Identification of viable myocardium in patients with chronic coronary artery disease and left ventricular dysfunction: Role of magnetic resonance imaging

Nineteen patients (16 men and 3 women, mean age 51 years) with previous anterior myocardial infarction and severe stenosis (≥90%) of the left anterior descending coronary artery were studied by magnetic resonance imaging (MRI) without and with contrast media to verify the capability of MRI in identifying viable myocardium in areas of severe systolic dysfunction. In corresponding left ventricular segments, a comparison was made between regional signal intensities (SI) determined on MRI images before and 4, 8, 12, and 30 minutes after administration of paramagnetic contrast media (gadolinium diethylenetriaminepentaacetic acid, 0.4 mmol/kg intravenously) and metabolic parameters determined by iodine 123 phenylpentadecanoic acid (IPPA) scintigraphy. The SI and the time of maximum postcontrast enhancement were analyzed by dividing the left ventricle into 11 segments. Each segment was classified as normal (group 1, $n = 116$), hibernating (group 2, $n = 50$), or necrotic (group 3, $n = 43$) on the basis of the IPPA washout rate (>30%, 10% to 30%, and <10%, respectively). Regional SI demonstrated significant differences in absolute values at 12 minutes (group 3: 1.62 ± 0.58 vs group 1: 1.32 ± 0.52, $p < 0.01$, and vs group 2: 1.34 ± 0.48, $p < 0.05$) and at 30 minutes (group 3: 1.71 ± 0.47 vs group 1: 1.21 ± 0.55, $p < 0.01$, and vs group 2: 1.49 ± 0.57, $p < 0.05$) and in temporal distribution. These results suggest that MRI has a potential role in differentiating viable from necrotic myocardium in patients with chronic severe systolic dysfunction. (Am Heart J 1994;128:484-9.)

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After reperfusion of acute myocardial infarctions, clinical evidence of lack of contraction does not necessarily indicate irreversible myocardial damage. Regional wall motion abnormality at rest may be the result of persistently depressed blood flow or to prolonged myocardial cellular dysfunction after transient ischemia, myocardial necrosis, or myocardial scarring. In patients with apparently infarcted myocardium, differentiating viable but functionally impaired myocardium from irreversibly infarcted myocardium is important if revascularization is contemplated for treatment.

Although echocardiography is extremely useful for assessing the mechanical consequences of ischemic or necrotic processes, it tends to overestimate infarcted areas and to be unable to discriminate reversible from irreversible myocardial injuries.[1, 2] Serial studies are needed to demonstrate myocardial viability by functional improvement in previously injured areas (myocardial stunning). The pharmacologic approach (echocardiography with dobutamine) is still under investigation.[3] Among the noninvasive cardiac imaging techniques, only positron emission tomography (PET) has proven adequate for distinguishing between reversible and irreversible ischemic tissue injury.[4-6] The combined evaluation of blood flow and glucose utilization aims to identify compromised but viable myocardium when wall motion is equally impaired in necrotic and reversibly damaged tissue.

More recently, magnetic resonance imaging (MRI)

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Received for publication July 19, 1993, accepted Jan. 6, 1994.

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0002-8703/94/$3.00 + 0 **4/1/56175**

has been used clinically and experimentally in the early detection of myocardial ischemia and infarction and has proven capable of distinguishing between occlusive and reperfused infarctions.[7-9] The diagnostic potential of contrast agents for improving MRI of reperfused and nonreperfused myocardial infarction also has been shown.[10, 11] However, the role of MRI in differentiating viable from necrotic tissue in patients with chronic ischemic heart disease has not been defined. The aim of this study was to determine whether MRI without and with contrast media has the capability of identifying viable myocardium in areas of severe systolic dysfunction and to discriminate reversibly from irreversibly damaged zones. Comparisons were made in corresponding left ventricular segments of regional perfusion and metabolism as determined by iodine 123 phenylpentadecanoic acid (IPPA) scintigraphy and regional signal intensity on MRI images obtained before and after administration of paramagnetic contrast media.

