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Quantitative evaluation of right heart hemodynamics by thallium-201 myocardial scintigraphy in infants and children with congenital heart disease

Ken UEDA
Akihiro SAITO
Hiroyuki NAKANO
Masayuki YANO*

Summary

Thallium-201 myocardial scintigraphy was done in 46 pediatric patients with congenital heart disease and 18 normals, whose ages ranged from 2 months to 13 years. The qualitative and quantitative analysis of right heart hemodynamics were performed by comparing with the findings of cardiac catheterization and echocardiography in 39 of these 64 patients.

Multi-gated diastolic images of 1,500 heart beats were obtained 5 minutes after rapid intravenous injection of 60 μCi/kg of thallium-201 chloride. Scintigrams were taken from the anterior view, left anterior oblique view at 30°, 45° and 60°, and lateral view. Among these 5 views the image, which demonstrated the inter-relationships of the left ventricle, interventricular septum and right ventricle most clearly, was used for this study. The technique of analysis involved assignment of 4 regions of interest over the upper mediastinum, left ventricular free wall, interventricular septum and right ventricular free wall on the graphic display of the computer-processed scintigram. The activities of right ventricular free wall (W_R) and left ventricular free wall (W_L) were determined by subtraction of the activity of background (B_K). Furthermore, the ratio of myocardial blood flow (MBF) to cardiac output (CO) was obtained by the method proposed by Ishii and his associates.[1]

Imaging of the right ventricular free wall was possible in all patients except 2 patients; one with tricuspid atresia and another with Uhl's anomaly. These 39 patients were divided into 5 different hemodynamic groups; normal, left ventricular volume overload with pulmonary hypertension (LVVL c̄ PH), left ventricular volume overload without pulmonary hypertension (LVVL s̄ PH), right ventricular pres-

静岡県立こども病院　循環器科
*同　放射線科
静岡市漆山 860 (〒420)

Department of Pediatric Cardiology, and *Radiology and Nuclear Medicine, Shizuoka Children's Hospital, Urushiyama 860, Shizuoka 420

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sure overload (RVPL), right ventricular volume overload (RVVL), and others. Each scintigram of these different hemodynamic groups showed the different morphologic characteristics of the images of left ventricular free wall, interventricular septum and right ventricular free wall. In normals, MBF/CO showed an inverse correlation with body surface area ($r = -0.85$). While MBF/CO was significantly high in LVVL c̄ PH ($p<0.001$) and RVPL (<p0.001), the ratio was low in RVVL ($p<0.05$). In addition, MBF/CO was well correlated with right ventricular systolic pressure ($r=0.80$). Both W_R/B_K and W_R/W_L were significantly high in LVVL c̄ PH and RVPL, respctively (all $p<0.001$). W_R/W_L showed a good correlation with right ventricular systolic pressure and right and left ventricular mass ratio, respectively ($r=0.77$ and $r=0.80$).

In conclusion, thallium-201 myocardial scintigraphy was considered to be useful for the noninvasive quantitative evaluation of right heart performance in infants and children with congenital heart disease.

Key words

Thallium-201 scintigraphy Right heart hemodynamics Quantitative analysis Infants and children Congenital heart disease

Thallium-201 (Tl-201) myocardial scintigraphy has been widely used for the diagnosis of myocardial infarction in adults[2~4] and recently its diagnostic value has been reported in infants and children with anomalous origin of the left coronary artery from the pulmonary artery[5,6] and myocardial infarction following mucocutaneous lymph node syndrome[7]. Although there have been several reports[8~11] in which Tl-201 scintigraphy was utilized for the evaluation of the right heart hemodynamics, these studies were qualitative or semiquantitative. The present study was performed to evaluate right heart hemodynamics quantitatively in infants and children with congenital heart disease by comparing the findings of Tl-201 scintigraphy with those of cardiac catheterization and echocardiography.

Table 1. Materials

Control	18
TF	10
VSD	7
ASD	6
PDA	5
TA	2
PS	1
p.o. TF	4
Misc.	11
Total	64

TF=tetralogy of Fallot; VSD=ventricular septal defect; ASD=atrial septal defect; PDA=patent ductus arteriosus; TA=tricuspid atresia; PS=pulmonary stenosis; p.o. TF=postoperation of TF; Misc=miscellaneous.

