Significance of Ultrafast Computed Tomography in Cardiac Imaging: Usefulness in Assessment of Myocardial Characteristics and Cardiac Function

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The usefulness of cardiac ultrafast computed tomography (CT) is discussed in this article. Thirty-three patients with ischemic heart disease and 15 patients with hypertrophic cardiomyopathy were assessed for myocardial characteristics, while 30 patients with various heart diseases were assessed for cardiac function. Volume mode (100 msec scan) and cine mode (50 msec scan) studies were applied.

As the findings of abnormal myocardial characteristics, early defect (ED) and late enhancement (LE) of the left ventricular (LV) wall were observed after injection of contrast medium. In ischemic heart disease, all 27 patients with myocardial infarction (MI) and all 16 MI sites showed LE, while 25 ED sites were well correlated with MI or significant coronary stenosis. LE was quite sensitive for MI and ED was highly predictive for ischemia. Seven of 15 HCM patients (47%) also showed LE, indicating that LE occurs in tissues with a different capillary architecture from that observed in normal myocardium.

For evaluation of cardiac function, ventricular volumetry was performed by summation of a sliced area of the ventricles. End-diastolic volume and LV ejection fraction calculated by this means correlated excellently with the values obtained using left ventriculography ($R = 0.97$ and 0.96). The stroke volumes for both ventricles were nearly equal when calculated using ultrafast CT. Consequently, the study of cardiac volumetry using ultrafast CT was thought to be reliable and utilizable in clinical practice.

ALTHOUGH X-ray computed tomography (CT) is an excellent imaging methodology, its utilization in cardiac examination is limited due to the slow scan time and scan repetition of conventional CT scanners.¹ The ultrafast CT (UFCT) scanner is a product of technological innovation having the ability to scan fast and do rapid repetition of scans, thus making it possible to examine the heart.² Our recent experience of the UFCT has confirmed that it is absolutely

suitable for cardiac imaging.³ This reports on the usefulness of UFCT in assessment of myocardial characteristics and in evaluation of cardiac function, especially in ventricular volumetry.

MATERIALS AND METHODS

The UFCT scanner used was an IMATRON C-100 (USA), using an electron beam scan system. On this machine, three scanning modes, volume, cine and flow, are available. The volume mode scans with a table incrementation. ECG-triggered 100 msec scans are commonly used in cardiac examination, and 20 contiguous images covering the whole heart can be obtained within 30 to 40 heart beats. Cine mode scanning

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TABLE I LATE ENHANCEMENT OF MYOCARDIUM

1. Patient		MI (+) 27		MI (?) 6	
LE (+)	30	27		3	
LE (?)	3	0		3	
2. Site		MI (+) 16		MI (?) SCA PD other	
LE (+)	35	16	5	4	10
LE (?)		0	—	—	—
3. Size		LE > MI		LE = MI	
MI Site	16	5	11	0	

LE = late enhancement; MI = myocardial infarction; (?) = undefined; SCA = severe contraction abnormality; PD = perfusion defect in $^{99m}\text{TlCl}$ -myocardial imaging

TABLE II EARLY DEFECT OF MYOCARDIUM

1. Patient		MI (+) 27		MI (?) 6	
ED (+)	20	18		2	
ED (?)	13	9		4	
2. Site		MI (+) 16		MI (?) coronary stenosis	
				$\geq 90\%$ 75% 50% $\leq$	no CAG (?)
ED (+)	25	8	10	1	0
ED (?)		8	—	—	—
3. Size (vs. late enhancement (LE))		LE (+)		LE (?)	
		ED > LE	ED = LE	ED < LE	
ED Sites	25	1	5	17	2

ED = early defect; CAG = coronary angiography

employs rapid repetition of 50 msec scans, with the shortest interscan delay time (8 msec) after the ECG R-wave in the same level. Images of 6 to 8 contiguous levels are obtained during several heart beats using multiple target and detector rings. The flow mode is comparable to dynamic scanning in conventional CT.

Thirty-three adult patients with ischemic

heart disease and 15 patients with hypertrophic cardiomyopathy (HCM) were examined using UFCT for assessment of left ventricular (LV) myocardial characteristics. In the group of patients with ischemic heart disease, 27 had myocardial infarction (MI) diagnosed on ECG findings and creatine kinase elevation. Time after onset of MI ranged from 4 days to 17 years. We

Fig.1. Early defect and late enhancement of myocardium. Patient with an old myocardial infarction (2 months after onset).

A: Early phase image after start of contrast medium injection. Scan time is 100 msec. An early defect is visible on the anterior wall of the left ventricle (arrow heads). B: Late enhancement is also seen (arrows). Scan time is 300 msec.