METHODS

Nineteen patients (16 men and 3 women, mean age 51 years) with anterior myocardial infarction and severe stenosis (≥90%) of the left anterior descending (LAD) artery were studied. Selection criteria included severe hypokinesis, akinesis, or diskinesis in anterior, septal, and/or apical regions (without asynergy in other segments) on x-ray left ventriculography and on two-dimensional (2D) echocardiography. Although all patients had evidence of previous myocardial infarction, we studied only patients with chronic stable coronary artery disease; no patient had suffered from an acute myocardial infarction or unstable angina within 3 months of the study. Coronary angiography showed single-vessel disease in 9 patients, two-vessel disease in 3 patients, and three-vessel disease in 1 patient. Collateral vessels were present in 8 patients (42%). Patients underwent IPPA scintigraphy and magnetic resonance imaging after discontinuation of all antianginal medications.

Magnetic resonance imaging. MRI examinations were performed with a 0.2 T permanent magnet. Cardiosynchronized spin-echo sequences were acquired (TR = R − R, TE = 25 msec, where TR = repetition time and TE = end time; matrix 128 × 256) with 10 mm slice thickness and, depending on the cardiac rate, an acquisition time of 2 minutes and 50 seconds to 3 minutes and 10 seconds. Short-axis scans were acquired on the mitral valve and papillary muscle levels and at the apical level.

Acquisitions with the same characteristics were repeated at 4, 8, 12, and 30 minutes after contrast medium administration. Gadolinium-diethylenetriaminepentaacetic acid (Gd-DTPA) (Magnevist, Schering), 0.4 mmol/kg was administered by rapid intravenous injection of 0.2 mmol/kg before the first acquisition and by infusion, lasting the whole acquisition time, of the remaining 0.2 mmol/kg to preserve a steady state of contrast in the plasma. Signal intensity (SI) analysis was performed by dividing the left ventricle into 11 segments, 5 (anterior, anteroseptal, posteroseptal, posterior, and lateral) at the mitral valve and papillary muscles levels and 1 at the apical level: this subdivision is similar to that applied to 2D echocardiographic images. The SI was calculated before administration of contrast medium and serially during the subsequent acquisitions: by a manual cursor system 11 regions of interest (ROIs) corresponding to the identified segments were analyzed. SI values of all ROIs were normalized with the SI of the subcutaneous fat. The time of maximum postcontrast enhancement also was determined.

Myocardial scintigraphy. Before the scintigraphic study, patients ate a no-fat breakfast and then fasted for 4 to 8 hours; 1 ml of Lugol's solution was given orally 30 to 60 minutes before the injection of IPPA. Three to 6 mCi of IPPA was injected intravenously with the patient upright at rest.

Planar imaging was performed with a standard–field-of-view gamma camera (General Electric) equipped with a general-purpose, low-energy, parallel-hole collimator interfaced to a dedicated nuclear medicine computer for data acquisition, storage, and analysis (Starcam 2000). Energy discrimination was provided by a 20% window centered on the 159 keV photopeak of iodine 123. Images were acquired in the 40- and 70-degree anterior oblique and anterior projections with a digital resolution of 128 × 128 at 4 and 30 minutes after IPPA injection. Each view was divided into 5 segments, for a total of 15 segments, by method proposed by Rigo et al.[12] Although this segmental analysis does not provide a perfect correspondence with the subdivision applied on magnetic resonance and on 2D echocardiographic images, it allows precise identification of the same 11 anatomic myocardial territories.

Quantitative analysis of regional myocardial IPPA activity was performed after background correction. Activity within each region was normalized to the mean activity of all segments within the image. Segmental washout rates were calculated from the mean activity in each segment before normalization, according to the formula: (total counts at 4 minutes − background counts at 4 minutes) − (total counts at 30 minutes − background counts at 30 minutes)/(total counts at 4 minutes − background counts at 4 minutes) × 100. IPPA washout rates were classified as normal (>30%), reduced (10% to 30%), or absent (<10%). The regions with normal or reduced IPPA activity and washout were considered to indicate myocardial viability; IPPA segmental distribution and washout absence were considered to represent irreversibly damaged myocardium (necrotic or fibrotic).

Statistical analysis. Results are expressed as mean values ± SD or as proportions. Univariate analysis of mean data between groups was performed by Student's t test with pooled variance or one-way analysis of variance. Univariate analysis of proportions between groups was performed by the chi square test. A p value <0.05 was considered significant.

