Evaluation of Left Ventricular Function Using Digital Subtraction Angiography

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To evaluate function of the left ventricle and myocardial perfusion images, digital subtraction angiography (DSA) was performed in 45 patients with ischemic heart disease.

Validity of the technique was compared with data obtained from cine left ventriculogram in all patients and 201 Tl myocardial images in 20 patients.

End-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF) calculated from DSA were correlated closely with those from cine left ventriculogram ($r = 0.92$, $r = 0.94$ and $r = 0.86$, respectively). Regional contractility at the antero-lateral wall of the left ventricle, assessed by DSA, was also correlated well with cine left ventriculogram ($r = 0.75$). Evaluation of the inferior wall motion showed less correlation in both procedures ($r = 0.68$). Phase and amplitude analysis with the same technique with radionuclide cardiac angiography was successfully applied in left ventriculogram obtained by DSA. The procedure seems to be helpful for objective evaluation of the left ventricular wall motion.

Myocardial perfusion image, obtained with modified Radtke's technique, showed good coincidence with 201 Tl images.

Thus, DSA is applicable for evaluation of function of the left ventricle and myocardial perfusion in patients with ischemic heart disease.

DIGITAL subtraction angiography (DSA) has been used for examination of diseases of the aorta and peripheral arteries.¹⁻¹⁰ Digital processing of fluoroscopic images of the heart and great vessels can be utilized for analysis of cardiac anatomy and cardiovascular dynamics. Despite of potential capability of DSA, however, few reports have appeared on literature concerning cardiovascular dynamics. This paper describes experience of the authors with digital imaging techniques for qualitative and quantitative analysis of cardiovascular dynamics in patients with ischemic heart disease. The several cardiovascular applications of DSA described in the paper suggest that DSA will provide useful information concerning cardiovascular physiolo-

gy of patients with ischemic heart disease.

METHODS

Fluoroscopy was performed using a Toshiba 9"/6" cesium iodide image intensifier and vidicon television camera. The data obtained with fluoroscopy were digitized at a rate of 30 frames per second and processed using Toshiba Digiformer-X (DFP-02A). The system uses 512×512 pixels and 10 bits for A/D conversion and 8 bits for D/A conversion. The data stored in VDR are transferred to the computer system for analysis of cardiovascular dynamics through a video-interface. The computer has a capacity of 68M Byte and can store 112 frames of images in 128×128 matrix.

The material comprised 45 patients with ischemic heart disease. Beside DSA, cine left ventriculography was performed in all patients

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Fig.1. Method of myocardial imaging.

and myocardial imaging with ^{201}Tl in 20 patients.

Forty ml of 76% Urografin was injected into the vena cava or right atrium at a rate of 16 ml/sec through 5F thin wall catheter with side holes. Left ventricular volumetric and functional data were derived from intravenous digital subtraction angiography in 30° right anterior oblique position.

After the outline of the left ventricle was automatically determined by means of threshold method, left ventricular volume was calculated, using standard single plane technique.¹¹

Myocardial perfusion image was obtained with such image processing as shown in Fig. 1. This followed Radtke's Method¹² with some modification of the author. Myocardial density reached to the maximum 3 to 5 seconds after visualization of the left ventricle. After the background was subtracted from the myocardial image, the second subtraction, performed between the myocardial and left ventricular images, gives pure myocardial image without intra- and extra-cardiac background.

Myocardial images of the left ventricular wall obtained with DSA and ^{201}Tl scintigraphy were divided into 5 segments and compared in 20 patients.

RESULTS

Left ventricular images, obtained with the technique described above, were satisfactory in quality for computer processing and global functional analysis.

End-diastolic volume (LVEDV), end-systolic volume (LVESV) and ejection fraction (LVEF) measured from DSA images correlated well with those obtained from ordinary cine ventriculography ($r = 0.92$ in LVEDV, $r = 0.94$ in LVESV and $r = 0.86$ in LVEF) (Fig. 2).

