A NEW METHOD FOR QUANTITATIVE ANALYSIS OF THALLIUM-201 MYOCARDIAL IMAGE
— "Corrected" Circumferential Profile Method —

Hajime Kataoka, M.D., Keiji Ueda, M.D.*, Makoto Sakai, M.D.*
Hiromi Tabuchi, M.D.*, Hinako Toyama, Ph.D.*, Hajime Murata, M.D.*
Shigeru Takaoka, M.D., Kazuhiro Nakamura, M.D.
Shuji Hashimoto, M.D., and Masahiro Iio, M.D.**

A new method for computer-assisted quantitative analysis of a thallium (TI)-201 myocardial image ("corrected" circumferential profile method) was described. Since the TI-201 myocardial image of a normal subject is not homogeneous, an attempt was made to correct for this non-homogeneity. Three groups of subjects were studied, including 10 normal volunteers (group A, mean age of 27.5 years), 14 patients with atypical chest pain and normal coronary arteriogram (group B, mean age of 56.7 years) and 16 patients with first transmural myocardial infarction (group C, mean age of 71.0 years). The myocardial images were acquired at rest at anterior, left anterior oblique (30° and 60°) and left lateral projections. With a scintigram, the left ventricle was outlined and divided into 24 radial segments by radii drawn from the center of the left ventricle. Average radioactivity per pixel in normal subjects was obtained in each segment and normalized to the highest segment (=100%). The ratio of 100% to the mean of normalized radioactivity in percent in each segment from 10 normal volunteers was calculated and designated as a correction factor for each segment. After the correction of average radioactivity per pixel in each segment using this correction factor and after relating it to the highest radioactive segment, the mean (=100%) and standard deviation (SD) were calculated and (100—4SD)% was defined as the normal lower limit. In the scintigram of groups B and C, "corrected" circumferential profiles were obtained from the regional radioactivity multiplied by the correction factor, normalized to the highest segment (100%) and compared with the lower normal limit. The ratio (%) of the area of patient's circumferential profile curve below the normal limit to the total area below the normal limit was obtained at each view and the sum of them was called the total "corrected" defect score. Infarct size analyzed by the "corrected" circumferential profile method correlated well with that analyzed by visual interpretation, and was useful in differentiating group C from group B.

Key Words:
TI-201 myocardial image
Quantitative analysis
Correction factor
Non-homogeneity
Myocardial infarction

(Received June 11, 1982; accepted November 12, 1982)
The Second Department of Internal Medicine, Kagoshima University School of Medicine, Kagoshima; *Division of Internal Medicine and Department of Nuclear Medicine, Tokyo Metropolitan Geriatric Hospital, Tokyo; **Department of Radiology, Faculty of Medicine, University of Tokyo, Tokyo, Japan
The outline of this paper was presented at the 46th Annual Meeting of the Japanese Circulation Society on March 25, 1981 in Tokyo, Japan.
Mailing address: Hajime Kataoka, M.D., The Second Department of Internal Medicine, Kagoshima University School of Medicine, 1208-1 Usuki-cho, Kagoshima 890, Japan

Japanese Circulation Journal Vol. 47, May 1983 503
The thallium (TI)-201 myocardial image is an accepted non-invasive test for the evaluation of regional myocardial perfusion. In order to evaluate the TI-201 myocardial image more objectively, research on the quantitative analysis of the myocardial image has been performed. Although TI-201 radioactivity over the left ventricle in normal subjects is never homogeneous and characteristic variation of regional TI-201 radioactivity exists, there is no report of quantitative analysis of the TI-201 myocardial image, which takes this variation into consideration.

This report describes the quantitative analysis of the TI-201 myocardial image, taking the variation of the TI-201 radioactivity over the left ventricle into consideration. At first, the morphology of the left ventricle and distribution of TI-201 radioactivity over the left ventricle in normal volunteers are analyzed. Then, our new method for the quantification of the infarct size on TI-201 myocardial image is presented.