RESULTS

Regional fatty acid metabolism and function. Of the 209 myocardial regions evaluated of the 19 patients,

Table I. Signal intensities classified by metabolic pattern

Time after gadolinium-DTPA administration (min)	*Group I: Normal metabolism (n = 116)*	*I vs II (p)*	*Group II: Reduced metabolism (n = 50)*	*II vs III (p)*	*Group III: No metabolism (n = 43)*	*I vs III (p)*
Baseline	1.12 ± 0.45	<0.03	1.32 ± 0.45	NS	1.20 ± 0.54	NS
4	1.30 ± 0.52	<0.01	1.57 ± 0.59	NS	1.47 ± 0.20	<0.05
8	1.20 ± 0.43	<0.01	1.38 ± 0.34	<0.03	1.50 ± 0.20	<0.01
12	1.32 ± 0.52	NS	1.34 ± 0.58	<0.05	1.62 ± 0.58	<0.01
30	1.21 ± 0.55	<0.01	1.49 ± 0.57	<0.05	1.71 ± 0.47	<0.01

NS, Not significant.

Table II. Time of maximum postcontrast enhancement distribution

Time after gadolinium-DTPA administration (min)	*Group I: Normal metabolism (n = 116)*	*I vs II (p)*	*Group II: Reduced metabolism (n = 50)*	*II vs III (p)*	*Group III: No metabolism (n = 43)*	*I vs III (p)*
4	53 (45.7%)	NS	32 (64.0%)	<0.001	6 (13.9%)	<0.01
8	36 (31.0%)	NS	8 (16.0%)	NS	4 (9.3%)	<0.05
12	16 (13.8%)	NS	4 (8.0%)	NS	4 (9.3%)	<0.05
30	11 (9.5%)	NS	6 (12.0%)	<0.001	29 (67.5%)	<0.0001

NS, Difference not significant.

116 (55.5%) had normal IPPA distribution and washout; 50 (24.0%) showed a pattern of reduced metabolism; and in 43 (20.5%) fatty acid activity was absent. The relations between regional metabolic pattern and regional myocardial function as evaluated by 2D echocardiography were follows. A normal metabolism was found in 91 of 121 segments showing normal wall motion and in 25 of 88 regions with abnormal wall motion; reduced metabolism was present in 20 of 121 normally functioning areas and in 30 of 88 dysfunctioning ones; finally, in 10 of 121 segments with normal function and 33 of 88 with asynergy, metabolism was absent.

Regional fatty acid metabolism and magnetic resonance imaging parameters. The data relative to values of MRI SI calculated before and after Gd-DTPA administration in the regions classified as having normal (group 1), reduced (group 2), or no (group 3) metabolism are shown in Table I. The differences between regions without metabolism and the other regions were significant at 12 minutes (group 3: 1.62 ± 0.58 vs group 1: 1.32 ± 0.52, $p < 0.01$, and vs group 2: 1.34 ± 0.48, $p < 0.05$) and at 30 minutes (group 3: 1.71 ± 0.47 vs group 1: 1.21 ± 0.55, $p < 0.01$, and vs group 2: 1.49 ± 0.57, $p < 0.05$).

The results relative to time peak of maximum postcontrast enhancement demonstrated significantly different distribution among the three groups (Table II). The segments classified as metabolically inactive had a time peak significantly delayed compared with regions with normal or reduced fatty acid activity: at 30 minutes, 29 (67.5%) of 43 segments of group 3 had attained the maximum enhancement as compared with group 1 (11 [9.5%] of 116, $p < 0.0001$) and with group 2 (6 [12.0%] of 50, $p < 0.001$).

