Special article

Journal of Cardiography 10: 609-626, 1980

Real time moving image analysis of right and left ventricular function and perfusion by integrated nuclear medicine technology

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Key words
Nuclear cardiology Image analysis Isotope Computer analysis Moving image

Early in 1958 one of the authors had engaged in the external measurement of cardiac output by using low frequency radiocardiograms[1,2]. Off line computer was adopted for its calculation[3]. At the same period one of the authors developed the rapid recording system with very short time constant by which high frequency radiocardiogram was recorded. Beat-to-beat recording of the first pass radio isotope dilution curve made it possible to analyze ejection fraction of the canine left ventricle as early as in 1959[4].

In the past several years, cardiovascular nuclear medicine disclosed its real value by the effective combination of computer technology and the advanced nuclear position counter as γ-camera. Especially, a method of data acquisition showed remarkable improvement as observed the original single gate method[5] replaced recently by multigate method[6~8]. These technical improvement was the real motivation by which original research cardiovascular nuclear medicine was widely adopted as a routine clinical method.

Since a multigated method requires the rapid data acquisition of the order of 10 msec, earlier approach was based upon the LIST mode which requires minimum capacity of the buffer memory and transport frequency, as author's previous report indicated[8]. However, recent introduction of high transportation speed magnetic disc and large memory made it possible to acquire data in " IMAGE mode " rather than " LIST mode " which requires time consuming processing of the data. Image mode data acquisition as reported in this paper is able to provide the data required immediately after data acquisition.

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Special lecture presented at the 18th Meeting of the Japanese Society of Cardiovascular Sound held in Tokyo, April 2-3, 1979
Received for publication March 31, 1980

This report also includes the result obtained by Kirch's 7 pinhole-collimator and bilateral collimator to reconstruct the three dimensional image of the heart muscle and ventricles.

Method

I. Gamma-camera computer system

Fig. 1 indicates the blockdiagram of γ-camera computer system (COSNM-TMGH) of our department which was introduced two years ago replacing the old system and is still under continuous improvement. Based upon the 5 years' experiences using on-line 32 KW mini-computer system[8], present system has NOVA-03 with 128 KW memory in CPU. This CPU is controled by two grounds using two console key boards. As additional large capacity and high speed memory, the magnetic disc with 24 MW memory and transfer speed of 100 KW/sec magnetic tape with 1,600 BPI and 2,400 ft. length are adopted. Different from the previous small scale minicomputer system, these memories serve as buffer memory for input data. This

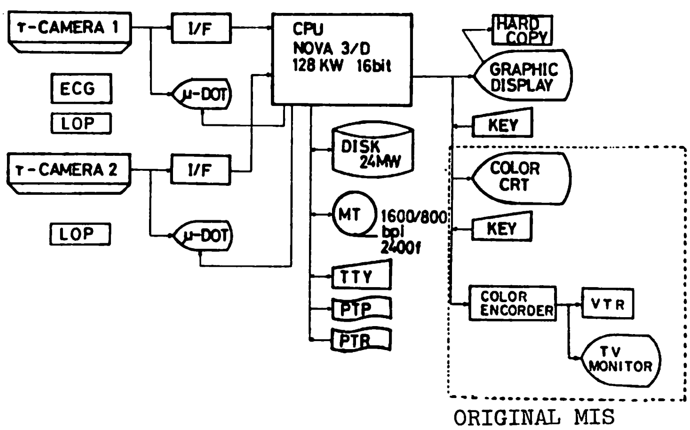


Fig. 1. Blockdiagram of the on-line γ-camera computer system with 128 KW CPU and high transportation speed magnetic disc.

Table 1. Comparison of various data acquisition modes for cardiovascular nuclear medicine (COSNM-TMGH, constructed in collaboration with Shimazu Co, Kyoto)

Data acquisition	Application	Buffer size in CPU	Disc capacity	Processing of gate image	Max. CPS	Time resolution per frame	Elimination of arrhythmia	Image size
Image mode	First pass study	4K×2	4K×750 (~1000)	Unnecessary	250K	40 msec	Possible	64K×64K
List mode	First pass	8K×2	4K×300	Necessary	130K	10 msec	Possible	64K×64K 128K×128K
	Equilibrium	4K×2	4K×2000	Necessary	130K	10 msec	Possible	256K×256K
Multigate mode	Equilibrium	4K×24 1K×96	4K×24 1K×96	Unnecessary	250K	10 msec	Impossible	64K×64K 32K×32K

disc, when one half is spared for programme, still able to acquire 5,000 frames of 4 KW image. And this memory space is necessary for the high sequential first pass study analysis. One MT roll can contain approximately 50 tests of dynamic patient studies. Informations from two gamma cameras can be stored and analized simultaneously, as well as physiological data such as EKG. Data from gamma cameras are processed by graphic terminal and then read out by various systems. For example, micro-dot system reads out computer processed data onto radiological film with satisfactory gray scale expression. Printer-plotter reads out precision graphs of gray scale images. One digital color TV system, 256×256 picture elements refresh type, indicates 16 color display of functional images. Another color TV displays real time moving image by using 4KW memory as refresh memory. The latter color TV system is named MIS (moving image system).

Operation of this computer system is based on the Mapped Real Time Disc Operating System (MRDOS), and dual programming method for foreground and background is adopted. Image acquisition and analysis are performed by Assembly language and Fortran language.

II. MIS (moving image system)

Fig. 2 indicates the blockdiagram of MIS we have developed. Processed sequential images stored in the disc is transfered into the refresh memory in the CPU and moving dynamic images are displayed on the color TV. This color TV is designed to mix the amounts of red, green, and blue colors by the programming, thus optional color images is synthesized. Picture elements of this color TV is 128× 120.

This MIS is applied on the various dynamic function studies including brain radio nuclide (RN) angiography, cardiac RN angiography, RN renography, hepatobiliary studies and multigated analysis of cardiac function. MIS is especially of value as the final data presentation of heart function. As discussed before MIS is the method to display the moving image on color CRT by sequentially transferring the successive image data to the refresh memory in the core which is fed original processed image data stored in the disc. Therefore display interval can be modified if it is long enough compared with transferring time of the disc into core (~40 msec/4 KW).

