z. and WI × Cl/Crl (Fig. 13)

Similar as in the case of right ventricle, correlation between T.Z. and WI × Cl/Crl in each group was examined 23 cases of which Cl/Crl was measured. While LVH group showing a considerably high positive correlation as in the case of (10) \( r = 0.89, P < 0.02 \) but correlation figure was minor to that of (10). RVH group had only 1 case and the other groups showed no significant correlation.

12. Correlation between WI and RV₅, WI and RV₅ + SV₁, and WI and Ventricular Activation Time at V₅ (VATv₅) (Fig. 14, 15, 16, 17)

As in the case of (6) correlation between WI and RV₅, RV₅ + SV₁, and VATv₅, which have been very often adopted as diagnostic criteria of left ventricular hypertrophy.

As to RV₅ correlation with WI was traced on the 35 cases of which RV₅ were measured but no group showed particular correlation.

Fig. 11. LV-thickness (WI) and transitional zone.

Fig. 12. LV-capacity (Cl) and transitional zone.

Fig. 13. LV-thickness (WI) × LV-capacity (Cl) R & L-capacity (Crl) and transitional zone.

Fig. 14. LV-thickness (WI) and height of RV₅.
The cases which showed RV₁ higher than 26 mV⁷,⁹ are 1 out of 7 with RVH group (14%), 4 out of 10 with LVH group (40%) and 5 out of 14 with CVH group (36%).

As to RV₅ + SV₁, 33 cases, of which RV₅ and SV₁ were measured, were studied but no group was found to have particular correlation with WI.

However, the cases showing RV₅ + SV₁ ≥ 3.5 mV⁹ are 1 out of 7 with NVH group (14%). 5 out of 10 with LVH group (50%) and 7 out of 12 with CVH group (58%).

As to VATV₅ no significant correlation with WI was found on the 35 cases which could be measured.

13. RV₅ and WI/Wr (Fig. 18)
   Of the 35 cases which RV₅ were measured no group disclosed significant correlation.

**Discussion**

Along with the development of the study of clinical electrocardiogram there have been many reports on the correlation between anatomical heart position and its electrical phenomenon. Concerning the normal human heart EINTHOVEN⁴ discussed the correlation of maximum electrical axis with anatomical heart position and standard limb lead pattern, and on the other hand, with introduction of standard chest lead WILSON et al.² proposed a new conception of electrical heart position in relation with anatomical heart position. Concerning the tran-
sition zone Rosenburg et al.\textsuperscript{43} and others\textsuperscript{16, 42, 44} emphasize its correlation with anatomical ventricular septum position. However, on the other hand, there are reports such as of Grant\textsuperscript{48} stating that, anatomically, rotation of the heart along with longitudinal axis is very rare and that of along with anteroposterior axis may also be about 30° at maximum. Schwede\textsuperscript{19} also concluded that judging from X-ray photogram degree of the chest rotation of the heart along the longitudinal axis will be less than 15°. All these reports deny the correlation with electrical phenomena on electrocardiogram and also the reports of Guntheroth\textsuperscript{45} emphasizes, from the point of angiocardiology, lack of unity in anatomical heart position and QRS axis or transitional zone.

In case there is a deviation of QRS axis possible anatomical dislocation of the heart are said to be about 30° along with anteroposterior axis, while that of QRS axis is said to be as large as ±180°. As to T.Z., however, possible dislocation of the heart is, supposing from the author's personal experience (Table II Case D.E.L.) in the range of left sternal rand and the left axillary line, i.e. about 90°. (Rosenburg\textsuperscript{43} states similar estimation in his report) and possible dislocation of T.Z. is considered to be similar to this. From these facts, and compared with QRS axis deviation, T.Z. is supposed to have higher correlation with anatomical heart position, i.e. interventricular septum.

