MYOCARDIAL POSITRON TOMOGRAPHY WITH N-13 AMMONIA IN ASSESSMENT OF AORTOCORONARY BYPASS SURGERY

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A total of 20 patients were examined at rest and during stress with N-13-ammonia myocardial positron emission tomography (PET) before and after aortocoronary bypass surgery in an attempt to evaluate the effect of surgery on myocardial perfusion and to predict the graft status. The PET images were divided into anterior, septal, apical, lateral and posteroinferior segments for analysis and were evaluated as "normal" (no perfusion defects during stress and at rest), "ischemia" (stress-induced defects) and "fibrosis" (persistent defects both at rest and during stress). Approximately 90% of the segments which were ischemic before surgery became normal after surgery. Thus, ischemic changes are highly reversible, and the vessels perfusing these ischemic areas are most suitable for bypass surgery. However, most of the persistent defects failed to respond to revascularization surgery and, hence, represented irreversibly damaged myocardium. In predicting graft status, graft patency could be demonstrated by normal perfusion in postoperative images ($p < 0.01$) or by improved perfusion when pre- and postoperative images were compared ($p < 0.01$). However, graft occlusion could not be predicted reliably.

This study demonstrated that PET with N-13 ammonia was useful in the assessment of the effects of aortocoronary bypass surgery. However, this technique was not significantly superior to thallium-201 single-photon emission computed tomography for only qualitative analysis.

THE recent development of positron emission tomography (PET) makes possible the assessment and measurement of regional myo-

cardial blood flow and, more interestingly, of regional myocardial metabolism.^{1,2} We have developed a high resolution whole body multi-slice PET scanner^{3,4} and used it in myocardial PET studies with N-13 ammonia to evaluate regional myocardial blood flow and with F-18-2-fluoro-2-deoxyglucose to evaluate regional myocardial glucose metabolism.⁵⁻⁷ It has been demonstrated that myocardial PET is a valuable technique for

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Fig.1. Schematic presentation of contiguous transverse sections and distribution of right coronary artery (RCA), left anterior descending artery (LAD) and left circumflex artery (LCX). Transverse sections are displayed as viewed from below, proceeding from cephalic to caudal planes.

detecting coronary artery disease. However, the value of this new method in assessing the effects of aortocoronary bypass grafting has not been adequately examined.

In this study, we used PET and N-13 ammonia to examine the myocardium before and after aortocoronary bypass surgery in an attempt to evaluate the effects of surgery on myocardial perfusion and to predict graft patency.

MATERIALS AND METHODS

Patients: Twenty patients who underwent aortocoronary bypass surgery were studied at rest and during exercise with N-13 ammonia myocardial PET before and at one to 2 months after surgery. Eighteen were men and two were women. Their ages ranged from 34 to 69 (mean 55 ± 10) years. A total of 54 grafts (1 to 4 grafts per patient) were used for coronary revascularization and their patency was confirmed by post-operative coronary angiography.

PET studies: PET scan was performed with a multi-slice whole body PET (Positologica III³), which provides 7 tomographic images at 16 mm intervals in a single scan. Our method has been described in detail elsewhere⁵⁻⁷. In brief, 3 min after the intravenous injection of 10 to 20 mCi of N-13 ammonia, contiguous transverse sectional images of the myocardium

were obtained for 5 min. Two hours after the initial study, the procedure was repeated during exercise on a supine bicycle ergometer with an initial work load of 25 watts, which was increased by 25 watts every 3 min. The N-13 ammonia was injected when the patient noted chest oppression, or leg fatigue, or there was more than 1 mm ST depression on the electrocardiogram, or the heart rate reached 80% of the predicted maximum. The exercise was continued 30 sec longer after the injection. The myocardial PET scan was performed 3 min after the injection as in the initial study.

Informed consent for PET studies was obtained from each patient.