Magnetic resonance imaging parameters and viable myocardium in dysfunctional areas. When we consider only the dysfunctioning regions on 2D echocardiography ($n = 88$), classified as viable (normal or reduced metabolism, group 1A, $n = 55$) or as irreversibly damaged (absent metabolism, group 2A, $n = 33$), results relative to MRI parameters can be summarized as follows. (1) The mean SI in postcontrast images was significantly different between the two groups at 12 minutes (group 1A: 1.29 ± 0.68 vs group 2A: 1.68 ± 0.54, $p < 0.01$) and at 30 minutes (group 1A: 1.17 ± 0.61 vs group 2A: 1.65 ± 0.55, $p < 0.01$) (Table III). (2) The distribution of time peaks of maximum contrast enhancement were significantly different between the two groups: at 30 minutes, only 7 (12.7%) of 55 segments of group 1A had attained the maximum postcontrast enhancement as compared to 22 (66.7%) of 33 of group 2A ($p < 0.001$) (Table IV).

DISCUSSION

The results of this study confirm the high incidence (62.5%) of viable myocardium in regions of abnormal

wall motion at rest in patients with previous infarction and chronic coronary artery disease.[13-16] In these patients, ventricular function may improve considerably after revascularization. Thus left ventricular dysfunction in chronic coronary artery disease may be reversible, and the identification of viable myocardium has important clinical implications. In this setting the assessment of myocardial viability on the basis of regional ventricular function measurements at rest, obtained by contrast ventriculography, radionuclide angiography, or echocardiography, is often imprecise, as confirmed also by our data. Although enhanced regional left ventricular function during nitroglycerin administration,[17] during postextrasystolic potentiation,[18] during low-dose catecholamine infusion,[3, 19] or immediately after exercise[20] has been proposed to identify more accurately viable myocardium in patients with chronic regional asinergy, the application of these techniques during contrast, radionuclide, or ultrasonic ventriculography has yet to gain widespread clinical acceptance.

The presence of viable myocardium in areas of severe dysfunction might be ascribed to stunning or hibernating myocardium. The first was brilliantly defined by Jennings et al.[21] as "prolonged contractile dysfunction exhibited by viable myocardium which has been damaged by ischemia and salvaged by reperfusion"; the term "hibernated myocardium" was introduced by Rahimtoola[22] to define left ventricular dysfunction due to chronic and profound ischemia.

Because dysfunction and viability are common to both pathophysiologic conditions, precise differentiation requires knowledge of the perfusional pattern: stunned myocardium has normal perfusion, whereas hibernated myocardium is hypoperfused. At present, only simultaneous metabolic and perfusional PET imaging has emerged as a promising method for identifying viable myocardium and for differentiating stunned from hibernated myocardium. The metabolic imaging technique that we used does not allow this distinction; however, IPPA scintigraphy was demonstrated to be an accurate method for studying metabolic markers in various pathophysiologic conditions (chronic and acute ischemia and myocardial infarction).[23-25] The choice of fatty acid scintigraphy seems appropriate to the aim of this study: it allows identification of different metabolic patterns and satisfying differentiation between viable and unviable myocardium, as recently demonstrated by comparison with myocardial biopsy specimens and postoperative outcomes.[26] Furthermore, fatty acid scintigraphy with respect to PET offers the advantages of a wider diffusion and reduced cost.

Table III. Signal intensities in viable and irreversibly damaged dysfunctioning segments

Time after gadolinium-DTPA administration (min)	*Group IA: Normal or reduced metabolism (n = 55)*	*I vs II (p)*	*Group IIA: No metabolism (n = 33)*
Baseline	1.02 ± 0.50	NS	1.11 ± 0.59
4	1.24 ± 0.63	NS	1.39 ± 0.65
8	1.01 ± 0.46	NS	1.13 ± 0.52
12	1.29 ± 0.68	<0.01	1.68 ± 0.54
30	1.17 ± 0.61	<0.01	1.65 ± 0.55

NS, Not significant.

Table IV. Time of maximum contrast enhancement distribution between viable and irreversibly damaged dysfunctioning segments

Time after gadolinium-DTPA administration (min)	*Group IA: Normal or reduced metabolism (n = 55)*	*I vs II (p)*	*Group IIA: No metabolism (n = 33)*
4	31 (56.4%)	<0.001	4 (12.1%)
8	10 (18.2%)	NS	4 (12.1%)
12	7 (12.7%)	NS	3 (9.1%)
30	7 (12.7%)	<0.001	22 (66.7%)

NS, Not significant.