Shifting of T.Z. is not only affected by the rotation of the heart along with the longitudinal axis but also the rotation toward the anteroposterior axis cannot be overlooked. However, the fact\textsuperscript{48} that the heart revolves with anteroposterior axis about 30° is considered to be reliable report thinking of anatomical position of the heart. Thus the main factor affecting the shifting of transitional zone is considered to be revolving of the heart along with longitudinal axis and we decided to start the study with this viewpoint.

Considering cardiac enlargement as a whole, either it is the ventricular hypertrophy accompanied with ventricular dilatation or the hypertrophy without dilatation, the most suitable index of its degree is heart weight. Thinking about the cases which we have taken up for this study, all of them showed positive correlation (r=0.42, P<0.02) between heart weight and T.Z. This means T.Z. varies in parallel with the heart weight and suggests the propriety of adopting T.Z. as an index of cardiac enlargement (Fig. 19).

Deviation of T.Z., especially to the leftward is reported to appear often with cases of left ventricular hypertrophy\textsuperscript{7} or combined hypertrophy\textsuperscript{40, 50}. Especially with combined hypertrophy this indication is very often used as diagnostic criteria\textsuperscript{21} together with the existence of vertical position. However, no report has ever been brought out dealing with the relation of this leftward transition with Wr, Wl, Cr or Cl.

Investigating the distribution of T.Z. the author found only RVH group and CVH group have the T.Z. lefthand of V₃ among cardiac enlargement groups and as for LVH group T.Z. are all at righthand of V₃. This fact may indicate that right ventricular hypertrophy, rather than left ventricular hypertrophy, plays an important role in deviation of T.Z. to leftward.

This tendency seems to be more convinceable when the relation of T.Z. and Wr, Wl, Crl/Cr are discussed in its ratio.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig19.png}
\caption{Cardiac weight and transitional zone.}
\end{figure}
First of all, the relation between T.Z. and Wr is studied. With CVH group, although some correlation is seen between them this cannot be realized between T.Z. and WI. This may mean that the deviation of T.Z. to leftward may be caused by the increase of Wr but not that of WI. With RVH group, because of the lack of data though the correlation cannot be studied the fact that T.Z. of all 4 cases are at V₆ or further left to V₆ may confirm the above opinion. Although Wilson⁷ states that with right ventricular hypertrophy T.Z. moves toward right and with left ventricular hypertrophy that moves to left we observed that T.Z. tends to move toward left at least as right ventricular hypertrophy is concerned.

T.Z. is reported to move toward left with acute pulmonary embolism⁵¹,⁵² and from our experience it happens to occur at the time of congestive heart failure and restores when the heart failure is recovered. This cannot be explained only with the increase of Wr. In this case, change in ventricular capacity, i.e. dilatation must be considered. The author tried to find some clue to solve this problem by measuring ventricle volume at the time of autopsy. In order to avoid the error as much as possible we tried to obtain the autoptic data as soon as death takes place and used the latest electrocardiograms excepting the cases those which are affected by abnormal electrolyte or heart failure.

It is very difficult problem to measure the ventricular volume accurately. According to Hochrein's report⁵⁵ he has measured average volume of normal ventricles by keeping the pressure of intraventricular cavity of the heart at same level immediately after the death and measured it after fixing. The values thus obtained was 137 cc at right ventricles and 121cc at left. Even with same heart ventricular volume may fluctuate whether the cardiac arrest took place at systolic or diastolic phase. The author was unable to follow after Hochrein's method of keeping the intraventricular cavity at the same level in order to adjust the difference between systole and diastole, and as more simple method was used the errors could not be avoided. As the adjustment of the difference between systolic and diastolic value the author adopted the ratio of each left and right ventricular volume against the sum of both left and right ventricular volume. Hochrein reported the 16cc difference in absolute value between left and right ventricular volumes, but according to our study the value was 0.53 in the ratio of right ventricular volume (Cr) against the sum of left and right ventricular volume (Crl). The ratio of left ventricular volume (Cl) is 0.47 and the ratio of right ventricular to left ventricular is Cr/Cl = 1.13. This means Cr = Cl actually. Thus we considered the above-mentioned ratios are enough to be regarded as index of relative dilatations.