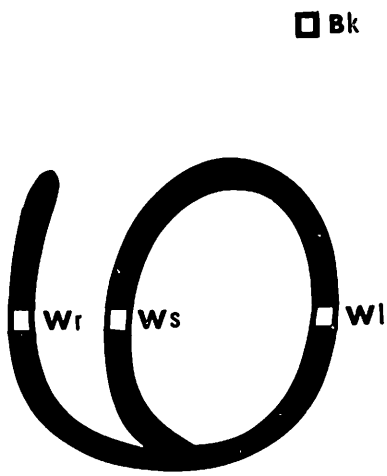

Fig. 1. Diagrammatic representation of four regions of interest on the images on the graphic display.

Bk=activity of the background; Wr=activity of the right ventricular free wall; Ws=activity of the interventricular septum; Wl=activity of the left ventricular free wall.

Patients and Methods

Tl-201 scintigraphy was performed in 46 patients with congenital heart disease and in 18 normals as shown in **Table 1.** Eighteen normals included 15 patients with mucocutaneous lymph node syndrome having no aneurysms of the coronary arteries cofirmed by selective coronary angiography, and 3 patients with small ventricular septal defect with $Q_p/Q_s<1.3$. Their ages ranged from 2 months to 13 years.

The myocardial scintigraphy and quantitative analysis were performed using a Toshiba Gamma Camera GCA-402 and Toshiba computer TOSBAC-40C. Images were taken 5 minutes after rapid intravenous injection of 60 μCi/kg of Tl-201 chloride in the anterior view, left anterior oblique views at 30°, 45°, 60° and left lateral view. Multi-gated diastolic images of 1,500 heart beats were obtained at 80 keV of energy with 30 percent of window width. The quantitative study was done in 39 of these 64 patients and they were divided into six subgroups; normal, left ventricular volume overload with pulmonary hypertension (LVVL c̄ PH), left ventricular volume overload without pul-

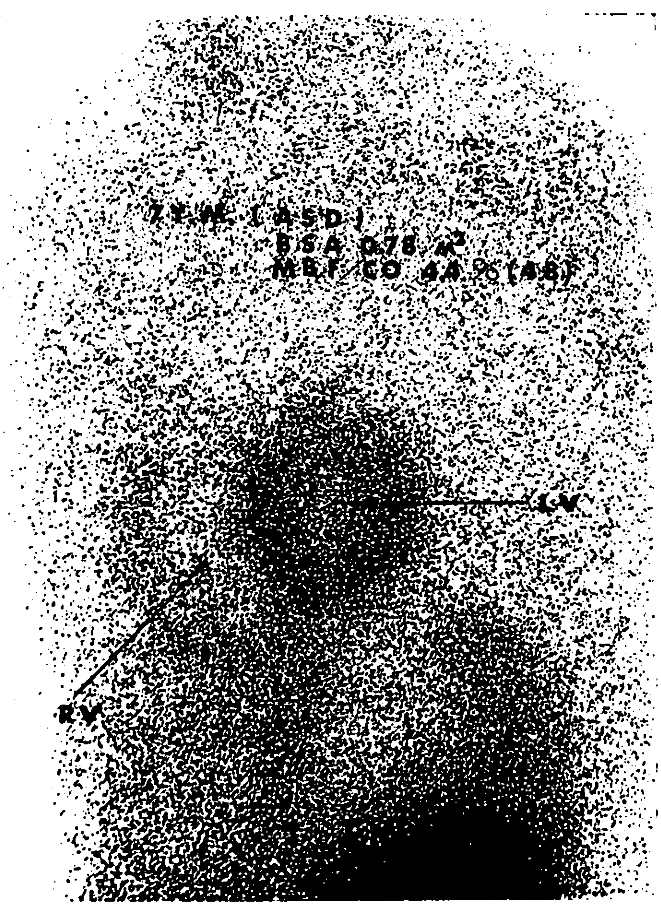

Fig. 2. Thallium-201 scintigram of a patient with atrial septal defect.
ASD=atrial septal defect; BSA=body surface area; MBF/CO=myocardial blood flow/cardiac output; RV=right ventricle; LV=left ventricle.

monary hypertension (LVVL s̄ PH), right ventricular pressure overload (RVPL), right ventricular volume overload (RVVL), and others.