The results relative to the comparison between MRI parameters and regional metabolic patterns suggest the potential role of MRI in the identification of viable myocardium: regional SIs demonstrate significant differences in absolute value and temporal distribution not only among the three groups classified by metabolic pattern but also, and even more markedly, between the viable and unviable dysfunctional segments.

Our data demonstrate that the use of contrast medium is of crucial importance. The ionic contrast agent Gd-DTPA proved capable of improving the differences between infarcted and normal myocardium in the acute phase[27]; similar good results were achieved when Gd-DTPA was used to differentiate reperfused from nonreperfused infarctions in animal models.[28-30] However, clinical studies are lacking in the setting of chronic ischemia.[31] Although the patients we studied were affected by chronic coronary artery disease, the administration of contrast medium was useful in differentiating viable from unviable myocardium. Tissue contrast depends on differences in tissue perfusion, blood content, size of extracellular space, and myocardial contrast agent distribution. Although a kinetic model for Gd-DTPA

is lacking, the high dose used and the administration modalities (bolus plus constant infusion) were designed (1) to address the problem of rapid washout of a water-space paramagnetic agent that has a short residence time after bolus injection,[32] and (2) to avoid the time-dependent fluctuation of the enhancement during image acquisition.[33] Although we cannot be sure that a steady-state concentration of Gd-DTPA was achieved, other investigators,[33] using the same protocol, have demonstrated a sustained plateau in paramagnetic effect that remained stable until Gd-DTPA infusion was completed. Differences in regional paramagnetic enhancement may be explained by changes in the volume of distribution or compartmentalization (intravascular and interstitial compartments) of gadolinium in the myocardium. In patients with chronic coronary artery disease, these changes are due to the complex modifications in myocardial structure, metabolism, and perfusion that occur in this condition: in particular, the more pronounced and delayed paramagnetic enhancement observed in regions without metabolism may be ascribed to the more profound abnormalities in membrane partition coefficient between intravascular and interstitial space and in gadolinium clearance in areas irreversibly damaged but probably still not completely fibrotic. The lack of significant modifications of myocardial thickness on MRI images confirms the absence of evident scarring processes.

Some limitations of our study deserve further consideration. First, one might object to the lack of controls; however, the absence of a patient control group may be overcome by a segment control group, i.e., a group of segments with normal metabolism and wall motion. The variability of signal intensities also observed in this group may affect our conclusions. Although there are difficulties in comparing ventricular segments derived from planar (fatty acid scintigraphy) and tomographic (MRI) imaging techniques, we believe that the precise identification of 11 anatomic territories corresponding to well-defined vascular beds may be sufficient to minimize those inherent differences. Furthermore, there is close correspondence, at present commonly accepted, in segmental wall motion assessment by planar (contrast ventriculography) and tomographic (2D echocardiography) techniques.

Our study involved patients with chronic coronary artery disease, and thus the results may not apply to patients with acute ischemia or to patients undergoing fibrinolytic treatment or revascularization procedures. Considering the relatively small number of patients, none of whom underwent successful revascularization, definitive conclusions regarding the overall efficacy of MRI compared with fatty acid scintigraphy in predicting favorable outcome after revascularization will require further experience in a larger series.

However, our data, concerning the analysis of a large number of myocardial regions with a variety of metabolic patterns, do allow an evaluation of MRI parameters in comparison with IPPA imaging in the assessment of myocardial viability. The results suggest the potential role of MRI in providing information approximately comparable to that obtained by fatty acid scintigraphy in identifying viable myocardium in patients with chronic coronary artery disease and left ventricular dysfunction.

We thank Dr. Charles B. Higgins, Dr. Mihai Gheorghiade, and Paola Luciolli.