Wall motion of the left ventricle was evaluated with following 3 methods. First, the left ventricle was divided into 5 areas with hemiaxis method and regional contractility estimated by DSA was compared with those data obtained by conventional cine left ventriculography. The contraction mode evaluated with DSA correlated closely with those obtained from conventional cine left ventriculography in the anterolateral and apical segments. Less correlation was demonstrated in the inferior segment than the anterolateral and apical segments (Fig. 3). Second, global left ventricular wall motion can be displayed on the monitor TV by superimposition of the enddiastolic and endsystolic images (Fig. 4). Third, regional per cent shortening can be shown in each of 36 areas of the left ventricle

Fig.2. Volume of left ventricle at end-diastole (a), end-systole (b), and ejection fraction (c). Comparison between DSA and cine ventriculography.

which were obtained by dividing lines radiated from the gravity center of ventricle (Fig. 5). In the way, abnormal regional contraction can definitely be shown in a patient with old myocardial infarction (Fig. 6). In the same way as nuclear medicine, phase and amplitude analysis is possible in DSA. In the patient with broad anterior infarction, both amplitude and phase analysis showed objectively akinesis and delayed wall motion in the infarcted area (Fig. 7a). In another patient with angina pectoris showing normal contraction mode in amplitude analysis, phase analysis revealed delayed initiation of contraction of the anterolateral segment (Fig. 7b). In this patient, 201 Tl myocardial image showed no perfusion defect in any divisions.

Perfusion defect can be shown in the infarcted

area of the myocardium in a patient with old myocardial infarction (Fig. 8). Good correlation was obtained from DSA and 201 Tl scintigraphy especially in the anterolateral and posterobasal segments. Correlation was inferior in the segment from apical to diaphragmatic wall than the other segments. Total concurrence ratio was 76% (Fig. 9).

DISCUSSION

Selective angiocardiology with injection of the contrast medium into the cardiac chambers and great arteries has been commonly used in the diagnosis of various heart diseases. The procedure may have an associated complication. Sufficient training is absolutely required for

Fig.3. Evaluation of left ventricular wall motion at anterolateral (a) and inferior wall (b).

Fig.4. Evaluation of global left ventricular wall motion by superimposition of end-diastolic and end-systolic images in normal case (a) and patient with anterior myocardial infarction.

performing the procedure to give the satisfactorily diagnostic images with least morbidity and mortality. To replace such invasive technique, attempts have been made to develop noninvasive methods for diagnosis of heart disease. Development of digital subtraction angiography, in a sense, may correspond to the requirement.

While the usefulness of DSA has been confirmed in diagnosis of disease of the aorta and peripheral arteries, application of the technique and evaluation of its efficacy in diagnosis of heart disease is now undergoing. Axial projection was shown to be useful to overcome the disadvantage of superimposition of different cardiac chambers

Fig.5. Evaluation of regional wall motion of left ventricle in normal case.

Fig.6. Evaluation of regional wall motion of left ventricle in patient with broad anterior myocardial infarction.

Fig.7. Amplitude and phase analysis in patients with broad anterior myocardial infarction (a) and with angina pectoris (b).

Fig. 8. Perfusion defect in patient with antero-lateral apical region (arrow).

inherent in intravenous technique.¹³ Detection of left-to-right shunt was attempted in an animal model.¹⁴ Although DSA provides increased contrast resolution, the spatial resolution of this procedure is inferior to conventional cine angiography. Based on limitation of this technique, DSA may be advocated in the field where anatomy is known and only specified information, such as volume measurement and evaluation

of wall motion, is required.¹⁵ In this meaning, left ventriculography, using DSA in patient with coronary artery disease, is considered to be best application, because the left ventricle has a known, simple structure. As global quantitative parameters of the left ventricular function, volume, ejection fraction and wall motion, obtained with DSA has good correlation with those using conventional left ventriculography, as several reports on literature.¹⁶⁻²⁰ The results mean that conventional left ventriculography may be replaced by DSA in coronary artery disease.

Digitization of analog data is used for objective analysis of left ventricular function, with the same way as the procedure in nuclear medicine. In DSA, right anterior oblique view is available and more convenient for functional analysis of the left ventricle than left anterior oblique view which is used in nuclear medicine.