**MATERIALS**

The subjects consisted of 3 groups. Group A included 10 normal volunteers, ranging in age from 25 to 32 with an average of 27.5. All had no previous history or current evidence of cardiovascular disease, and had normal chest X-rays and electrocardiographic findings. Group B consisted of 14 patients with normal coronary arteriogram, ranging in age from 30 to 78 with an average of 56.7. They were admitted to the hospital for evaluation of atypical chest pain and/or electrocardiographic ST changes. Selective coronary arteriography and left ventriculography were performed on this group using Sones' technique. Arteriograms were obtained at left and right anterior oblique positions with an injection of 6–8 ml of 76% Urographin® (meglumine sodium amidotrizoate). Left ventricular angiography was performed at the right anterior oblique position with an injection of 40–45 ml of 76% Urographin. Only stenosis of more than 50% was considered significant for each of the three coronary arteries. The ejection fraction was obtained using the area-length method. The subjects of group B had no significant coronary artery stenosis and had an ejection fraction of more than 60% (range 62–85%, mean 71.6%). Group C included 16 patients with first transmural myocardial infarction. The mean age of this group was 71.0 (range 58 to 83). The criteria for diagnosis of transmural myocardial infarction were: 1) a typical clinical history of chest pain, 2) evolutional electrocardiographic ST-T changes of myocardial infarction with Q waves of 0.03 sec in duration or the presence of QS complex in at least 2 of the standard 12 electrocardiographic leads and 3) a typical rise in serum creatinine kinase.

**METHODS**

**TI-201 Myocardial Image**

The TI-201 myocardial images were obtained using the standard technique. TI-201 was administered intravenously in a dose of 2 mCi for the myocardial images, when the subjects were supine and at rest. An Anger-type scintillation camera connected to a computer (Scintipac-1200) was equipped with a converging collimator. The camera was closely applied to the chest, and positioned in front of the left ventricle under oscilloscopic control. Images were recorded by the mercury X-ray peaks (69–80 keV) with 20% window width. The myocardial images were obtained at the anterior, left anterior oblique (30° and 60°) and left lateral projections 10 min
after the administration of TI-201 (Fig. 1). For each view, 400,000 counts were collected for approximately 5 min for the analog image. Images were simultaneously stored in the computer for the further analysis.

Left Ventricular Morphology in TI-201 Myocardial Images of Normal Volunteers

Left ventricular morphology in the TI-201 myocardial image was evaluated using the relative wall thickness (RWT). The RWT of the left ventricle was obtained from the planar images. The inner (along the left ventricular cavity) and outer edge of a tangentially projected left ventricular wall was evaluated by visual inspection. For each view, the absolute thickness of the left ventricle was measured in the planar image at 4 different locations, i.e., 2 measurements at the basal two-thirds, and the other 2 at apical two-thirds of the wall. RWT was calculated from the following formula: RWT at specified location = absolute left ventricular wall thickness at specified location/mean of absolute thickness in four locations.

Analysis of TI-201 Myocardial Image Using Circumferential Profile Method “without Correction”

We have previously reported the validity of placing the region of interest according to Burow’s method. Because radioactivity of the left ventricle was precisely analyzed by Burow’s

---

**TABLE I** SEGMENT NUMBERS OF THE AORTIC AND THE MITRAL ORIFICE, AND APEX OF THE LEFT VENTRICLE ON THE TI-201 MYOCARDIAL IMAGES OF NORMAL VOLUNTEERS

<table>
<thead>
<tr>
<th>Projection</th>
<th>Orifice</th>
<th>Apex</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANT</td>
<td>20–24</td>
<td>8–11</td>
</tr>
<tr>
<td>30° LAO</td>
<td>1, 21–24</td>
<td>11–13</td>
</tr>
<tr>
<td>60° LAO</td>
<td>1–3, 24</td>
<td>13–15</td>
</tr>
<tr>
<td>L-LAT</td>
<td>1–7</td>
<td>14–16</td>
</tr>
</tbody>
</table>

Numerals indicate the segment numbers.
Abbreviations: ANT = anterior, LAO = left anterior oblique, L-LAT = left lateral

---

Fig. 2. The placing method of the region of interest. Upper panel shows a processed image on a cathode ray tube and lower panel represents its schematic drawing. Numerals represent the segment numbers.

Fig. 3. Representative drawing of a “corrected” circumferential profile curve obtained from a patient with inferoposterior myocardial infarction. Patient’s profile curve was obtained by an image analysis at 60° left anterior oblique projection. Shaded area shows the normal limit and solid line represents the patient’s curve.
Fig. 4. The estimating method of infarct size by visual interpretation. Dotted area represents the decreased radioactivity area.