REFERENCES

1. Force T, Kemper A, Perkins L, Gilfoil M, Cohen C, Parisi AF. Overestimation of infarct size by quantitative two-dimensional echocardiography: the role of tethering and of analytic procedures. Circulation 1986;73:1360-8.
2. Fedele F, Biasi S, Casolo F, Capozzi A, Calastra C, Cipressi F, Marani SD, Mattioli G, Mattioli AV, Di Renzi P, Di Cesare E, Passariello R, Fabietti F, Sciomer S, Agati L, Penco M, Dagianti A. Stunned and necrotic areas: role of MRI—Italian Cooperative Study. In: Dagianti A, Feigenbaum H, eds. Echocardiography 1990. Amsterdam: Excerpta Medica, Elsevier Science Publishers, 1990:197-202.
3. Pierard LA, De Landsheere CM, Berthe C, Rigo P, Kulbertus HE. Identification of viable myocardium by echocardiography during dobutamine infusion in patients with myocardial infarction after thrombolytic therapy: comparison with positron emission tomography. J Am Coll Cardiol 1990; 15:1021-31.
4. Marshall RC, Tillish JH, Phelps ME, Huang SC, Carson R, Henze E, Schelbert HR. Identification and differentiation of resting myocardial ischemia and infarction in man with positron computed tomography, 18F-labeled fluorodeoxyglucose and N-13 ammonia. Circulation 1983;67:766-78.
5. Geltman EM, Biello D, Welch MJ, Ter-Pogossian MM, Roberts R, Sobel BE. Characterization of nontransmural myocardial infarction by positron-emission tomography. Circulation 1982;65:747-55.
6. Schwaiger M, Brunken R, Grover McKay M, Krivokapich J, Child J, Tillisch JH, Phelps ME, Schelbert HR. Regional myocardial metabolism in patients with acute myocardial infarction assessed by positron emission tomography. J Am Coll Cardiol 1986;8:800-8.
7. Johnston DL, Brady TJ, Ratner AV, Rosen BR, Newell JB, Pohost GM, Okada RD. Assessment of myocardial ischemia with proton magnetic resonance: effects of the three hour coronary occlusion with and without reperfusion. Circulation 1985;71:595-601.
8. Johnston DL, Liu P, Rosen BR, Levine RA, Beaulieu PA, Brady TJ, Okada RD. In vivo detection of reperfused myocardium by nuclear magnetic resonance imaging. J Am Coll Cardiol 1987;9:127-35.
9. Tscholakoff D, Higgins CB, Sechtem U, Caputo G, Derugin N. MRI of reperfused myocardial infarct in dogs. AJR 1986; 146:925-30.
10. Takayuki M, Maythem S, Wendland MF, Higgins CB. Occlusive and reperfused myocardial infarcts: MR imaging differentiation with nonionic Gd-DTPA-BMA. Radiology 1991; 181:77-83.