Phase and amplitude analysis in DSA may have a possibility to give new information, which is not available with present procedures. Phase analysis was reported to be useful for evaluation of WPW syndrome in nuclear medicine.²¹ Evaluation of these technique using DSA in diagnosis of coronary artery disease is now undergoing in comparison with conventional imaging techniques. Myocardial images were given by modification of Radtke's method.¹² Original

- 1: antero-basal (AB)
- 2: antero-lateral (AL)
- 3: antero-lateral~apical (AL~AP)
- 4: apical~diaphragmatic (AP~DP)
- 5: postero-basal (PB)

MYOCARDIAL PERFUSION: DSA and RI

DSA	RI			concurrence
		O	X	
AB	O	15	4	75%
	X	1	0	
AL	O	10	4	80%
	X	0	6	
AL~AP	O	4	4	75%
	X	1	11	
AP~DP	O	8	3	60%
	X	5	4	
PB	O	17	0	90%
	X	2	1	
total concurrence 76/100				76%

O : filling defect

X : normal

Fig. 9. Comparison of myocardial perfusion with DSA and 201 Tl.

myocardial image obtained in our study is so excellent that no integration is required. Myocardial images given by this technique show good correlation with 201 Tl images besides the diaphragmatic segments. Inferior correlation in the diaphragmatic segment may result from superimposition with the liver and diaphragm. While myocardial images using DSA and 201 Tl seem to be quite similar, physiological and pathological meaning is considered to be different. Images of 201 Tl mean rather presence of viable myocardial cells and those of DSA show blood perfusion in the myocardium. Both types of myocardial images using DSA and 201 Tl have a capability to be a useful tool in diagnosis of coronary artery disease. Further investigation is necessary to evaluate a clinical efficacy of DSA in myocardial imaging.

DSA has been applied for evaluation of patency of aortocoronary bypass graft with excellent diagnostic accuracy.²²

Spatial resolution of DSA should be improved a little more for evaluation of coronary artery disease to have capability for detection of such fine arterial branches as collateral circulation. High resolution imaging using 512×512 matrix or more pixels, however, the limits of present digital angiographic systems. Real-time digital subtraction at 30 fps on a 512×512 matrix requires immense data processing and image storage capacity on disk. After overcome of several disadvantages of this technique, DSA will play an important role in diagnosis of coronary artery disease.