Fig. 5. Relative thickness of the tangentially projected left ventricular wall in normal volunteers. Abbreviations: A = anterior, AL = anterolateral, Ap = apical, AS = anteroseptal, I = inferior, P = posterior, PL = posterolateral, PS = posteroseptal, \(*p < 0.05, \quad **p < 0.02, \quad ***p < 0.01\)

method? TI-201 distribution over the left ventricle in normal volunteers was assessed using this method (circumferential profile method "without correction"). Furthermore, the analysis of the TI-201 myocardial image in the patient groups (groups B and C) was also done using this method in order to compare it with ours.

The left ventricle was outlined visually along the outer edge of the left ventricle on the cathod ray tube connected to the computer, and divided into radial segments by radii (15° arc) constructed from the center of the left ventricular cavity to the outer edge, beginning at 12 o'clock and proceeding clockwise around the outer edge (Fig. 2). Each segment was numbered from 1 to 24 in a clockwise rotation. The segments containing the aortic ostium and the mitral orifice were excluded from this analysis (Table I). Each image was smoothed by 9-point averaging algorithm. No background was subtracted from the image. Average radioactivity per pixel was obtained in each segment and normalized to the highest segment (=100%).

In order to assess the inherent non-homogeneity of TI-201 myocardial image of normal volunteers in each projection, 4 different radial segments, i.e., 2 segments near the base and other 2 near the apex, were chosen and differences of mean value of the relative radioactivity among them were evaluated.

A circumferential profile curve "without correction" for the controls in each projection was taken from 10 normal volunteers by plotting normalized radioactivity against segment number and the normal limit was defined as the mean ± 2SD. Patient's profile curve "without correction" was also obtained by the same way and compared with the normal limit. The ratio (%) of the area of patient's circumferential profile
curve below the normal limit to the total area below the normal limit was obtained from 4 projections, and the sum of them was called the total “non-corrected” defect score.

"Corrected" Circumferential Profile Method

A TI-201 myocardial image is never homogeneous and has a specific distribution pattern at each view. A new method for quantitative analysis of the TI-201 myocardial image, which took the non-homogeneity into consideration, was used. The main difference between our method and Burrow's was the use of a correction factor in order to correct the normal variation of the TI-201 radioactivity over the left ventricle.

The method of placing the region of interest on the myocardial image was the same as circumferential profile method “without correction” (Fig. 2). A correction factor for each segment was obtained from normal volunteers. The correction factor was the ratio of 100% to the mean of normalized radioactivity in each segment of 10 normal volunteers. After correcting the average radioactivity using this factor and normalized to the highest segment (=100%) in each volunteer, the mean and SD were calculated from the 10 normal volunteers and (100 – 4SD)% was defined as the normal lower limit.

In the TI-201 myocardial image of groups B and C, the patient's “corrected” circumferential profile curve was obtained with an average radioactivity of each segment multiplied by the correction factor and normalized to the highest segment (100%), and this was compared with lower normal limit. The ratio (%) of the area of the patient's "corrected" circumferential profile curve below the normal limit to the total area below the normal limit was obtained at each view, and the sum of them at 4 views was called the total "corrected" defect score. In Fig. 3, a representative drawing of the "corrected" circumferential profile curve from a patient with inferior myocardial infarction is presented.

To assess the validity of the "corrected" circumferential profile method, correlation between the infarct size obtained by a visual interpretation of the TI-201 myocardial image and that calculated from the "corrected" circumferential profile method was investigated. Visually interpreted infarct size was obtained from the planar image of group C. The area surrounded by inner and outer edges of the tangentially projected left ventricular wall except for the aortic and the mitral ostium and the decreased TI-201 radioactivity area were outlined on the transparent paper by 2 experienced...
observers having no knowledge of the clinical data (Fig. 4). Both areas were calculated using a planimetry. The ratio (%) of the decreased Tl-201 area to the whole tangentially projected left ventricular wall area was determined and was defined as visual defect score.

Differences of mean value were evaluated by an analysis of variance and Student's t-test. Linear correlation was found by the method of least squares analysis.

RESULTS

Morphology of the Left Ventricle in Tl-201 Myocardial Image of Normal Volunteers

Figure 5 shows the RWT of the tangentially projected left ventricular wall at 4 views. Except at the lateral view, the sites of basal two-thirds were thicker than those of apical two-thirds. At the left anterior oblique 30° and 60° projections, the locations of the basal two-thirds at the posterolateral and posterior wall were thicker than the remaining locations.