Several modes can be generated, such as real time mode, compressed time mode, expanded time mode and complex mode. In this report of the study of the heart, real time mode is more frequently utilized. In our MIS system, RAM for color table is included. Therefore it is optional to select different color table and even to select limited color level(s) from among 16 color levels, permitting practical edge detection of the ventricle to study abnormal wall motion of IHD (cf. Figs. 18, 19).

III. Edge detection method

In order to meet the increasing request to

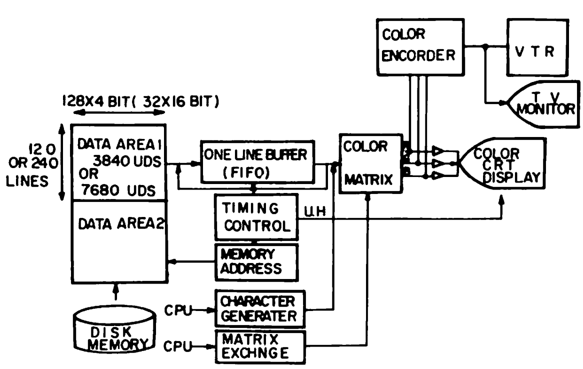


Fig. 2. Blockdiagram of MIS (moving image system) (manufactured in collaboration with Shimazu Co, Kyoto).

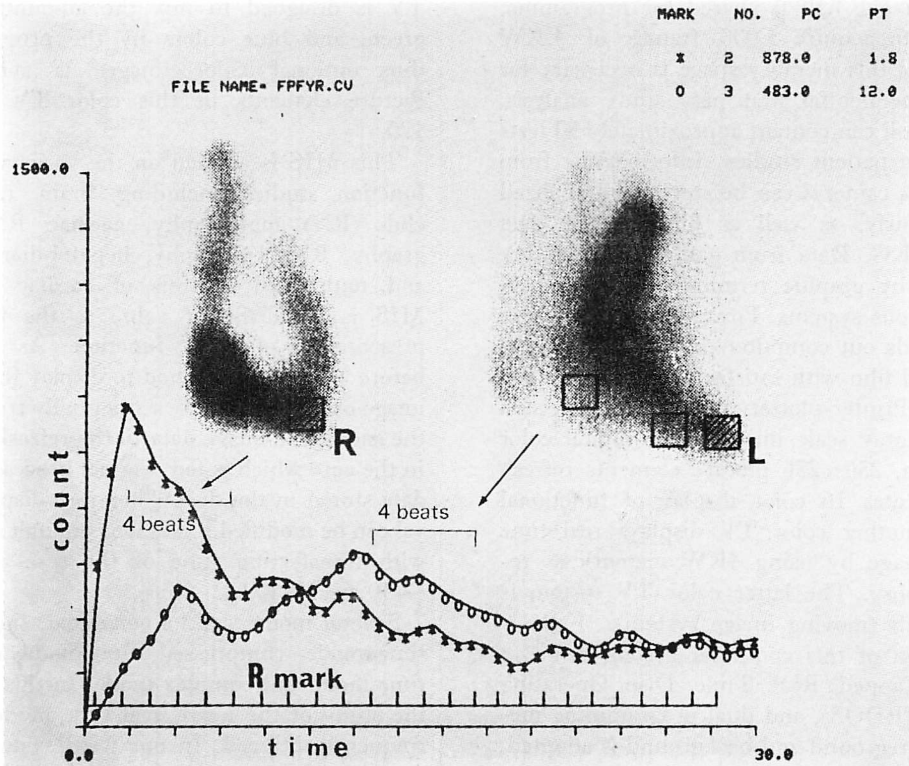


Fig. 3. Method of first pass study.
Low frequency radiocardiograms generated from CPU serve to select peak times of RV and LV curves, from where multigated 4 beats' 40 msec successive frames are sorted.

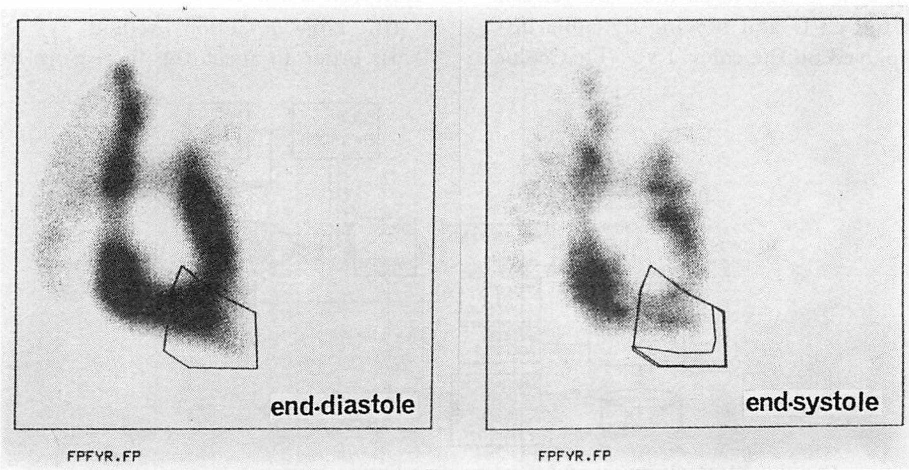


Fig. 4. RV images at diastole and systole obtained by the first pass method.

automate the contour detection of the left ventricle in sequential 20～40 msec images of the equilibrium method, variable ROI determination was performed by approximation of the Tschebyscheff's formula of the profile curves on the radias from the center of the ventricle. The detail of this method is discussed elsewhere[11].

IV. Specially designed collimators

Seven pinhole collimator was developed according to Kirch[12] and applied on the ^{201}Tl study. The bilateral collimator with two 30° slant collimator was also adopted to measure first pass study in both RAO and LAO projections simultaneously.

Result

I. First pass study

Increased CPU memory and high speed disc memory of the reported system made it practical to perform first pass study almost in real time mode. Twenty mCi of ^{99m}Tc albumine or RBC was administered into the antecubital vein and γ-camera was directed to the patient heart from RAO 30° position. R wave of the patient's EKG was used as gate signal and sequential 40 msec interv al data were acquired as image mode into disc up to 600 frames (24 sec) and 0.6 sec interval data up to 610 frames (30 sec) (**Fig. 3**).