REFERENCES

1. KRUGER RA, MISTRETTA CA, HOUK TL, RIEDERER SJ, SHAW C-G, GOODSITT MM, CRUMMY AB, ZWIEBEL WJ, LANCASTER JC, FLEMMING DC: Computerized fluoroscopy in real time for noninvasive visualization of the cardiovascular system. Preliminary studies. *Radiology* 130: 49, 1979
2. STROTHER CM, SACKETT JF, CRUMMY AB, LILLEAS FG, ZWIEBEL WJ, TURNIPSEED WD, JAVID MJ, MISTRETTA CA, KRUGER RA, ERGUN DL, SHAW C-G: Clinical applications of computerized fluoroscopy. The extracranial carotid arteries. *Radiology* 136: 781, 1980
3. CRUMMY AB, STROTHER CM, SACKETT JF, ERGUN DL, SHAW C-G, KRUGER RA, MISTRETTA CA, TURNIPSEED WD, LIEBERMAN RP, MYEROWITZ PD, RUZICKA FF: Computerized fluoroscopy: Digital subtraction for intravenous angiography and arteriography. *AJR* 135: 1131, 1980
4. CRUMMY AB, STROTHER CM, LIEBERMAN RP, STIEGHORST MF, SACKETT JF, WOJNOWYCZ MM, KRUGER RA, TURNIPSEED WD, ERGUN DL, SHAW C-G, MISTRETTA CA, RUZICKA FF: Digital video subtraction angiography for evaluation of peripheral vascular disease. *Radiology* 141: 33, 1981
5. MEANEY TF, WEINSTEIN MA, BUONOCORE E, PAVLICEK W, BORKOWSKI GP, GALLAGHER JH, SUFKA B, MacINTYRE WJ: Digital subtraction angiography of the human cardiovascular system. *AJR* 135: 1153, 1980
6. HILLMAN BJ, OVITT TW, NUDELMAN S, FISHER HD III, FROST MM, CAPP MP, ROEHRIG H, SEELEY G: Digital video subtraction angiography of renal vascular abnormalities. *Radiology* 139: 277, 1981
7. BUONOCORE E, MEANEY TF, BORKOWSKI GP, PAVLICEK W, GALLAGHER J: Digital subtraction angiography of the abdominal aorta and renal arteries. *Radiology* 139: 281, 1981
8. KOZUKA T, TAKAMIYA M, NISHIMURA G, YAMADA T, IDE K: A comparative study of digital subtraction angiography, direct aortography and computerized tomography in aortic dissection. *Contrast Medium in Digital Radiography*. ed by R FELIX, et al., Excerpta Medica, Amsterdam, 1983, p 281
9. GUTHANER DF, MILLER DC: Digital subtraction angiography of aortic dissection. *AJR* 141: 157, 1983
10. POND GD, OVITT TW, CAPP MP: Comparison of conventional pulmonary angiography with intravenous digital subtraction angiography for pulmonary embolic disease. *Radiology* 147: 345, 1983
11. KASSER I, KENNEDY JW: Measurement of the left ventricle volumes in man by single plane cine angiography. *Invest Radiol* 4: 83, 1969
12. RADTKE W, BURSCH JH, BRENNECKE R, HAHNE HJ, HEINTZEN PH: Assessment of left ventricular muscle volume by digital angiocardiology. *Invest Radiol* 18: 149, 1983
13. BOGREN HG, BÜRSCH JH, BRENNECKE R, HEINTZEN PH: Intravenous angiocardiology using digital image processing. I. Experience with axial projections in normal pigs. *Invest Radiol* 17: 216, 1982
14. BOGREN HG, BÜRSCH JH, BRENNECKE R, HEINTZEN PH: Intravenous angiocardiology using digital image processing. II. Detection of left-to-right shunts in an animal model. *Invest Radiol* 18: 11, 1983
15. CAPP MP, OVITT TW: Digital angiography in the diagnosis of congenital heart disease: An alternative viewpoint. *Cardiovasc Intervent Radiol* 7: 190, 1984
16. KRUGER RA, MISTRETTA CA, HOUK TL, KUBAL W, RIEDERER SJ, ERGUN DL, SHAW CG, LANCASTER JC, ROWE GG: Computerized fluoroscopy technique for intravenous study of cardiac chamber dynamics. *Invest Radiol* 14: 279, 1979
17. HIGGINGS CB, NORRIS SL, GERBER KH, SLUTSKY RA, ASHBURN WL, BAILY N: Quantitation of left ventricular dimensions and

- function by digital video subtraction angiography. *Radiology* 144: 461, 1982
18. SLUTSKY RA, MANCINI GBJ, NORRIS SL, ASHBURN WL, HIGGRNS CB: Digital intravenous ventriculography: Comparison of volumes from mask-mode and nonsubtracted images with thermodilution and sonocardiometric measurements. *Invest Radiol* 18: 327, 1983
 19. TOBIS J, NALCIOGLU O, SEIBERT A, HOHNSTON WD, HENRY WL: Measurement of left ventricular ejection fraction by videodensitometric analysis of digital subtraction angiograms. *Am J Cardiol* 52: 871, 1983
 20. FELIX R, EICHSTÄDT H: Assessment of left ventricular wall motion in digital subtraction angiography. A comparative study. Contrast Medium in Digital Radiography. ed by R FELIX, et al., Excerpta Medica, Amsterdam, 1983, p 241
 21. NAKAJIMA K, BUNKO H, TADA A, TAKI A, TONAMI N, HISADA K, MISAKI T, IWA T: Phase analysis in patients with Wolf-Parkinson-White syndrome: Correlations to surgically confirmed accessory conduction pathway. *Jpn J Nucl Med* 20: 1101, 1983 (in Japanese)
 22. TAKAMIYA M, NISHIMURA G, NAITO H, KOZUKA T, KIMURA K, OHTA M, KIMURA M, IDE K, YAMADA T, KURISU Y, KITO Y, OHARA K, FUJITA T, HAZE K: Diagnostic accuracy of intravenous digital subtraction angiography (IVDSA) in the evaluation of patency of AC-bypass. 47th Annual Meeting of Japanese Circulation Society, Osaka, 1983