The technique of analysis involved assignment of four regions of interest (ROIs) on the graphic display of the computer-processed scintigrams as shown in **Fig. 1.** For this study the image, which demonstrated the inter-relationships of the right ventricular free wall, interventricular septum and left ventricular free wall most clearly, was chosen from these five views. The ROI of background was selected over the upper mediastinum. The other three ROIs were determined at the points of the right ventricular and left ventricular free walls and the interventricular septum on the line parallel to the X axis of the display and with the maximum distance between the right ventricular and left ventricular free walls. Each ROI contained 3×3 matrix of elements and the activity of each ROI was represented as a total of these 9 matrix of elements. The activities of the ROIs of the left ventricular free wall (W_L), right ventricular free wall (W_R) and interventricular septum (W_S) were calculated by subtraction of the activity of background (B_K). Furthermore, the ROIs of

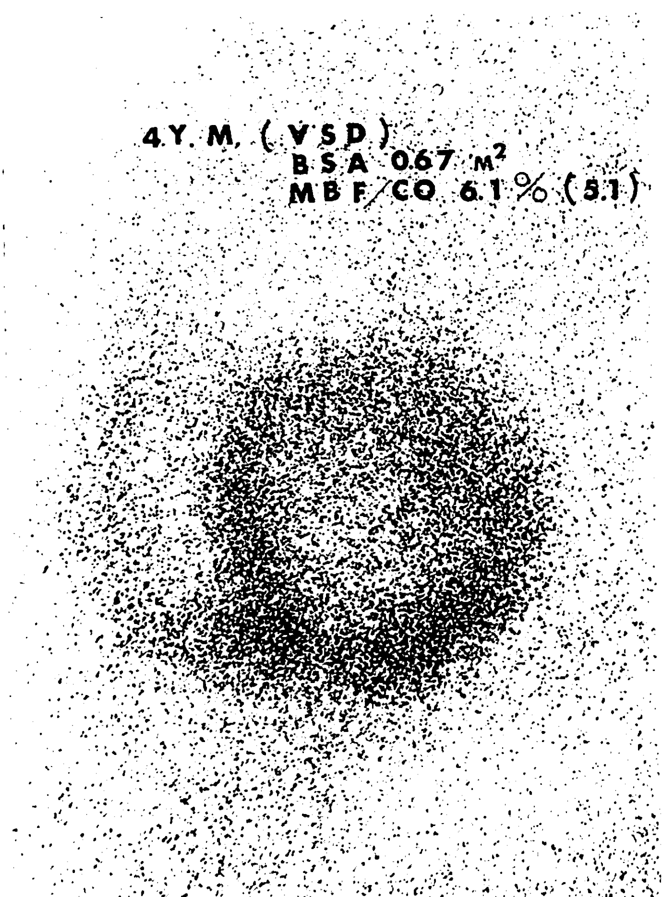

Fig. 3. Thallium-201 scintigram of a patient with ventricular septal defect.
VSD=ventricular septal defect; BSA=body surface area; MBF/CO=myocardial blood flow/cardiac output.

the whole heart and the background were defined and the ratio of myocardial blood flow (MBF) to cardiac output (CO) was obtained by the method proposed by Ishii and his associates[1].

In the patients in which cardiac catheterization and echocardiography were performed, right ventricular systolic pressure (RVSP) was determined by a catheter tip micromanometer. Right ventricular mass (RVM) was calculated by combination of angiographic right ventricular image and echocardiographic right ventricular anterior wall according to the method of Arcilla and his associates[12]. Right ventricular end diastolic volume (RVV) was obtained by Simpson's method[13], left ventricular end diastolic volumes (LVV) by area-length method[14] and left ventricular mass (LVM) by Rackley's method[15]. These findings were compared with those of Tl-201 myocardial scintigraphy.