And then 0.6 sec interval low frequency radiocardiogram was generated from the above data up to 30 sec. As **Fig. 3** indicated, each four beats data from the peak times of right and left ventricles were selected for multigated processing. **Fig. 4** indicates the diastolic and systolic images of the right ventricle with ROIs for right ventricular volume curves and background calculation. **Fig. 5** shows the comparison of right ventricular volume curves obtained by summation of 3 beats and 4 beats data. Ejection fractions calculated were 50% and 47%, respectively. **Fig. 6** indicates the first pass images of the left ventricle at diastole and systole. Again ROIs were superimposed. **Fig. 7** represents 4 left ventricular volume curves obtained by addition of 2, 4, 6 and 8 beats' data. Estimated left ventricular ejection fractions showed good agreement excluding 8 beats' data, as 67, 67 and 65%, respectively.

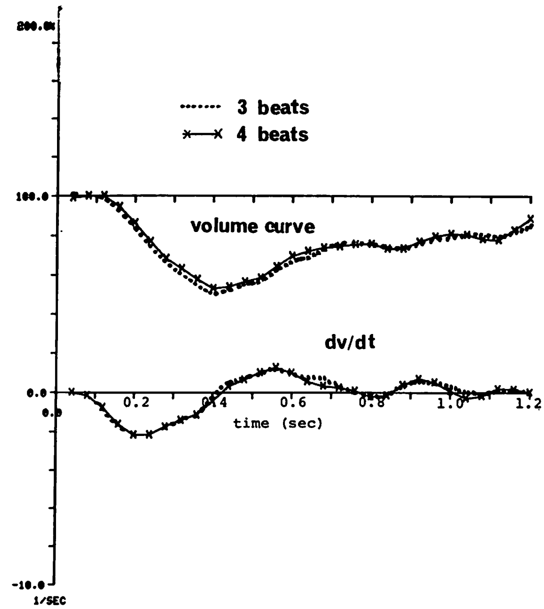


Fig. 5. RV volume curves obtained by summation of 3 and 4 beats by the first pass method.

II. Equilibrium study

Following to the first pass study, after the bolus injection of the tracer becomes equilibrated with the total body blood pool at 5 to 10 min, so-called equilibrium study was performed.

In this study γ-camera was directed from 30° ～40° LAO position perpendicular to the septal wall to avoid superimposition of the right ventricle over the left. **Fig. 8** indicates the equilibrium images of the left ventricle from LAO position with ROIs for background and volume curves calculation. Data were stored both in list mode and image mode and volume curves, dV/dt and ejection fractions thus measured were compared. **Fig. 9** indicates the volume curves obtained by LIST mode and IMAGE mode. Good agreement of the data was observed. **Fig. 10** is a detailed analysis of LIST mode data acquisition with various time intervals of 20, 40 and 60 msec. Volume curves thus obtained showed good agreement, however, dV/dt obtained by 20 msec intervals showed variation due to poor statistics.

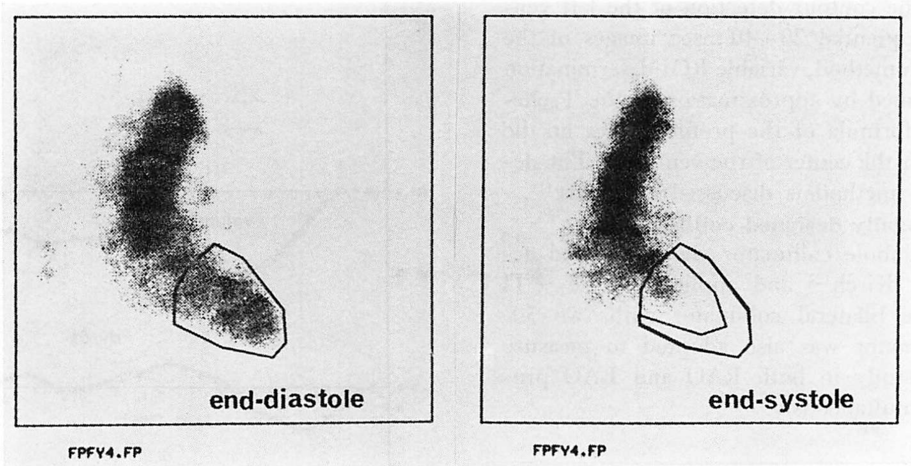


Fig. 6. Left ventricular images at systole and diastole by the first pass method.

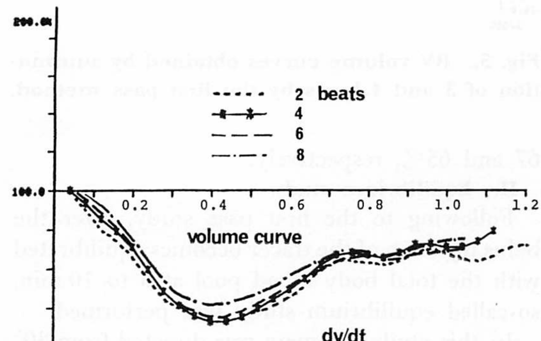


Fig. 7. LV volume curves obtained by summation of 2, 4, 6 and 8 beats by the first pass method.

III. Comparison of first pass and equilibrium methods

Fig. 11 summarizes the results of first pass and equilibrium methods. The first pass method with 4 beats summation acquired mean count per channel of 12 and 30% background. Whereas in the equilibrium study LIST mode analysis with 460 beats summation, mean counts per channel turned out to be 73, 168 and 249 for 20, 40 of 60 msec intervals data acquisition, respectively, with background ranging 60~70%. IMAGE mode equilibrium analysis of 820 beats resulted in the increased mean count per channel of 512 with similar background ranging 65~69%.

IV. Multigate myocardial perfusion scan

Two to four mCi of ^{201}Tl i.v. injection was followed by multigated image mode analysis. These gated analysis of ^{201}Tl image served for the precision analysis of myocardium without motion blurring and quantitative analysis of myocardial mass change. MIS was also served for the dynamic presentation of the myocardial movement.

V. Correlations of ejection fraction measured by first pass, equilibrium method and area-length method

Fig. 12 shows the correlation of ejection fractions measured by first pass and equilibrium method. Twelve cases of MI, 10 cases of control and 6 other cases were evaluated simultaneously. Good correlation of 0.922 was obtained with slightly higher value by first pass method.