Fig.2. Measurement of LV end-diastolic volume and ejection fraction. Comparison between UFCT (cine study) and left ventriculography.

clinically defined the site of the MI as the region of the LV wall in which both severe contraction abnormalities detected by left ventriculography (LVG) or echocardiography, and a perfusion defect without redistribution during exercise $^{99m}\text{TlCl}$ myocardial imaging were combined. In assessment of myocardial characteristics, volume

mode scanning was applied, and contrast medium was administered intravenously (Iopamiron 370, 1.2 ml/kg, injection speed 1–3 ml/sec). Early phase images of contrast enhancement were obtained 30 to 60 sec after the start of the injection, followed by delayed scans performed 4 to 10 min after contrast medium injection. Poor enhance-

Fig.3. Measurement of LV volume.
Comparison between near end-diastolic volume calculated using UFCT (volume mode study) and the EDV calculated using LVG.

ment of the LV wall in early phase images (early defect (ED)) and intense stain in delayed images (late enhancement (LE)) were observed, indicating myocardial abnormalities (Fig. 1). These were compared with the findings of other imaging methodologies.

Thirty patients with various heart diseases and

regular sinus rhythm and who were undergoing cardiac catheterization and LVG were assessed for cardiac function. Patient ages ranged from 1 to 69 years. Volume mode or cine mode scans covering both ventricles were performed following injection of contrast medium. ECG-triggered scans in the volume mode study were timed to occur in the near end-diastolic phase, using a delay time after the R-wave trigger. Then, volumetry of both ventricles was performed by summation of a sliced area of the ventricular cavity. End-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV) and ejection fraction (EF) were calculated from cine mode images, and the volume of the near end-diastole was obtained from volume mode images. The values calculated for these parameters, which represent patient cardiac function, were compared with those obtained by LVG. In 8 patients without any evidence of valvular regurgitation or intracardiac shunts, the SVs of the two ventricles were compared.

RESULTS

Correlations between CT abnormalities identified using myocardial contrast enhancement, and the existence, site and size of MIs in 33 patients with ischemic heart disease are shown in Tables I and II. Late enhancement (LE) was found in all 27 patients with MI. There were 35 sites with LE, showing almost equal intensity to the LV cavity. Of the 35 LE sites, 16 (46%) had clinically defined MI, 9 with either severe asynergy

Fig.4. Measurement of stroke volume of the ventricles.
Comparison between right and left ventricular stroke volumes.

or a perfusion defect identified by TI-myocardial imaging, and the remaining 10 sites showed nontransmural distribution of LE. In 2 patients without significant coronary stenosis responsible for MI, LE sites did not correlate with coronary lesions. No site of an MI was larger in size than the LE site. Twenty out of the 33 patients with ischemic heart disease (61%) and 18 out of 27 MI patients (67%) had early defect (ED). Twenty-five ED sites were found in all 33 patients, and 8 of 16 MI sites (50%) showed ED. MI was found associated with ED 4 days to 17 years after MI onset. ED sites found in regions without MI correlated well with significant coronary stenosis. The majority of ED sites were combined with LE (92%), but were smaller than LE in size. Seven out of 15 HCM patients (47%) showed rather patchy distribution of LE in the LV wall.

Figures 2 and 3 demonstrate the correlation between CT volumetry and LVG. Left ventricular ejection fraction (LVEF) and EDV calculated from cine mode images showed excellent agreement with those calculated using LVG (Fig. 2), with correlation coefficients of 0.96 and 0.97, respectively. The near EDV of LV calculated on the volume mode study was almost equal to the EDV value obtained with LVG, the two correlating very closely (Fig. 3). Comparison of the SVs of the right and left ventricles is shown in Fig. 4, indicating that the SVs of the two ventricles, calculated by CT measurement, were almost the same.

DISCUSSION

In CT assessment of myocardial characteristics, it is necessary to use contrast medium for all procedures other than detection of calcification and fatty infiltration. It is well known that ED and LE were found in dog cardiac CT experiments to indicate myocardial infarction. With an old MI, the latter is thought to correspond to a fibrotic scar containing abundant capillaries^{4,5}. However, these findings have not been utilized in clinical practice because of the poor cardiac CT image quality and slow repetition of scans available with conventional scanners.