Results

The images of the right ventricular free wall were obtained in all patients except for 2 patients (tricuspid atresia and Uhl's anomaly). Firstly, we studied the morphologic characteristics of the Tl-201 images in the different hemodynamic groups. The scintigram of a patient with atrial septal defect showed the dilated right ventricular cavity and convex interventricular septum toward the right ventricle, but the uptake of the right ventricular free wall was lesser than that of the left ventricular free wall (**Fig. 2**). **Fig. 3** demonstrated the dilated left ventricular cavity and normal-sized right ventricle in a patient with ventricular septal defect. In contrast, in a patient with ventricular septal defect with mean pulmonary pressure of 70 mmHg, the uptake of the right ventricular free wall was markedly increased and the interventricular

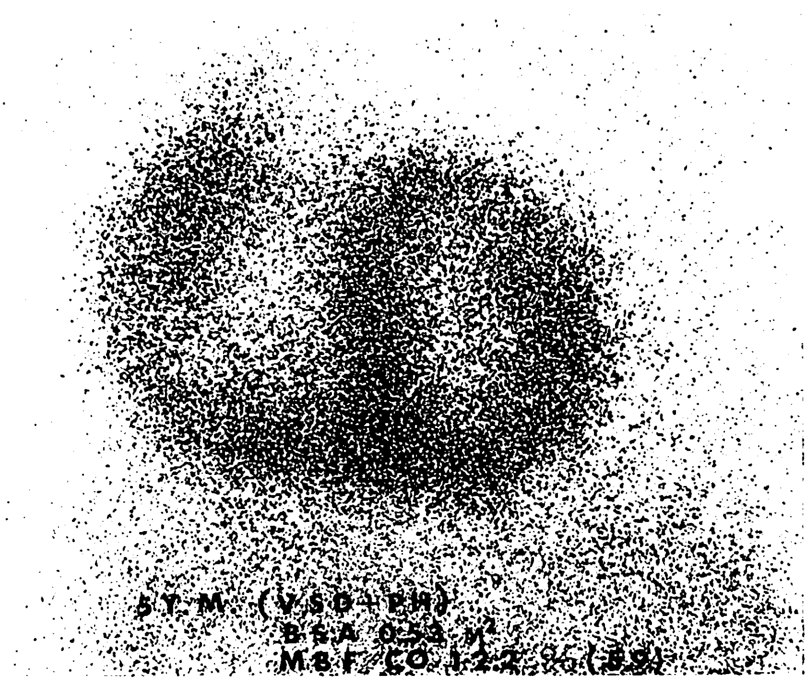

Fig. 4. Thallium-201 scintigram of a patient with ventricular septal defect with pulmonary hypertension.

VSD+PH = ventricular septal defect with pulmonary hypertension; BSA = body surface area; MBF/CO = myocardial blood flow/cardiac output.

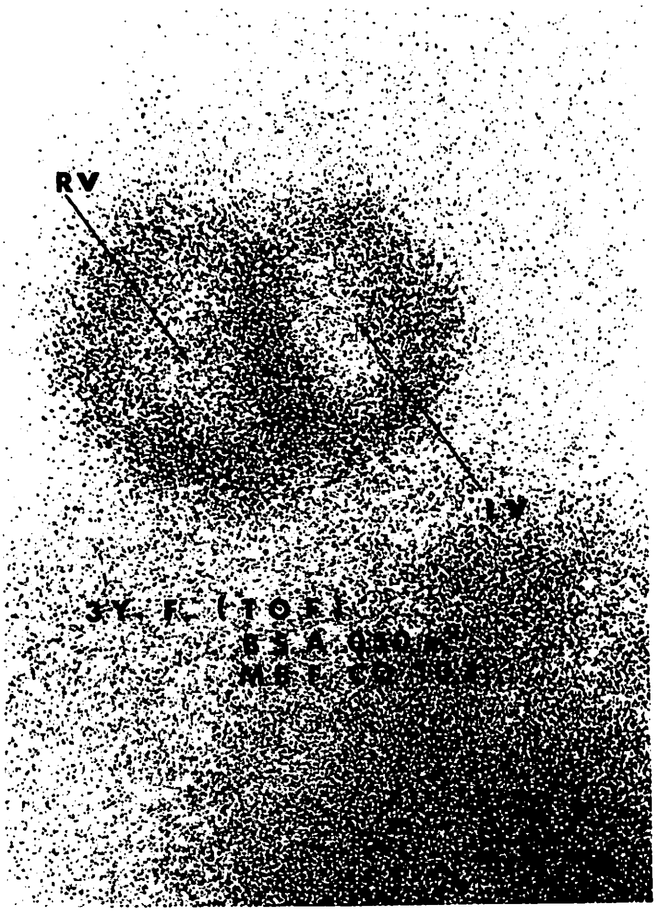

Fig. 5. Thallium-201 scintigram of a patient with tetralogy of Fallot.
RV=right ventricle; LV=left ventricle; TOF=tetralogy of Fallot; BSA=body surface area; MBF/CO=myocardial blood flow/cardiac output.

septum was straight (**Fig. 4**). Small left ventricular image, narrow right ventricular outflow tract and straight interventricular septum were demonstrated in the scintigram of a patient with tetralogy of Fallot (**Fig. 5**).