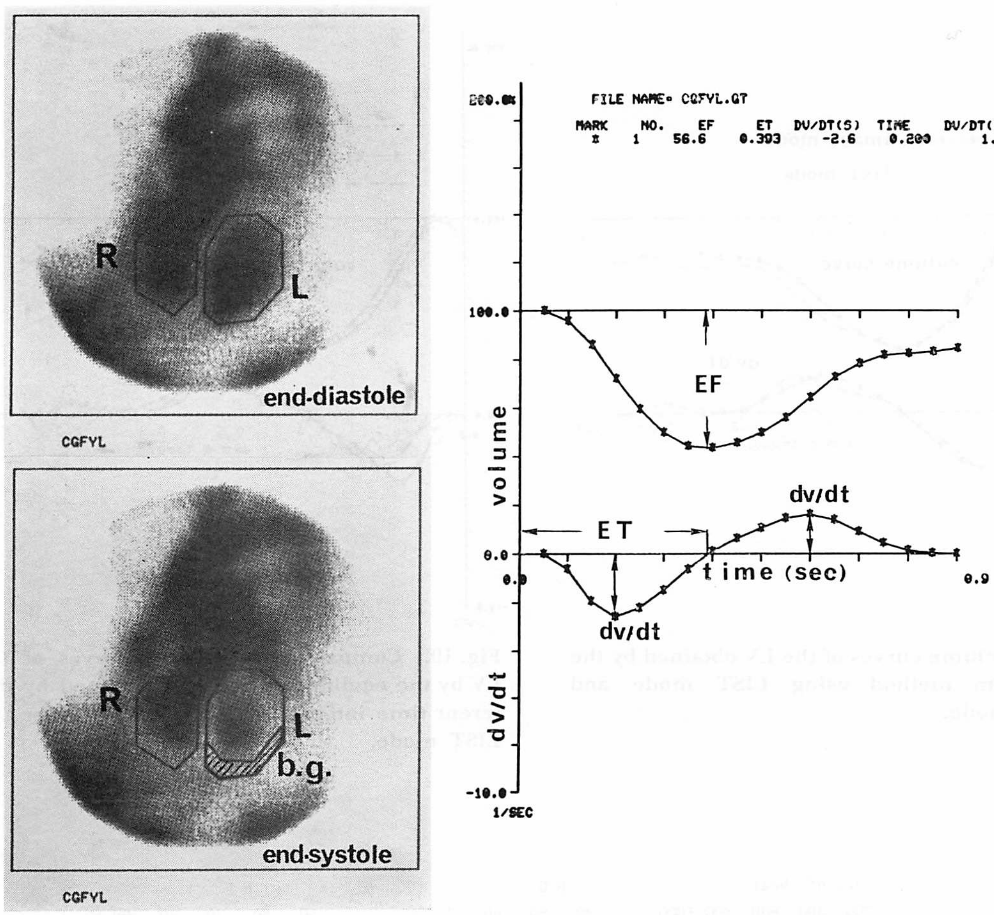


Fig. 8. RV and LV images from LAO by the equilibrium method.
LV volume curve and dV/dt obtained in this case is shown in the right.

Even though the area method is not recommended in RN study, equilibrium method was analized by the conventional count method and the area method (**Fig. 13**). Fairly good correlation of 0.909 was obtained with higher value by area-length method.

Compared with these methods, reference study by nuclear stethoscope did not show a satisfactory correlation with multigate equilibrium method (**Fig. 14**), even though this simple method is suited for individual follow up study and emergency check up.

VI. 7 pinhole and bilateral collimators

As indicated in **Fig. 19** and **Figs. 15**, **16**, bilateral collimator and 7 pinhole collimator proved their usefulness in the routine simultaneous examination of cardiac function from RAO and LAO and in the detection of transmural infarction. Details of these applications will be discussed in the pertinent case presentations.

VII. Case presentation

Case 1: 25 y.o. male. First pass study using bilateral collimator is shown in **Fig. 15** and **16**. Figures showed the right ventricular diastolic, systolic phase images and contour depiction from RAO and LAO positions recorded by the bilateral collimator. Ejection fractions of RV and LV were 50% and 67%, respectively. No abnormal wall motion was noted.

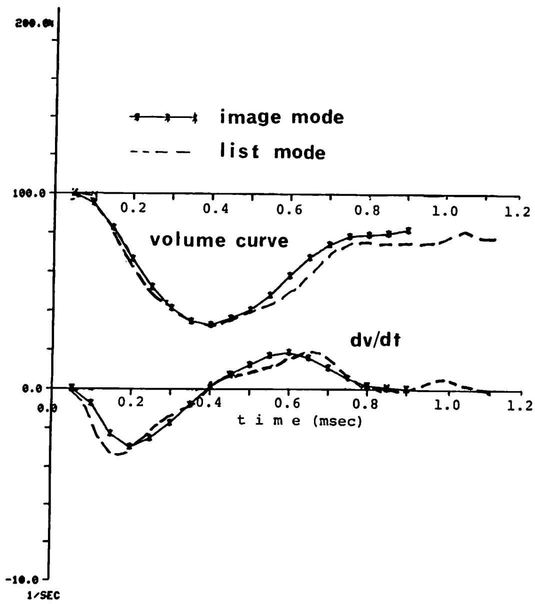


Fig. 9. Volume curves of the LV obtained by the equilibrium method using LIST mode and IMAGE mode.

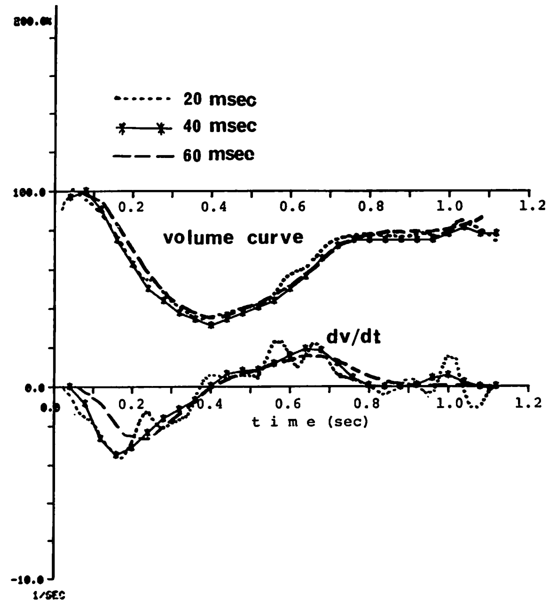


Fig. 10. Comparison of volume curves of the LV by the equilibrium method obtained by different time interval of 20, 40 and 60 msec, in LIST mode.