11. De Roos A, van Rossum AC, van der Waal E, Postema S, Doornbos J, Matheijssen N, van Dijkman PRM, Visser FC, van Voorthuisen AE. Reperfused and nonreperfused myocardial infarction: diagnostic potential of Gd-DTPA-enhanced MR imaging. Radiology 1989;172:717-20.
12. Rigo P, Bailey IK, Griffit LSC, Pitt B, Burow RD, Wagner HN, Becker L. Value and limitations of segmental analysis of stress thallium myocardial imaging for localization of coronary artery disease. Circulation 1980; 61:973-81.
13. Bonow RO, Dilsizian V, Cuocolo A, Bacharach S. Identification of viable myocardium in patients with chronic coronary artery disease and left ventricular dysfunction. Circulation 1991;83:26-37.
14. Brunken R, Tillisch J, Schwaiger M, Child JS, Marshall R, Mandelkern M, Phelps ME, Schelbert HR. Regional perfusion, glucose metabolism and wall motion in patients with chronic electrocardiographic Q wave infarctions: evidence for persistence of viable tissue in some infarct regions by positron emission tomography. Circulation 1986;73:951-63.
15. Tamaki N, Yonekura Y, Yamashita K, Senda M, Saj H, Hashimoto T, Fudo T, Kambara H, Kawai C, Ban T, Konishi J. Relation of left ventricular perfusion and wall motion with metabolic activity in persistent defects on thallium-201 tomography in healed myocardial infarction. Am J Cardiol 1988;62:202-8.
16. Fudo R, Kambara H, Hashimoto T, Hayashi M, Nohara R, Tamaki N, Yonekura Y, Senda M, Konishi J, Kawai C. F-18 deoxyglucose and stress N-13 ammonia positron emission tomography in anterior wall healed myocardial infarction. Am J Cardiol 1988;61:1191-1197.
17. Helfant RH, Pine R, Meister SG, Feldman MS, Trout RG, Banka VS. Nitroglycerin to unmask reversible asynergy: correlation with postcoronary bypass ventriculography. Circulation 1974;50:108-13.
18. Popio KA, Gorlin R, Bechtel D, Levine JA. Postextrasystolic potentiation as a predictor of potential myocardial viability: preoperative analysis compared with studies after coronary bypass surgery. Am J Cardiol 1977;39:944-53.
19. Horn HR, Teichholz LE, Cohn PF, Herman MV, Gorlin R. Augmentation of left ventricular contraction pattern in coronary artery disease by an inotropic catecholamine: the epinephrine ventriculogram. Circulation 1974;49:1063-71.
20. Rozanski A, Berman D, Gray R, Diamond G, Raymond M, Prause J, Maddahi J, Swan HJC, Matloff J. Preoperative prediction of reversible myocardial asynergy by postexercise radionuclide ventriculography. N Engl J Med 1982;307:212-6.
21. Jennings RB, Murry CE, Reimer KA. Myocardial effects of brief periods of ischemia followed by reperfusion. Adv Cardiol 1990;37:7-31.
22. Rahimtoola SH. A perspective on the three large multicenter randomized clinical trials of coronary bypass surgery for chronic stable angina. Circulation 1985;72:V-123-35.
23. Kennedy PL, Corbett JR, Kulkarni PV, Wolfe CL, Jansen DE, Hansen CL, Buja LM, Parkey RW, Willerson JT. Iodine 123-phenilpentadecanoic acid myocardial scintigraphy: usefulness in the identification of myocardial ischemia. Circulation 1986;74:1007-15.
24. Van der Wall EE, Heidendal GAK, den Hollander W, Westera G, Roos JP. Metabolic myocardial imaging with ^{123}I-labeled heptadecanoic acid in patients with angina pectoris. Eur J Nucl Med 1981;6:391-6.
25. Visser FC, Westera G, Eenige van MJ, van der Wall EE. Den Hollander W, Roos JP. The myocardial elimination rate of radioiodinated heptadecanoic acid. Eur J Nucl Med 1985;10:118-22.
26. Murray G, Schad N, Ladd W, Allie D, Vander Zwagg R, Avet P, Rockett J. Metabolic cardiac imaging in severe coronary disease: assessment of viability with Iodine-123-iodophenylpentadecanoid acid and multicrystal gamma camera, and correlation with biopsy. J Nucl Med 1992;33:1269-77.
27. Dijkman PRM, van der Wall EE, de Roos A, Doornbos J, van der Laarse A, Martheijssen NAA, van Rossum AC, van Voorthuisen AE, Bruschke AVG. Gadolinium-enhanced magnetic resonance imaging in acute myocardial infarction. Eur J Radiol 1990;11:1-9.
28. Saeed M, Wendland FM, Takehara Y, Higgins CB. Reversible and irreversible injury in the reperfused myocardium: differentiation with contrast material-enhanced MR imaging. Radiology 1990;175:633-7.
29. Johnston DL, Liu P, Lauffer RB, Newell JB, Wedeen VJ, Rosen BR, Brady TJ, Okada RD. Use of gadolinium-DTPA as a myocardial perfusion agent: potential applications and limitations for magnetic resonance imaging. J Nucl Med 1987;28:871-7.
30. Nishimura T, Kobayashi H, Ohara Y, Yamada N, Haze K, Takamiya M, Hiramori K. Serial assessment of myocardial infarction by using gated MR imaging and Gd-DTPA. AJR 1989;153:715-20.
31. Wolfe CL. Assessment of myocardial ischemia and infarction by contrast enhanced magnetic resonance imaging. Cardiol Clin 1989;7:685-96.
32. Miller DD, Holmvang G, Gill JB, Dragotakes D, Kantor HL, Okada RD, Brady T. MRI detection of myocardial perfusion changes by gadolinium-DTPA infusion during dipyridamole hyperemia. Magn Reson Med 1989;10:246-55.
33. Tscholakoff DT, Higgins CB, Sechtem U, McNamara MT. Occlusive and reperfused myocardial infarcts: effect of Gd-DTPA on ECG-gated MR imaging. Radiology 1986;160:515-9.