According to the above method the correlation of ventricular volumes (ratio) and T.Z. was studied.

First of all, as for Cr/Crl and Cl/Crl only LVH group revealed the precise negative correlation (r = -0.91, P < 0.05) and positive (r = 0.92 and P < 0.01) respectively. However, since both Cr/Crl and Cl/Crl are expressed with ratio against the sum of both left and right ventricles the results are to be interpreted either to mean, with left ventricular hypertrophy, T.Z. deviates to rightward due to the increase of Cr/Crl, i.e. right ventricular dilatation, or T.Z. deviates to leftward due to the increase in Cl/Crl, i.e. left ventricular dilatation. With left ventricular hypertrophy X-ray examination reveals the shadow of the heart enlarged to left side downward. This means the deviation of T.Z. to leftward, but on the other hand simple right ventricular dilatation is unconceivable with left ventricular hypertrophy.

Next, since chest wall thickness (W) as an indication of ventricular hypertrophy and ventricular volume (C) as an indication of ventricular dilatation must be discussed at the same time, the correlation between T.Z. and W × C was studied. Significant correlations are found on: 1) CVH group Wr × Cr/Crl to T.Z. (r = 0.79, P < 0.02), 2) LVH group Wl × Cl/Crl to T.Z. (r = 0.89, P < 0.02).

1) shows more close correlation than that of Wr to T.Z. This fact suggests that when discussing deviation of T.Z. to leftward not only Wr but Cr/Crl must also be considered. In other words an important factor to cause the deviation of T.Z. leftward is right ventricular
dilatation together with right ventricular hypertrophy.

As stated before the results as obtained in 2) involves the question that which of the correlation, Cr/Crl, CI/Crl to T.Z. respectively, with left ventricular hypertrophy, is to be the real factor. Considering the opinion\(^a\) that always left ventricular hypertrophy precedes left ventricular dilatation, deviation of T.Z. is considered to be caused mainly by left ventricular hypertrophy together with dilatation.

The results that leftward deviation of T.Z. was caused by increase of Wr, Cr/Crl with CVH group and increase of CI/Crl, W1 with LVH group, though the degree of deviation was very small, are considered to suggest that the rotation of heart is tend to be caused in the direction of clockwise with longitudinal axis and to the left-upper-ward with antero-posterior axis, in view of the anatomical position of the heart in thoracic cavity.

Compared with ventricular hypertrophy group NVH group has wide distribution of T.Z. ranging from \(V_2\) to \(V_{5,6}\), as shown in Fig. 2 Case II. The above may be interpreted as, compared with hypertrophy group, NVH group have a wider distance between chest wall and cardiac surface.

Therefore, the position of T.Z. is said to be very important factor in the diagnosis for ventricular hypertrophy and dilatation, which can not be overlooked together with other electrocardiographic findings.

Next, high voltage of QRS wave and VAT, both of them having been common diagnostic criteria for ventricular hypertrophy, and studied in relation to chest wall thickness, but the results revealed no significant correlation. However, the criteria \(RV_v + SV_v \geq 3.5 \text{ mV}\), which has been praised of its reliability in the diagnosis of ventricular hypertrophy, is found to have considerably high positive percentage with LVH group and CVH group. This is in fair agreement with the reports\(^a\):\(^b\) made by other researchers.

Also in the same way, deviation of QRS axis was studied with each group. Although there were only a few cases, RVH group showed a tendency of slight deviation to right, but only 2 out of 3 cases showed higher figure of deviation more than \(+110^\circ\), the figure reported by Milnor\(^1\). However, it seems to be dangerous to discuss the rightward deviation of axis in right ventricular hypertrophy by having measured only three cases of QRS axis.