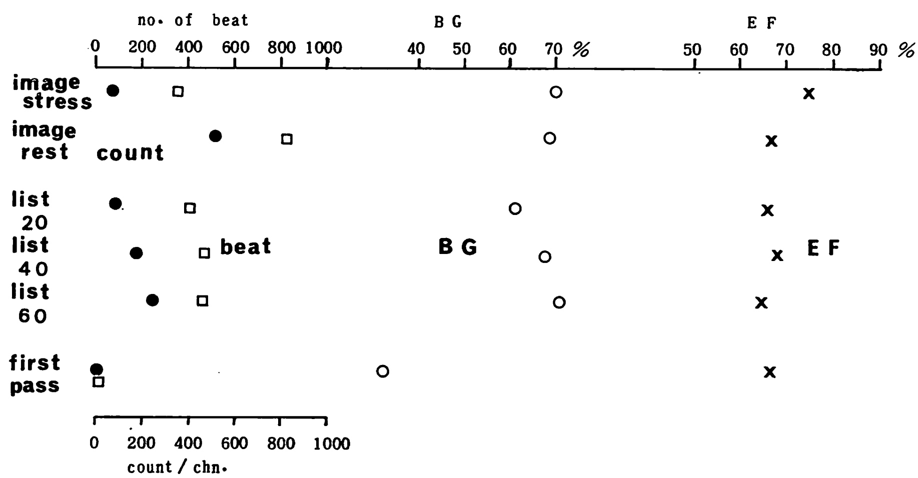


Fig. 11. Summary of the comparison of several parameters obtained by the first pass method and the equilibrium method.

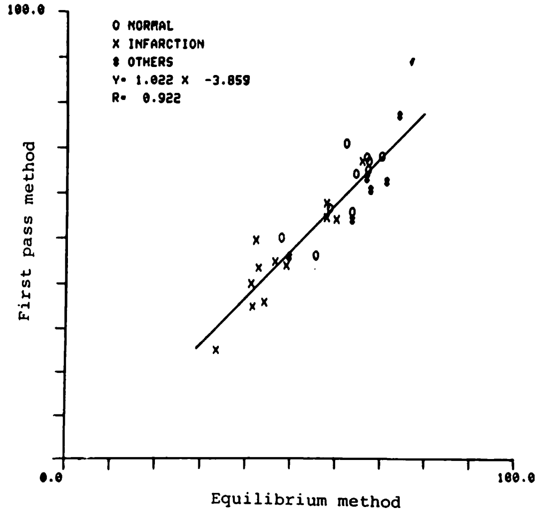


Fig. 12. Correlation of LVEF obtained by the first pass and equilibrium method.

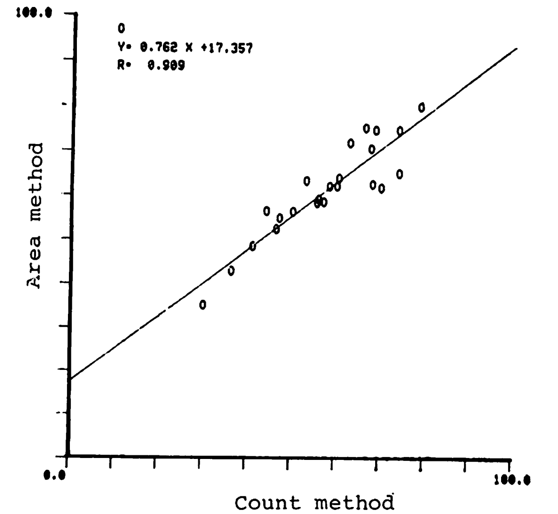


Fig. 13. Correlation of left ventricular ejection fraction (LVEF) obtained by area-length method and the equilibrium method (count method).

Case 2: 26 y.o. male. **Fig. 17** shows the example of the normal control by the equilibrium study. Right and left ventricles were observed simultaneously and contour image showed good wall motion of the left ventricle.

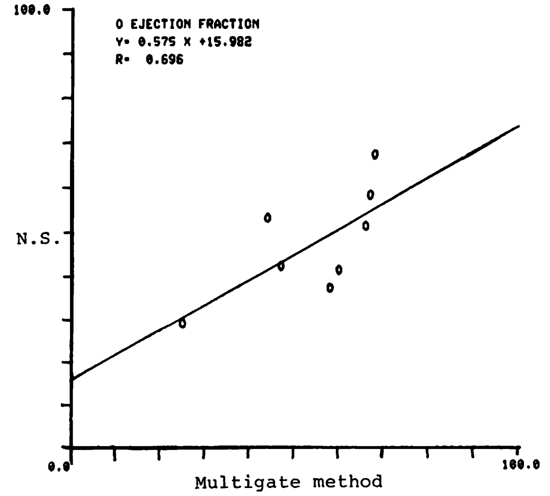


Fig. 14. Correlation of LVEF obtained by nuclear stethoscope (temporal imaging method) and the equilibrium method (spatial imaging method).

Case 3: 89 y.o. male. Anteroseptal infarction. EKG showed QS pattern in $V_1 \sim V_3$ leads.

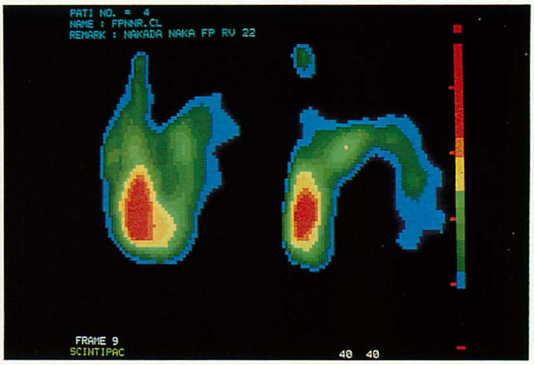
First pass study of the left ventricle showed decreased ejection fraction of 42.5% (**Fig. 18**). Contour study revealed the location of akinesia from the anterior wall to apex. This was also evidenced in the equilibrium study, however, no extension of the lesion was noted to the right ventricle (**Fig. 19**).