Analysis of PET images: The PET images were divided into anterior, septal, apical, lateral and posteroinferior segments and evaluated by two independent observers: 1) normal – no perfusion defect during stress and at rest; 2) ischemia – stress-induced ischemia or less perfusion during stress than at rest; 3) fibrosis – perfusion defect the same during stress and at rest. When the observers disagreed, the images were reviewed and a consensus was obtained. The results of the interpretation of segmental PET images were correlated with the corresponding grafted arteries, as shown in Fig. 1. Grafts of the left anterior descending artery (LAD) would be expected to provide perfusion to the septal, anterior and, in

Fig.2. Changes in pre- and postoperative images of 84 segments. Graft patency was confirmed by coronary angiography.

Preoperative	Postoperative	Total No. of Segments	Patent	Occluded
<u>Improved</u>				
NORMAL	→ NORMAL	23	18 (78%)	5 (22%)
ISCHEMIA	→ NORMAL	31	31 (100%)	0 (0%)
FIBROSIS	→ ISCHEMIA	2	2 (100%)	0 (0%)
			51 (91%)	5 (9%)
<u>Worse</u>				
NORMAL	→ ISCHEMIA	5	2 (40%)	3 (60%)
ISCHEMIA	→ FIBROSIS	4	2 (50%)	2 (50%)
			4 (44%)	5 (56%)
<u>Unchanged</u>				
ISCHEMIA	→ ISCHEMIA	9	2 (22%)	7 (78%)
FIBROSIS	→ FIBROSIS	10	6 (60%)	4 (40%)
			8 (42%)	11 (58%)

Fig.3. Correlation of pre- and postoperative images with graft status.

most cases, apical segments, left circumflex artery (LCX) grafts would supply the lateral segments, and right coronary artery (RCA) grafts, the posteroinferior segments. In some cases, perfusion areas showed individual differences depending on variations of coronary anatomy.

RESULT

Effects of surgery on myocardial perfusion:
Changes in PET images after surgery are shown in Fig. 2. Sixty-three segments were supplied by 36 patent grafts. Normal perfusion before surgery

Fig.4. Comparison of PET and SPECT images. This 35-year-old male patient had a history of anterior myocardial infarction and both PET and SPECT images showed persistent defects in the anterior region preoperatively. After revascularization PET demonstrated slightly improved perfusion on postoperative images (large arrows), but SPECT did not. This improvement seemed reasonable because the wall motion of the corresponding area also improved. Furthermore, the right ventricle was visualized in PET images (small arrows).

was observed in 20 segments, 18 of which (90%) remained normal. Preoperative imaging in 35 segments showed perfusion defects indicating ischemia, 31 of these (89%) showed normal perfusion on the postoperative scan. Six of 8 fibrotic segments (75%) were unchanged by surgery. On the other hand, in 21 segments supplied by 18 occluded grafts perfusion was unchanged or worsened postoperatively.

PET images and graft status: The postoperative images showed that 49 of 54 segments (91%) with normal perfusion were supplied by patent grafts. However, 6 of 16 ischemic segments (38%) and 8 of 14 fibrotic segments (57%) were also associated with patent grafts

(Fig. 2). A comparison of pre-and postoperative images revealed that 51 of 56 segments (91%) with improved perfusion (including normal perfusion in both pre- and postoperative scans), 4 of 9 segments (44%) with decreased perfusion and 8 of 19 segments (42%) with unchanged abnormal perfusion were supplied by patent grafts (Fig. 3).

DISCUSSION

The most definitive way to assess the effect of coronary revascularization is by cardiac catheterization. The anatomical demonstration of coronary lesions by angiography alone does not

TABLE I COMPARISON OF PET AND SPECT AS PREDICTORS OF GRAFT STATUS

Indicator of graft patency		PET	SPECT*
1. Postop. Image only	Sensitivity	72%	72%
	Specificity	83%	70%
		NS	
2. Comparison of pre- & postop. Images	Sensitivity	75%	72%
	Specificity	86%	72%
		NS	

*: SPECT data were obtained from 49 patients who underwent aortocoronary bypass surgery in our hospital.