Concerning criteria of electrocardiogram of ventricular hypertrophy reports are made by Walters\(^2\), Allenstein\(^3\), etc. with regard to right ventricular hypertrophy, and by Scott\(^4\), Allenstein\(^5\), etc. with regard to left, all of them admit high positive percentage with left ventricular hypertrophy leaving at the same time quite a high false positive percentage, but as to the right ventricular hypertrophy all of them emphatically point out that the precise diagnosis is impossible. In case QRS wave high voltage, which is main diagnostic criteria of hypertrophy, and the thickness of ventricular

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**Table VII** DETAILED VALUE IN THE STUDY OF THE CORRELATION BETWEEN EPICARDIUM- CHEST WALL DISTANCE AND HEIGHT OF R WAVE IN V2

<table>
<thead>
<tr>
<th>Pl.</th>
<th>Age</th>
<th>Sex</th>
<th>R in V2</th>
<th>E-C Distance(^a)</th>
<th>Clinical Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. I.</td>
<td>66</td>
<td>F</td>
<td>1.7</td>
<td>63 mm</td>
<td>Bronchial asthma</td>
</tr>
<tr>
<td>F. M.</td>
<td>80</td>
<td>F</td>
<td>2.6</td>
<td>58</td>
<td>Dementia senilis</td>
</tr>
<tr>
<td>T. A.</td>
<td>55</td>
<td>F</td>
<td>7.6</td>
<td>56</td>
<td>Myelitis</td>
</tr>
<tr>
<td>S. O.</td>
<td>60</td>
<td>M</td>
<td>9.2</td>
<td>37</td>
<td>Pulmonary tuberculosis</td>
</tr>
<tr>
<td>N. S.</td>
<td>60</td>
<td>F</td>
<td>10.0</td>
<td>37</td>
<td>Arachnomyelitis</td>
</tr>
<tr>
<td>K. T.</td>
<td>68</td>
<td>F</td>
<td>10.0</td>
<td>60</td>
<td>Rheumatoid arthritis</td>
</tr>
<tr>
<td>N. K.</td>
<td>71</td>
<td>F</td>
<td>10.3</td>
<td>28</td>
<td>Chronic bronchitis</td>
</tr>
<tr>
<td>S. Y.</td>
<td>49</td>
<td>M</td>
<td>14.9</td>
<td>30</td>
<td>Bronchial asthma</td>
</tr>
<tr>
<td>Y. S.</td>
<td>35</td>
<td>M</td>
<td>15.6</td>
<td>44</td>
<td>Myotonia congenita</td>
</tr>
<tr>
<td>T. I.</td>
<td>60</td>
<td>M</td>
<td>15.5</td>
<td>42</td>
<td>Osteoporosis</td>
</tr>
</tbody>
</table>

* Epicardium-Chest Wall Distance  Unit: R in V2 (1/10 mV)

Japanese Circulation Journal  Vol. 33, January 1969
wall not to meet it may mean not only the changes of wall thickness but many factors, such as increase of solid angle due to the increase of cardiac surface, close distance between the heart and chest wall due to the rotation of heart, etc. Like Uhley54, Konishi55 of this clinic discussed the high voltage on electrocardiogram in relation with the increase of solid angle, denying the increase of intracellular potential in hypertrophied heart.

The author examined the cases which were supposed to be normal heart and have comparatively high voltage in right ventricular lead. (Table VII). Tomogram was taken along sagittal surface at V5 lead point and the shortest distance from V5 lead point written on chest wall to the cardiac surface was measured. The results of this measurement and R wave at V5 revealed quite close negative correlation (r = −0.72, P<0.02) (Fig. 21). From the above we have to know the importance of the distance between chest wall and heart as a factor producing high voltage on electrocardiogram.

**SUMMARY**

1. Out of the cases went under autopsy during the period of 1958–1964 at 3rd Medical Clinic of Kyoto University Hospital 36 cases were studied. Macroscopic pathological findings of hearts (cardiac weight, ventricular wall thickness, ventricular volume, ventricular septum position) and its electrocardiographic findings, especially R wave height at V8 and V5 (RV1, RV5); ventricular activation time (VATV1, VATV5), S wave depth at V1 (SV1), QRS axis, and QRS transitional zone (T.Z.) are studied in comparison, and the following results are obtained.