Seven pinhole study of ^{201}Tl scan of this case is shown in **Fig. 20**. Myocardial tomography obtained in LAO 30° projection with 30° cephalad tilt showed a large defect in the anteroseptal wall of the LV.

Case 4: 30 y.o. female. This case of long standing ASD was examined by the equilibrium study before and after ASD operation. Marked right ventricular hypertrophy accompanied by the small left ventricle was noted by ^{201}Tl scan (**Fig. 21**).

Equilibrium preoperation study showed no visible left ventricle (**Fig. 22**). However post operative study showed marked dilatation and normalization of the left ventricle and a significant decrease in the size of the right ventricle.

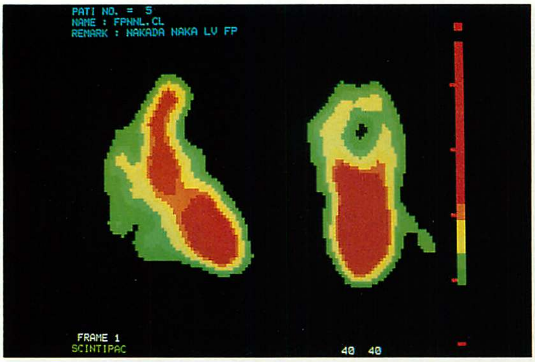
Diastole



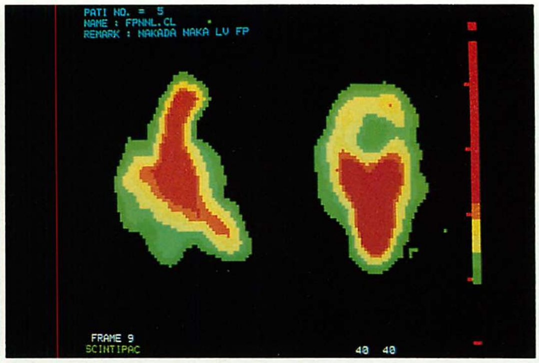
Systole

Nakamura

Fig. 15. Normal control (25 y.o.). **RV images at diastole and systole from RAO and LAO position obtained by bilateral collimator** (EF=50%).



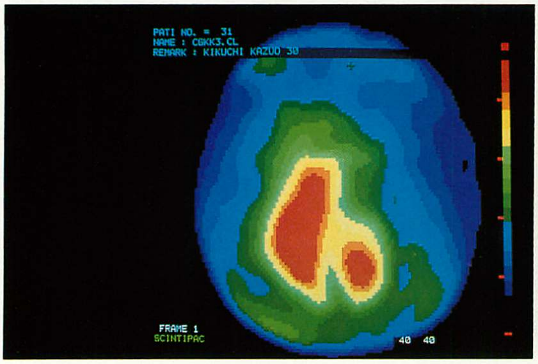
Diastole



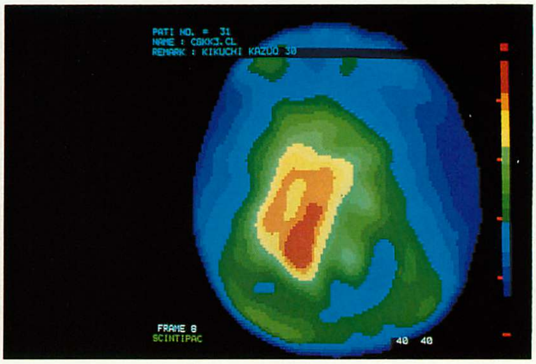
Systole

Edge detection

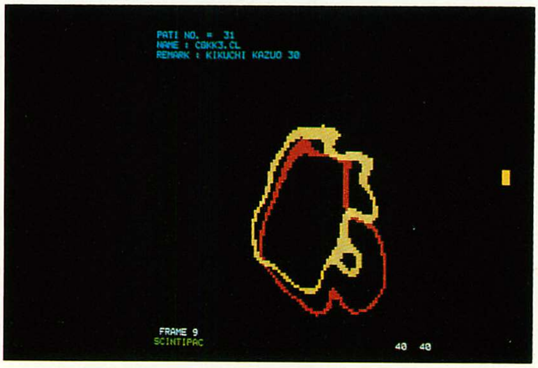
Fig. 16. Same data of LV images of the control case (EF=67%).



Diastole

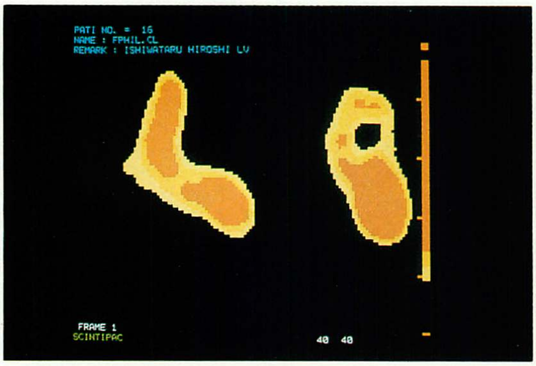


Systole

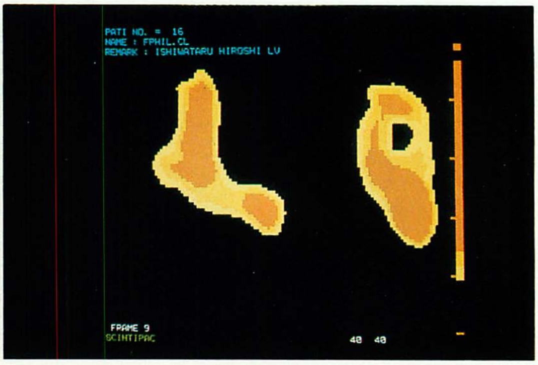


Edge detection

Fig. 17. Normal control (26 y.o. male).
LAO viewa of the LV and RV obtained by the equilibrium method (LVEF=59.9%)