Secondly, we performed the quantitative analysis of the Tl-201 myocardial scintigraphy. The MBF/CO demonstrated a good inverse correlation with body surface area ($r=-0.85$) in normals as shown in **Fig. 6** and a good positive correlation with RVSP ($r=0.80$) as shown in **Fig. 7**. Its value was significantly high in the groups of LVVL c̄ PH and RVPL ($p<0.001$, $p<0.001$), and low in the group of RVVL ($p<0.001$) (**Fig. 8**). The W_R/B_K showed significantly high value in the groups of LVVL c̄ PH and RVPL ($p<0.001$, $p<0.001$), respectively (**Fig. 9**). There was a poor correlation between RVM/RVV and W_R/B_K ($r=0.57$) as demonstrated in **Fig. 10**. **Fig. 11** showed significantly high value of the W_R/W_L in the groups of LVVL c̄ PH and RVPL ($p<0.001$, $p<0.001$), respectively. The W_R/W_L correlated well with RVSP ($r=0.77$) and RVM/LVM ($r=0.80$) as shown in **Fig. 12** and **Fig. 13**.

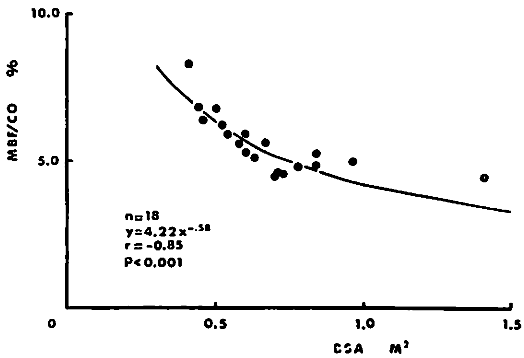

Fig. 6. Correlation between body surface area and myocardial blood flow/cardiac output in normals.

BSA=body surface area; MBF/CO=myocardial blood flow/cardiac output.

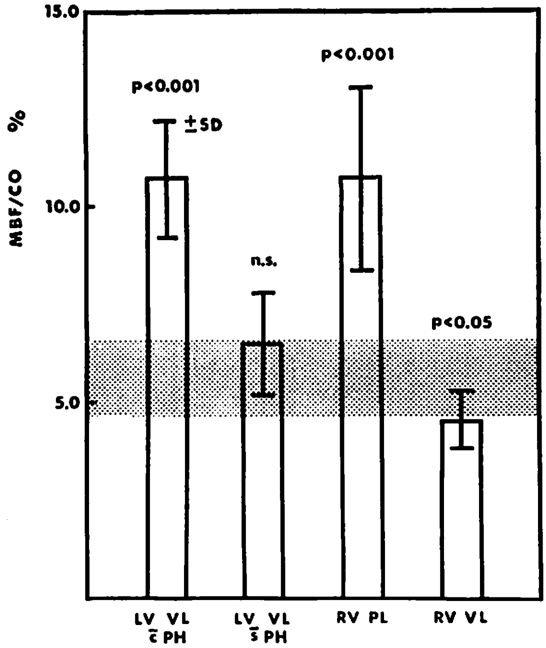

Fig. 8. Myocardial blood flow/cardiac output in four different hemodynamic groups.

Shaded area shows the mean±1SD of normals.

MBF/CO=myocardial blood flow/cardiac output; LVVL c̄ PH=left ventricular volume overload with pulmonary hypertension; LVVL s̄ PH=left ventricular volume overload without pulmonary hypertension; RVPL=right ventricular pressure overload; RVVL=right ventricular volume overload.