Tl-201 Myocardial Distribution Pattern in Normal Volunteers

Figure 6 represents the comparison of relative radioactivity among the selected radial segments of the left ventricle obtained from the analysis of the Tl-201 myocardial images of 10 normal volunteers using circumferential profile method "without correction". Except at the lateral projection, radioactivity of the segments near the apex was higher than that near the base, and segments at the lateral wall had higher radioactivity than those at the septal wall.

Circumferential profile curve "without correction" for the controls at each projection is presented in Fig. 7. Regional variation of Tl-201 radioactivity in normal volunteers is apparent in this figure. Segments situated at the apical portion demonstrated a slightly decreased radioactivity.

"Corrected" Circumferential Profile Curves of Normal Volunteers

"Corrected" circumferential profile curves and correction factors obtained from 10 normal volunteers are presented in Fig. 8. The segments near the base had a wider range of SD than those near the apex. As for the correction factors, large values were obtained at the segments near the base as compared with the segments near the apex.

Japanese Circulation Journal Vol. 47, May 1983
Correlation between the "Corrected" Defect Score and Visual Defect Score

The correlation between myocardial infarct size obtained by "corrected" circumferential profile method and that obtained by visual interpretation for 16 patients of group C at each view is shown in Fig. 9. A close linear relation was found between them. The r values for anterior, left anterior 30°, 60° and left lateral projections were 0.556, 0.659, 0.704 and 0.780, respectively. There also existed a good correlation (r = 0.790) of the total defect score (sum of the defect score at 4 views) (Fig. 10).

Comparison between Circumferential Profile Method "with" and "without" Correction

The TI-201 myocardial images of groups B and C were analyzed by the circumferential profile method both "with" and "without"

### TABLE II COMPARISON OF THE SENSITIVITY AND THE SPECIFICITY BETWEEN THE CIRCUMFERENTIAL PROFILE METHOD "WITH" AND "WITHOUT" CORRECTION

<table>
<thead>
<tr>
<th>Upper normal limit</th>
<th>With correction</th>
<th>Without correction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DS ≤ 5.0</td>
<td>DS ≤ 8.5</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>87.5% (14/16)</td>
<td>75.0% (12/16)</td>
</tr>
<tr>
<td>Specificity</td>
<td>92.8% (13/14)</td>
<td>100% (14/14)</td>
</tr>
</tbody>
</table>

DS = defect score

Japanese Circulation Journal Vol. 47, May 1983
Fig. 11. Comparison of the defect score between the circumferential profile method with (upper) and without correction (lower). Open circles represent the patients with normal coronary arteriogram and closed circles show the patients with acute myocardial infarction. Solid vertical lines indicate the 100% specificity lines and the dotted ones the 92.8% specificity lines, respectively.

Fig. 12. Comparison of the total “corrected” defect score among the normal volunteer, the normal coronary and the acute myocardial infarction group.

Fig. 13. Comparison of the circumferential profile curves with (lower) and without (upper) correction, obtained from 10 normal volunteers (anterior view).

sensitivity and specificity were obtained in the circumferential profile method “with correction”, as compared with the circumferential profile method “without correction” in our population. With the upper normal limit being equal to or less than 8.5, sensitivity and specificity were 75.0 and 100%, respectively, in the “corrected” circumferential profile method. The “corrected” circumferential profile method was useful in differentiating group C from B (Fig. 12).

DISCUSSION

Cook et al. have analyzed the dimension and the thickness of the left ventricle from a TI-201 myocardial image of the heart. They measured several dimensions and wall thicknesses of the left ventricle using a lead marker as the reference. We evaluated the relative wall thickness of the left ventricle instead of measuring the absolute value, and evaluated the morphology of the left ventricle.
ventricle in normal subjects. Although the TI-201 myocardial image may be a blurred image of moving target and the cardiac wall is not flat, being curved around the central cavity the anatomical left ventricular morphology, i.e., the gradual decrease in wall thickness from the base to apex, was reflected in the TI-201 myocardial image obtained.

As shown in this study, TI-201 distribution over the left ventricle is never homogeneous and there exist significant variations in the regional radioactivity among the different areas of the left ventricle in normal subjects. Radioactivity of the left ventricle was lower near the base and became higher near the apex. The apical portion had a slightly decreased radioactivity. Radioactivity of the septal and the anterior wall was low as compared with that of the lateral and the posterior wall.