Diastole

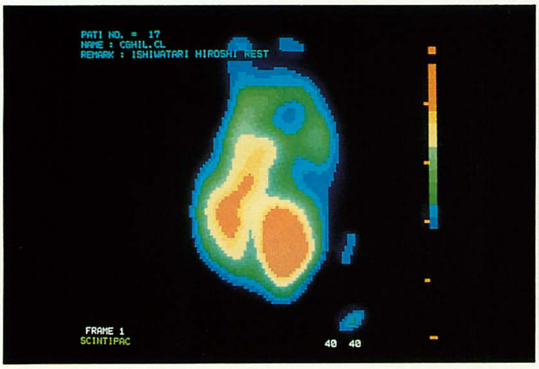


Systole

Edge detection

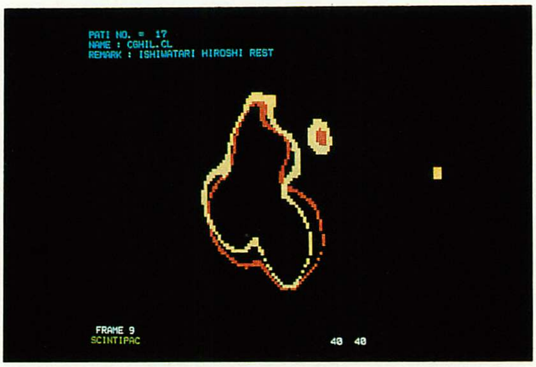
Fig. 18. A case of old myocardial infarction (89 y.o. male).

First pass study of the LV shows a decrease in EF (42.5%) and large area of akinetic regional wall motion as evidenced by contour expression.



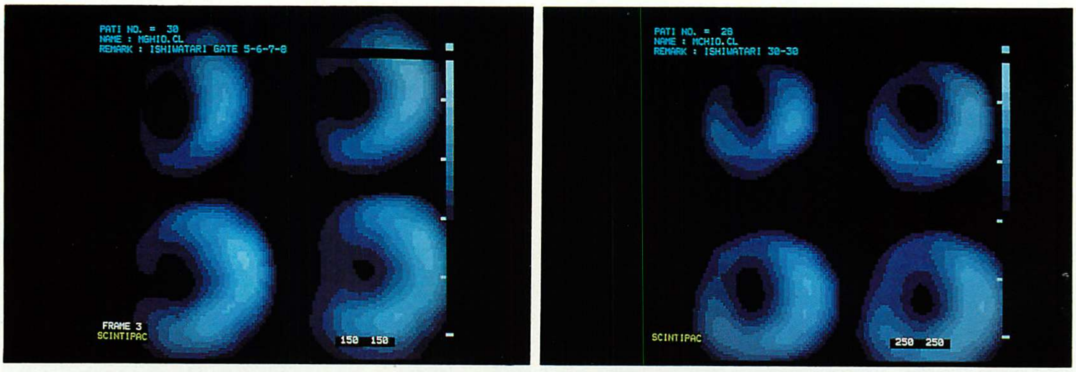
Diastole

Systole



Edge detection

Fig. 19. The same case in Fig. 18 studied by the equilibrium method.
Extension of akinesia to the apex is noted.



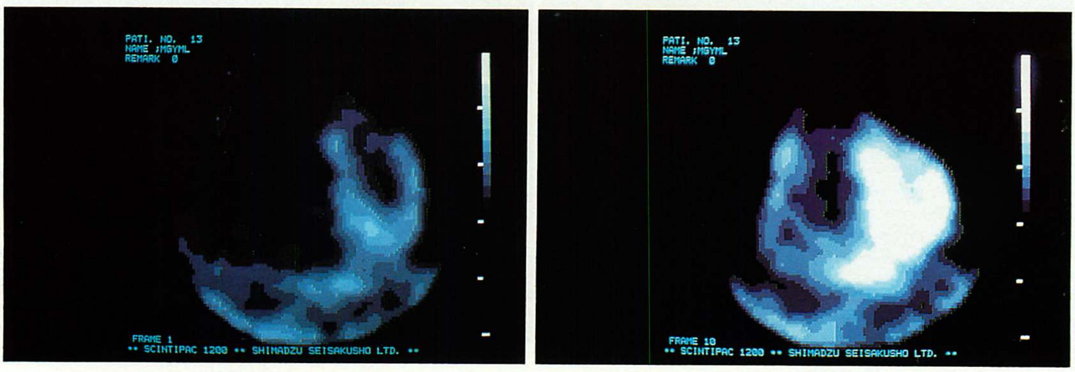
LAO 60° LAO 30° cephalad 30°

Fig. 20. A case of old myocardial infarction (89 y.o. male).

Seven pinhole study reveals large transmural infarction of antero-septal portion of the LV in both views of a) and b).

a) LAO 60°
upper right 5 cm, left 6 cm, lower right 7 cm and left 8 cm from chest wall.