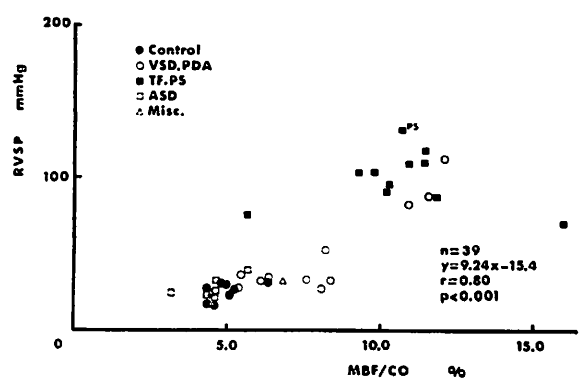

Fig. 7. Correlation between myocardial blood flow/cardiac output and right ventricular systolic pressure.

MBF/CO=myocardial blood flow/cardiac output; RVSP=right ventricular systolic pressure; VSD=ventricular septal defect; PDA=patent ductus arteriosus; TF=tetralogy of Fallot; PS=pulmonary stenosis; ASD=atrial septal defect; Misc=miscellaneous.

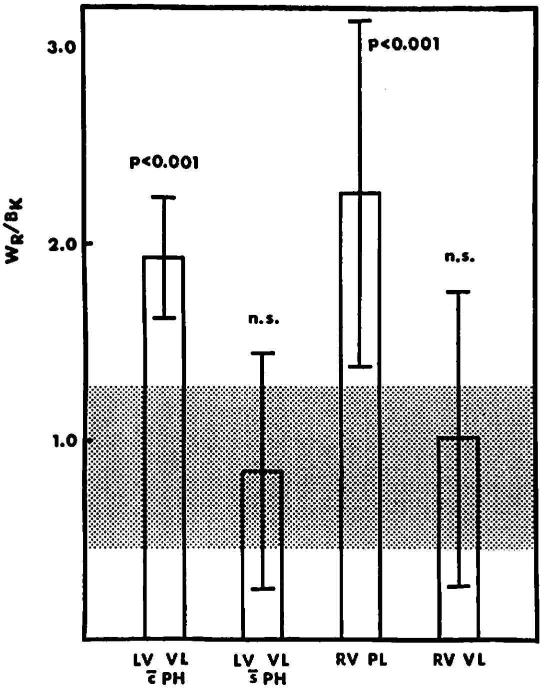

Fig. 9. Activity of the right ventricular free wall/activity of the background in four different hemodynamic groups.

Shaded area shows the mean±1SD of normals. W_R/B_K = activity of the right ventricular free wall/activity of the background; LV VL c̄ PH = left ventricular volume overload with pulmonary hypertension; LV VL s̄ PH = left ventricular volume overload without pulmonary hypertension; RV PL = right ventricular pressure overload; RV VL = right ventricular volume overload.

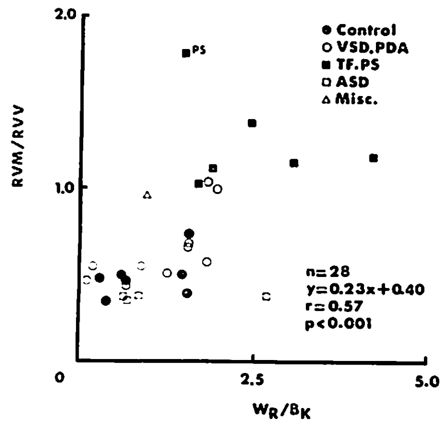

Fig. 10. Correlation between the ratio of activity of the right ventricular free wall to activity of the background and the ratio of right ventricular mass to right ventricular volume.

W_R/B_K = activity of the right ventricular free wall/activity of the background; RVM/RVV = right ventricular mass/right ventricular volume; VSD = ventricular septal defect; PDA = patent ductus arteriosus; TF = tetralogy of Fallot; PS = pulmonary stenosis; ASD = atrial septal defect; Misc = miscellaneous.

Discussion

It is important to define the ROIs precisely for the quantitative analysis of hemodynamics using Tl-201 myocardial scintigraphy. For this purpose, multi-gated disatolic images of 1,500 heart beats were obtained and the ROIs were assigned on the graphic display of computer-processed images using the above-mentioned method.