Our results demonstrate that LE is a sensitive clinical marker for MI and suggest that it is predictive of MI in patients with ischemic heart disease, since in this study the clinically defined MI regions were probably underestimated. It is suggested that UFCT can detect not only

transmural MI but also infarcts of nontransmural or subendocardial distribution. Because some HCM patients showed a patchy LE distribution, LE may not be specific for MI in a general cardiac examination, and may indicate existence of tissue with capillary architecture or other characteristics different from those of normal myocardium, such as occurs in fibrosis. In contrast, ED was a less sensitive marker for MI than LE, but correlated well with coronary stenosis. ED was seen in a few sites showing no evidence of MI or LE. This indicates that ED is highly predictive for ischemia or ischemic damage to the myocardium in ischemic heart disease. ED may correspond to delayed coronary perfusion due to severe coronary stenosis or increased resistance and decreased LV wall vascular bed volume. While a previous report using a conventional scanner found that ED was not detectable in an old MI, we were able to observe it even in an MI site 17 years after onset of the MI⁶. Thus, UFCT appears to be far more sensitive than conventional CT in detection of ED.

CT volumetry of the heart has an important role in evaluation of cardiac function, offering parallel contiguous sections of atria and ventricles. In spite of this valuable, CT has not been used clinically very much for this purpose⁷⁻⁹. Again, the poor time resolution of the image and poor scan repetition ability have been the problems of the conventional scanner. UFCT can resolve these difficulties. According to our results, the accuracy of LV volumetry by UFCT is satisfactory for clinical use, and the value for the near EDV obtained in the volume mode study agreed well with the value obtained using LVG¹⁰. The fact that the SVs of the two ventricles were nearly equal, indicates that right ventricular volumetry using UFCT is also reliable¹¹. In addition to EDV, ESV, SV and EF of the ventricles, measurement of ventricular muscular mass and both atrial volumes is possible using UFCT, and should be accurate because demarcation of the outer boundary of the ventricles and of the atrial cavities in the CT image is usually much easier than identification of the ventricular cavities¹². Consequently, UFCT is thought to be the best method for 4-chamber volumetry. UFCT measurement of cardiac geometry is destined to be a gold standard in clinical practice.

REFERENCES

1. NAITO H: Thoracic CT: Heart disease. *Jpn J Clin Radiol* 31: 1229, 1986 (in Japanese)

2. BOYD DP, GOULD RG, QUINN JK, SPARKS R, STNLEY JH, HERRMANNSELDT WB: A proposed dynamic cardiac 3-D densitometer for early detection and evaluation of heart disease. *IEEE Trans Nucl Sci* **26**: 2724, 1979
3. SAITO H, NAITO H, TAKAMIYA M, IMAKITA S, YAMADA N, SHIBA N, SAKASHITA Y, MOTOSUGI S: Ultrafast CT scanner - preliminary experience in Japan- *Jpn J Clin Radiol* (submitted) (in Japanese)
4. HIGGINS CB, CARLSSON E, LIPTON MJ: CT of the heart and the great vessels: Experimental evaluation and clinical application. Futura Co. New York, 1983
5. MASUDA Y, YOSHIDA H, MOROOKA N, WATANABE S, INAGAKI Y: The usefulness of X-ray computed tomography for the diagnosis of myocardial infarction. *Circulation* **70**: 217, 1984
6. MASUDA Y, UDA T, YOSHIDA K, YAMADA Z, MOROOKA N, YOSHIDA H, WATANABE S, INAGAKI Y, CARLSSON E: Diagnosis of myocardial infarction by CT: The study of an initial filling defect and late enhancement of the infarcted myocardium after injection of contrast material. *J Cardiatr* **13**: 809, 1983 (in Japanese)
7. NAITO H: Evaluation of cardiac function by computed tomography. *Resp and Circ* **32**: 249, 1984 (in Japanese)
8. NAITO H, ARISAWA J, KIMURA K, KOZUKA T, KITO Y, OHARA K, FUJITA T, NAGATA S, REDINGTON RW: Evaluation of left ventricular morphology and function by cardiac computed tomographic examination. *J Cardiatr* **12**: 425, 1982 (in Japanese)
9. KIMURA M, NAITO H, OHTA M, KOZUKA T, KITO K, FUJITA T, OKAMOTO M, MIYATAKE K: Measurement of four chambers' volumes and ventricular masses by cardiac CT examination. *J Cardiatr* **13**: 605, 1983 (in Japanese)
10. RICH S, CHOMKA EV, STAGL R, SHANE JG, KONDOS CT, BRUNDAGE BH: Determination of left ventricular ejection fraction using ultrafast computed tomography. *Am Heart J* **112**: 392, 1986
11. REITER SJ, RUMBERGER JA, FEIRING AJ, STANFORD W, MARCUS ML: Precision of measurements of right and left ventricular volume by cine computed tomography. *Circulation* **74**: 890, 1986
12. FEIRING AJ, RUMBERGER JA, REITER SJ, SKORTON DJ, COLLINS SM, LIPTON MJ, HIGGINS CB, ELL S, MARCUS ML: Determination of left ventricular mass in dogs with rapid-acquisition cardiac computed tomographic scanning. *Circulation* **72**: 1355, 1985