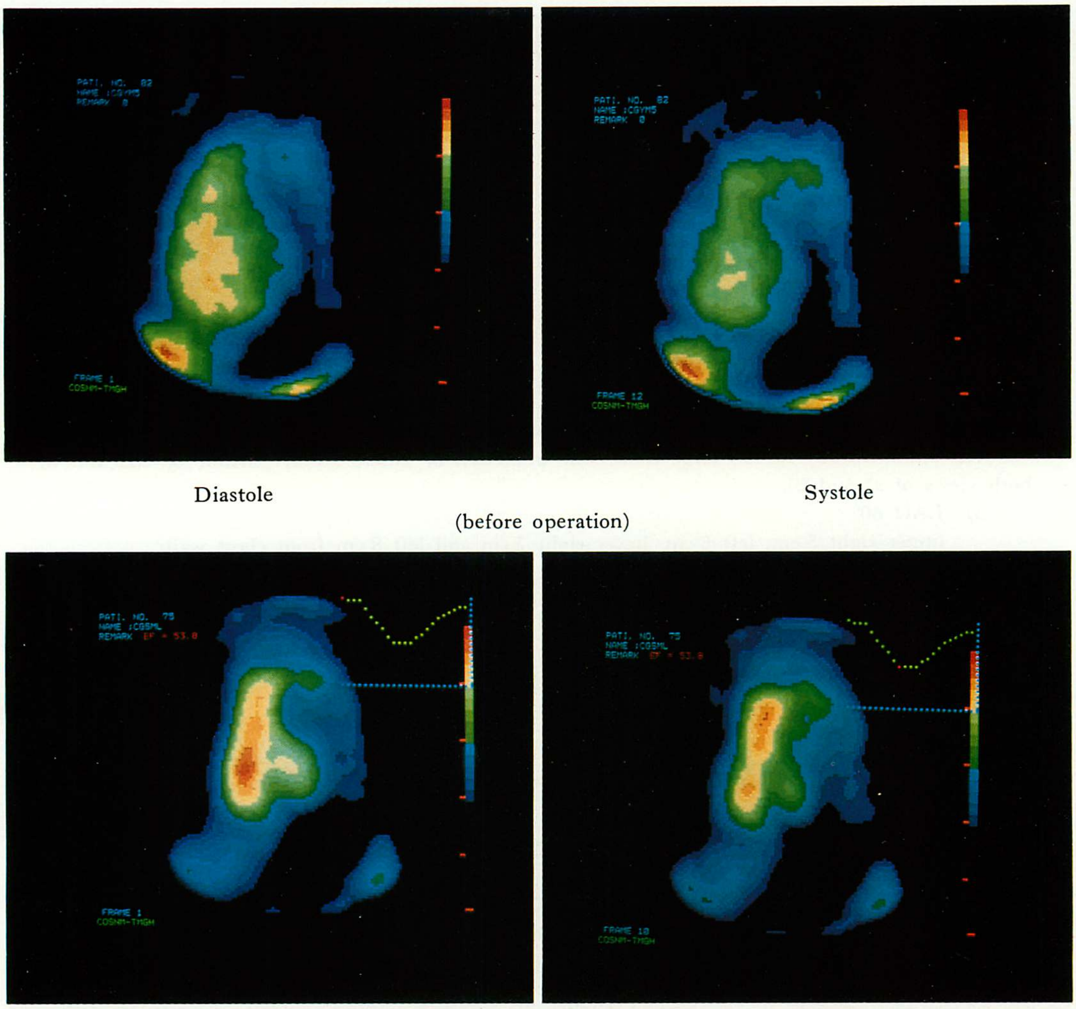
b) LAO 30°
with 30° tilting cephalad. Depths are same as above.



Diastole Systole

Fig. 21. ASD (30 y.o. female).

^{201}Tl scan reveals the hypertrophied and dilated right ventricle accompanied by the small left ventricle at this pre-operation study.



Diastole Systole

(before operation)

Diastole Systole

(after operation)

Fig. 22. The same case in Fig. 21, studied by the equilibrium study before and after operation (This case is kindly supplied by Dr. Furuta).

Ejection fraction of the left ventricle was now measurable and calculated to be 58.8% (**Fig. 22**).

Discussion

In the **Table 1** characteristics of several data acquisition method obtainable by our computer system were summarized.

Image mode (frame mode) disc store method receives the (x, y) signal from ADC and added one to the content in the coordinate (x, y) in one of the two buffer areas of CPU. These data are then transferred into the disc with time interval of 40 msec and maximum frame capacity of 1000. This mode based on the larger disc capacity enabled the first pass study which is designed for the analysis of RAO projection of the RV and LV.

List mode disc acquisition method accepts (x, y) signal from ADC as a word and stored the coordinate (x, y) in the buffer area of CPU in the order of incident signal. List mode can be applied both for first pass and equilibrium studies with advantage of high temporal resolution of 10 msec.

Multigate image mode core acquisition method for equilibrium study became possible due to large CPU memory providing 4K×24 frame buffer in the core in our system. Multigate mode, image mode core acquisition method, we call this method multigate method for convenience, is different from the image mode disc acquisition method. Image mode data are directly aquired in the core of CPU and gated images are superimposed according to the time sequences from R wave divided into 24 frames per beat. This method could provide high temporal resolution acquisition of image mode data if CPU has sufficient capacity. Number of frames, size and time resolution depends on the size of CPU. If necessary 96 frames of 32×32 (IK image) data can be acquired in this system.

Thus image mode first pass method adopted by our system requires large capacity of disc, however, advantage of this method lies in its capability to follow high count rate and in the simpleness of the method of data processing. Drawback of this method is 40 msec time resolution rather than 10 msec of the LIST mode. As routine examination we found this method of first pass study is most convenient. However whenever high temporal resolution is required LIST mode can be adopted with the cost of prolonged time of processing.

Multigate core acquisition method does not require sorting of the data with the cost of large CPU. However for the successive rest and stress test, advantage of this real time method is apparent. In our system 24 frame of 4K image is set in the core which allows data acquisition of all data of pulse rate more than 62 beats/min (R-R 960 msec).

Another advantage of the LIST mode lies in its capability to exclude the premature beat during the process of sorting, however, image mode does not allow this possibility.

Advantageous feature of the present system which is unable to present in the manuscript is the function of MIS. As discussed in detail high speed transportation from the disc to the refresh memory served to present the moving motion image on color CRT. This presentation allows physician to recognize the regional and global dysfunction of the ventricle more realistically than static image or numbers. Adoption of large capacity computer system made more practical image mode multigate study of the radio nuclide studies. By the reasons discussed before, authors construct first pass multigate image by summation of 4 successive beats from the peak of right and left radiocardiogram. Even though countrate per channel is smaller, low background of this method facilitates the construction of satisfactory volume curves.

Equilibrium method from LAO position by image mode has drawback of inability of excluding premature beat. Therefore if R-R interval varies markedly, we cannot expect to have precise left ventricular volume curve. In such case, LIST mode data acquisition is recommended, eventhough approximately 20～30 min is required for image reconstruction. Advantage of this LIST mode lies also in its ability to have high temporal resolution of 10 msec. Ability to select adequate R-R interval allows to exclude premature beat.

Even though there exist several disadvantages and advantages in three methods of computer application, data by all methods indicated good agreement for the evaluation of LVEF, LV volume curve and dV/dt.

Conclusion

Large memory CPU and high transportation speed magnetic disc system combined with γ-camera(s) made IMAGE mode analysis of first pass and equilibrium studies of the cardiovascular nuclear medicine.

This expanded system also speeded up the transformation of LIST mode data into image within tolerable time span of 20～30 min.

Applications of this computer system, MIS and various collimators dedicated to cardiovascular nuclear medicine were presented by showing typical clinical cases.

Authors wish to express our thanks for the support of the grants in part by the Ministry of Health and Welfare and Adult Disease Research Institute. We also extend our gratitude to Dr. Furuta for his kind offer to use his case in this manuscript.

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