In this study, images of the right ventricular free wall could be obtained in almost all patients. On the contrary, it has been reported that the right ventricular free wall could be imaged in only patients with RVVL or RVPL in adults[8~11]. Myocardial uptake of Tl-201 chloride is proportional to myocardial blood flow and is influenced by heart rate, blood gases and oxygen consumption[16~18]. Myocardial blood flow increases proportionally to increasing myocardial mass in the patients without the ischemic changes in chronic heart disease. Feasibility of good imaging of the right ventricular free wall in infants and children is probably explained by tachycardia and physiological right heart dominance after the newborn period. It is thought to be also originated from the same reason that the MBF/CO showed an inverse correlation with body surface area in normals. Since the MBF/CO reflects the total myocardial mass, its value depends on right ventricular mass in patients with normal left ventricular mass. The high value for the MBF/CO in the groups of LVVL c̄ PH and RVPL represents the increased right ventricular mass,

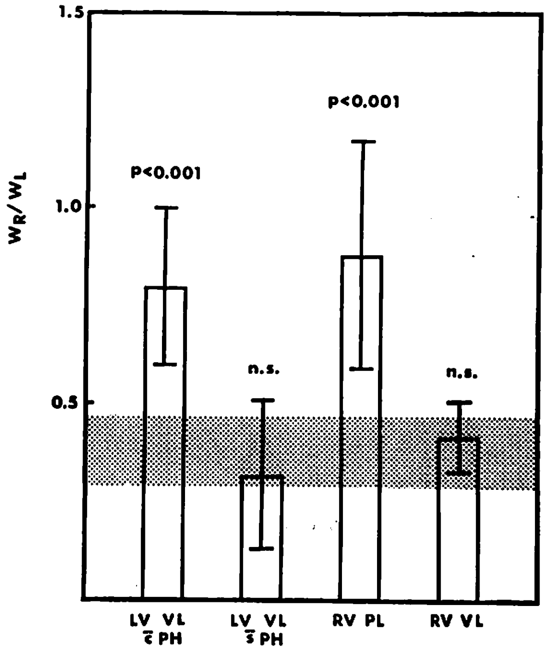

Fig. 11. Activity of the right ventricular free wall/activity of the left ventricular free wall in four different hemodynamic groups.

Shaded area shows the mean±1SD of normals.

W_R/w_L=activity of the right ventricular free wall/activity of the left ventricular free wall; LV VL c̄ PH =left ventricular volume overload with pulmonary hypertension; LV VL s̄ PH=left ventricular volume overload without pulmonary hypertension; RV PL= right ventricular pressure overload; RV VL=right ventricular volume overload.

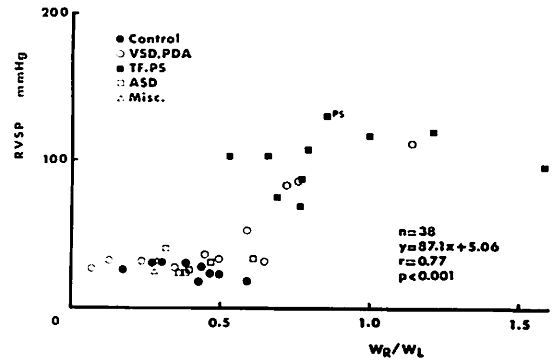

Fig. 12. Correlation between the ratio of activity of the right ventricular free wall to activity of the left ventricular free wall and right ventricular systolic pressure.

W_R/W_L=activity of the right ventricular free wall/activity of the left ventricular free wall; RVSP=right ventricular systolic pressure; VSD=ventricular septal defect; PDA=patent ductus arteriosus; TF=tetralogy of Fallot; PS=pulmonary stenosis; ASD= atrial septal defect; Misc=miscellaneous.

and the low value in the group of RVVL is based on the hypoplasia of the left ventricle. Since right ventricular pressure overload results in an increase of the right ventricular mass, it is reasonable that the MBF/CO correlates well with right ventricular systolic pressure. The W_R/B_K is thought to show the absolute uptake activity of the right ventricular free wall, and showed high value as increases of right ventricular mass in the groups of LVVL c̄ PH and RVPL. It is preferable to choose right ventricular mass instead of right ventricular systolic pressure in comparison with the findings of Tl-201 myocardial scintigraphy.