In TI-201 myocardial image of normal subjects, there exist several factors contributing to the inherent non-homogeneity of radioactivity over the left ventricle. Among them, depth of the heart, distance from the collimator to the heart and scattering and attenuation by intervening overlying tissue are thought to be important. The higher radioactivity near the apex as compared with the base may be due to the shorter distance between this area and collimator and smaller absorption of radioactivity by overlying tissue. Reduced radioactivity of the septal wall was thought to be partly due to an absorption of the radioactivity by the overlying right ventricle.

Taking the morphology and the TI-201 distribution of the left ventricle into consideration, we initiated a "corrected" circumferential profile method for a quantitative analysis of the TI-201 myocardial image. The significance of the correction of the inherent non-homogeneity is discussed as follows:

At first, there exists an inverse relationship between the wall thickness and the TI-201 distribution over the left ventricle, i.e., as the left ventricular wall thickness increases from the apex to the base, the TI-201 radioactivity over the left ventricle decreases. The radioactivity per unit volume of the myocardium does not seem equal among the different areas of the left ventricle, perhaps partly due to several factors mentioned above.

Second, when the regional radioactivity is evaluated by relative values, relating the regional radioactivity to the highest radioactivity segment (=100%), accurate measurement is handicapped due to the inherent unevenness of the TI-201 radioactivity, and the construction of a curve using correction factors for comparison of the regional radioactivity seems reasonable. For example, if a lesion occurred at an area with an inherent high radioactivity, this lesion may exhibit the highest radioactivity without correction, even if its absolute radioactivity is reduced, so that the presence of the lesion may be masked. By using a correction factor, the most normal radioactive segment of the myocardium can be evaluated as the one with the highest radioactivity and this segment can be used as the segment for reference (=100%).

Third, as presented in Fig. 13, the normal limit of the circumferential profile method "without correction" is not strictly equal to the mean ± 2SD, when a regional radioactivity is related to the highest radioactivity segment. Strictly speaking, the normal limit of this method is between a 100% line (upper) and a mean – 2SD line (lower). Thus, there exists an uneven normal range, i.e., a narrower normal range in high radioactivity segments and a wider normal range in low radioactivity segments. On the other hand, when correction factors are used, the normal range fits strictly within 4SD.

Infarct size analyzed by the "corrected" circumferential profile method correlated well with that analyzed by visual interpretation. At the anterior projection, correlation between them (r = 0.56) was not good as compared with that obtained at the other projections. One of the reasons for this may be a low contrast resolution of the septal wall due to an inherent low radioactivity at that wall, presumably due to an attenuation of the radioactivity by the right ventricle. The determination of the boundary between the lesion and the surrounding normal myocardium was often difficult by visual interpretation. Thus, the different defect score between the infarct size obtained by the visual interpretation method and that by ours seemed to be due to the difficulty in interpreting of the TI-201 myocardial image by visual analysis. In addition, methodological differences may be related to the discrepant estimation of the infarct size. That is, an ischemic lesion on the TI-201 myocardial image has not only two-dimensional extension of the lesion but also an abnormally concentrated tracer activity. Although a quantitative method can evaluate both of these, it is difficult to grade the abnormal tracer activity by...
visual interpretation. However, correlation of the total defect score was excellent ($r = 0.790$), and clinical application of our method proved to be feasible and valid in our preliminary study.13

The principle of the circumferential profile method “with” or “without” correction to analyze the TI-201 myocardial image is the evaluation of the deviation of the patient’s TI-201 radioactivity from the normal limit predetermined from normal volunteers. Extreme rotation of the heart, hypertrophy and dilatation of the left ventricle may cause the deviation of the TI-201 distribution pattern from the normal limit, and thus, an erroneous defect score may result in the cases without ischemic lesions. Care must be taken not to misinterpret such cases.

In conclusion, a new method for quantitative analysis of TI-201 myocardial image using a correction factor was presented in this study, and its diagnostic sensitivity and specificity proved to be equal to or greater than the circumferential profile method “without correction”. This method has also proved to be clinically valid for an assessment of the relation between the infarct size and echocardiographic findings.13

REFERENCES

2. BAILEY IK, GRiffith LSC, STRAUSS HW, PITT B: Detection of coronary artery disease and myocardial ischemia by electrocardiographic and myocardial perfusion scanning with thallium-201 (abstr). Am J Cardiol 37: 118, 1976
3. BULL U, NIENDORF HP, STRAUER B, HAST B: Evaluation of myocardial function with the $^{201}$thallium scintimetry in various diseases of the heart. Eur J Nucl Med 1: 125, 1976