For diagnostic test, the following definitions (for indicator 1 or 2) and equations were used. True positive (TP): occluded graft with an abnormal image (1), or with a worse or unchanged abnormal image (2). True negative (TN): patent graft with a normal image (1), or with an improved or pre- and postoperative normal image (2). False positive (FP): patent graft with an abnormal image (1), or with a worse or unchanged abnormal image (2). False negative (FN): occluded graft with normal image (1), or with improved or pre- and postoperative normal image (2).

Sensitivity: $TP/(TP + FN)$. Specificity: $TN/(TN + FP)$.

necessarily predict their functional status. Scintigraphic techniques are noninvasive and seem more rational for determining the functional consequences of coronary bypass surgery.

Effects of surgery on myocardial perfusion: Preoperative PET imaging may be useful for predicting postoperative improvement in regional myocardial perfusion. In this study, approximately 90% of segments, ischemic before surgery, reverted to normal after surgery. Thus, ischemic changes are highly reversible, and the vessels perfusing these ischemic areas are most suitable for bypass surgery. However, most of the persistent defects failed to respond to revascularization surgery and, therefore, represented irreversibly damaged myocardium. On the other hand, electrocardiographic evidence of transmural infarction did not always indicate irreversible damage (Fig. 2). In spite of the presence of significant coronary lesions, many segments showed normal perfusion. Since scintigraphic defects depend on relative hypoperfusion of the myocardial segments, the absence of perfusion defects per se does not necessarily indicate perfectly

normal perfusion, but relatively greater perfusion than in an infarcted or severely damaged myocardium.⁸ Thus, even areas of normal perfusion should be revascularized if the coronary arteries supplying these areas are diseased.

Prediction of graft patency: A graft patency can be predicted with great accuracy in segments with normal perfusion in postoperative images ($p < 0.01$) or improvement when pre- and postoperative images are compared ($p < 0.01$). It is difficult, however, to predict graft status when areas of abnormal perfusion show no change. Five of eight segments supplied by occluded grafts showed normal perfusion postoperatively. The reasons for this finding are unclear. Blood flow to these segments may originate from collaterals, native vessels or patent grafts in other areas of the heart.⁹ Of 36 grafts found to be patent by angiography, 27 (75%) were correctly predicted to be patent from the PET images. The ability to predict patency was not significantly different among RCA, LAD and LCX grafts.

PET versus SPECT: Although thallium-201 is a widely available tracer for myocardial perfusion imaging, the image quality of thallium-201 single-photon emission computed tomography (SPECT) is not always satisfactory. PET has been demonstrated to have better spatial resolution and sensitivity than SPECT. In previous studies the sensitivity and specificity for detecting coronary artery disease by stress PET were 88% and 97%, respectively⁶ and by SPECT 83% and 85%, respectively.¹⁰ Therefore, PET is expected to provide a more accurate evaluation of myocardial perfusion. Indeed, the image quality of PET is considerably better, as shown in Fig. 4. In this case, the slightly improved perfusion correlated with improved wall motion in the anterior region could not be documented by SPECT, but was demonstrated by PET. In the prediction of graft status, however, the present study indicates that PET and SPECT have similar value (Table I), and PET with N-13 ammonia was not significantly superior to SPECT with thallium-201 for only qualitative purposes. In these studies, the relatively low sensitivity and specificity for predicting graft status were probably due to the frequent use of bypass grafting for fibrotic areas where myocardial perfusion rarely changed, regardless of whether the grafts were patent or occluded. It is considered that the great advantages of PET are its ability to assess quantitatively regional myocardial metabolism as well as blood flow; the

use of various physiological or biochemical short-lived positron-emitting tracers and the possibility of calculating transport and reaction rates based on tracer kinetic principles.¹¹ These studies may become the most important contributions of PET to the field of cardiology.

In conclusion, PET with N-13 ammonia was useful for the assessment of the effects of aorto-coronary bypass surgery, especially for pre-operative evaluation of myocardial viability and prediction of graft patency. However, this technique was not significantly superior to SPECT with thallium-201 for only qualitative analysis.

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