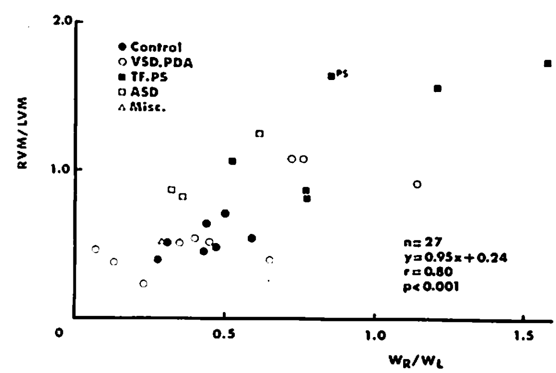

Fig. 13. Correlation between the ratio of activity of the right ventricular free wall to activity of the left ventricular free wall and the ratio of right ventricular mass to left ventricular mass.

W_R/W_L=activity of the right ventricular free wall/activity of the left ventricular free wall; RVM/LVM= right ventricular mass/left ventricular mass; VSD= ventricular septal defect; PDA=patent ductus arteriosus; TF=tetralogy of Fallot; PS=pulmonary stenosis; ASD=atrial septal defect; Misc=miscellaneous.

The RVM/RVV was calculated to normalize the body size and was compared with W_R/B_K. The result of a weak correlation and a wide scattering between these two parameters are thought to be caused by the influence of heart rate, blood gases and oxygen consumption over the myocardial uptake of Tl-201 chloride, because the W_R/B_K cannot cancel these effect. Therefore, the W_R/W_L, in which W_R and W_L are influenced equally by these factors, was obtained and was compared with hemodynamic data. The W_R/W_L is considered to be equal to RVM/LVM theoretically and showed the best correlation in this study.

In summary, Tl-201 myocardial scintigraphy is useful for the non-invasive quantitative evaluation of the right heart hemodynamics in infants and children with congenital heart disease. The MBF/CO is a good parameter for the evaluation of the total mass of the heart and so is W_R/W_L for the evaluation of right ventricular mass or the left ventricular mass.

要　約

Thallium-210 心筋シンチグラフィーによる小児期心疾患の右心血行動態の評価

上田　憲・斎藤彰博・中野博行・矢野正幸

正常 18 例および各種先天性心疾患 46 例に thallium-201 心筋シンチグラフィーを行い，心カテーテル検査および心エコー検査の結果と対比することにより，右心系血行動態の定量的評価を行った．対象の年齢は 2 ヵ月から 13 歳までである．

心筋シンチは 60 μCi/kg の thallium-201 chloride を手背静脈より急速注入し行い，心電図 R 波トリガーによる 1,500 心拍のデータを，5 分後より正面，左前斜位 30°, 45°, 60° および左側面の 5 方向のそれぞれについて収集した．5 方向のうち左心室自由壁，心室中隔，右心室自由壁の位置関係のもっとも明瞭な描出像を，定量化の対象とした．左室自由壁，心室中隔，右心室自由壁，上縦隔に 4 つの関心領域を同定し，それぞれの activity を W_L, W_S, W_R, B_K とした．また心臓全体，上肺野に関心領域を設定し，心筋血流量 (MBF)/心拍出量 (CO) を求めた．

右室自由壁は，三尖弁閉鎖症の 1 例と Uhl 奇型の 1 例を除き，全例に描出可能であった．右室自由壁，心室中隔，左室自由壁の描出像は，左室容量負荷＋肺高血圧群 (グループ 1)，左室容量負荷群 (グループ 2)，右室圧負荷群 (グループ 3)，右室容量負荷群 (グループ 4) の 4 群において，それぞれ特徴的なパターンを示した．

正常群では，MBF/CO と体表面積は r＝−0.85 の逆相関を示し，年少児ほどこの値は大であった．また MBF/CO はグループ 1 および 3 では有意に高く，グループ 4 では低値を示した．右室収縮期圧との対比では r＝0.80 の相関を認めた．

W_R/B_K, W_R/W_L はグループ 1 および 3 で高値を示し，とくに後者は右室収縮期圧と r＝0.77 の相関を，また右室 mass/左室 mass とは r＝0.80 の良い相関を認めた．

以上に示したように，thallium-201 心筋シンチグラフィーは，非観血的な右心系血行動態の定量的評価に有用と思われた．

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