2. Immediately after death punctuation was made from body surface with a long needle at electrocardiographic standard chest lead points V1−V6. After the chest was opened corresponding points on the surface of heart were decided. Electrocardiographic pattern at each lead point and location of various parts of heart were examined in its relation, especially QRS transitional zone was defined in relation with ventricular septum position.

3. On the basis of cardiac weight and ventricular wall thickness, all cases were divided into normal group, right ventricular hypertrophy group, left ventricular hypertrophy group, and combined ventricular hypertrophy group, and the correlation between T.Z. and ventricular wall thickness and ventricular volume (expressed with the ratio of each ventricular volume against the sum of both left and right ventricular volume).

4. As to the relation of standard chest lead points of electrocardiogram (V1−V6) and the position of anatomical longitudinal axis of heart, V1 and V6 are mainly at lower part under longitudinal axis, V3 and V4 are mainly at longitu-

![Fig. 21. Epicardium-chest wall distance (ECD) and height of RV5.](image-url)
dinal axis and $V_5$ and $V_6$ are mainly upper part of above longitudinal axis.

As regards the relation of the position between each lead point and the parts of heart were: $V_1$ was at right auricle and $V_2$ in most cases at right ventricle excepting a few at right auricle, $V_3$ mostly at right ventricle, $V_4$ as both right and left ventricles containing ventricular septum in the middle, $V_5$ and $V_6$ is at left ventricles.

5. Distribution of T.Z. was:

Normal cases

- $V_3$: 1 case
- $V_4$: 2 cases
- $V_5$: 3 cases
- $V_5-V_6$: 1 case total 7 cases

Right ventricular hypertrophy group

- $V_6$: 1 case
- $V_6$: 3 cases total 4 cases

Left ventricular hypertrophy group

- $V_3-V_4$: 3 cases
- $V_4$: 1 case
- $V_4-V_5$: 6 cases total 10 cases

Combined ventricular hypertrophy group

- $V_3-V_5$: 2 cases
- $V_4-V_5$: 8 cases
- $V_5-V_6$: 3 cases
- $V_5$: 2 cases total 15 cases

6. With combined ventricular hypertrophy group and right ventricular hypertrophy group the fact that the deviation of T.Z. to left on chest lead electrocardiogram is noted to have been caused by right ventricular wall thickness and increase of right ventricular volume. This is also understood from the position of the right ventricles with hypertrophy and dilatation against the front chest wall. Also with left ventricular hypertrophy group the increase of left ventricular volume and increase of left ventricular wall thickness causes the deviation of T.Z. to left, but this tendency is not so convincing as the leftward deviation with combined and right ventricular hypertrophy group. It is understood that this fact is caused by the deviation of ventricular septum position as a result of changes caused in thorax by left ventricular hypertrophy and dilatation.

The above fact points that in diagnosis of ventricular hypertrophy and dilatation, especially right ventricular hypertrophy and dilatation, on electrocardiogram, the position of QRS transitional zone must be taken into consideration.

7. Accurate correlation was not seen between $RV_1$, $RV_3$, $RV_3+SV_1$ and VAT against right ventricular wall thickness or left ventricular wall thickness respectively. However, in the diagnosis of left ventricular hypertrophy "$RV_3 SV_1 \geq 3.5$ mV" is recognized of its fairly importance.

8. With cases of supposedly having normal heart quite significant positive correlation was seen between R wave height at $V_2$ lead point and the distance of anterior heart surface and chest wall. From this fact it is understood that when discussing the high voltage of QRS wave on electrocardiogram the distance between the heart and front chest wall cannot be overlooked.

Acknowledgement

The author wishes to express his sincere gratitude to Prof. Emer. M. Maekawa, Assist. Prof. Y. Nohara and Dr. R. Kusakawa for their kind guidance and suggestion in this study.

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