Global and regional myocardial metabolism before and after successful aortocoronary artery bypass surgery

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Disabling angina remains the major indication for direct myocardial revascularization by aortocoronary artery bypass surgery in patients with obstructive coronary artery disease. Symptomatic relief of angina following surgery occurs in a vast majority of patients. However, evaluation of the efficacy of any therapy for angina, medical or surgical, based on subjective improvement alone is not only difficult, but may also be deceptive. Angina threshold may be reliably determined by atrial pacing stress which has been employed for the objective assessment of the results of therapy of angina. In order to evaluate changes in angina threshold and global myocardial metabolism, atrial pacing stress was applied before and after surgery in a group of patients with obstructive coronary artery disease. Eighteen patients were studied in an identical fashion before and 2 weeks to 6 months after their successful aortocoronary bypass surgery. All 18 patients developed typical angina during preoperative atrial pacing stress. All patients were men and their ages ranged from 44 to 62 years. The duration of angina varied from 1 week to 14 months before surgery. Six patients had historical and electrocardiographic evidence of old myocardial infarction (three

anterior, two inferior, one combined anterior and inferior). Preoperative selective coronary arteriography demonstrated significant obstructive lesions involving left anterior descending coronary artery, left circumflex, and right coronary arteries in the remaining three patients. Six patients had triple, eight had double, two had quadruple, and two had single aorto-LAD saphenous vein grafts. No patient had isolated right coronary artery graft. Forty-three of the 44 grafts were patent at the time of restudy. The one aorto-right coronary artery graft that was not visualized and considered to be closed was in a patient who had triple bypasses and had patent aorto-left anterior descending and aorto-left circumflex grafts.

Thus, all patients in this study had one or more grafts patent at the time of restudy. For superventricular pacing, a preshaped special coronary sinus catheter equipped with thermistors and platinum electrodes was inserted into the coronary sinus. The same catheter was used for the measurement of coronary sinus blood flow by the continuous infusion thermodilution technique and also for withdrawal of blood samples from the coronary sinus. Following aorto-coronary bypass surgery, 16 of the 18 patients did not develop angina at the maximum pacing rate. One patient developed angina postoperatively at the rate similar to that before surgery. In the other patient, postoperative angina threshold was much higher. In the group as a whole, postoperative maximum pacing rate was much higher than the preoperative angina rate (*Table 1*). Rate pressure product at maximum pacing rate postoperatively was also higher than rate pressure product and angina rate preoperatively. Although in the group as a whole, coronary sinus

Table 1. Changes in regional and global metabolism following successful aortocoronary bypass surgery

	Preop resting	Postop resting	p	Preop MPR	Postop MPR	p
R % L	+7 ± 1.4	+39 ± 4.4	NS	−49 ± 26	+32 ± 8.5	0.05
G % L	+19 ± 4.8	+44 ± 5.5	0.05	−22 ± 12	+34 ± 7.9	0.05
AIV pO2 (mm Hg)	18 ± 1.7	21 ± 1.1	0.05	19 ± 1.7	22 ± 1.3	0.05
AIV O2 saturation (%)	30 ± 2.7	34 ± 3.0	NS	33 ± 3.0	35 ± 2.1	NS
CS pO2 (mm Hg)	19 ± 1.3	22 ± 1.7	0.05	19 ± 1.8	21 ± 0.78	NS
CS O2 saturation (%)	32 ± 1.8	36 ± 3.4	NS	33 ± 3.0	35 ± 1.4	NS
Hb (g%)	14.5 ± 0.41	11.7 ± 0.86	0.005	14.5 ± 0.41	11.7 ± 0.86	0.005
Art-AIV O2 content (ml%)	13.0 ± 0.28	9.8 ± 0.74	0.005	12.1 ± 0.31	10.1 ± 0.80	0.05
Art-CS O2 content (ml%)	12.7 ± 0.34	8.8 ± 0.67	0.001	12.1 ± 0.30	9.4 ± 0.87	0.05
CSBF (ml/min)	136 ± 24	114 ± 19	NS	261 ± 40	199 ± 27	0.01
Global O2 delivery (ml/min)	25.0 ± 4.4	16.2 ± 2.7	0.005	49.5 ± 8.1	28.8 ± 4.5	0.005
MVO2 (ml/min)	17.3 ± 2.7	10.4 ± 1.5	0.005	31.8 ± 4.7	19.2 ± 2.2	0.005

MPR = at maximum pacing rate, R % L = anterior wall lactate extract, NS = not significant, G % L = global lactate extraction, AIV = anterior interventricular vein, CS = coronary sinus, Hb = hemoglobin, Art = arterial, CSBF = coronary sinus blood flow, O_2D = oxygen delivery, MVO_2 = myocardial oxygen consumption.

blood flow was higher postoperatively both at rest and at maximum pacing rate compared to the resting and angina values preoperatively, there were several in whom coronary sinus blood flow remained unchanged or even slightly lower compared to the preoperative values. As arterial coronary sinus oxygen content difference, that is transmyocardial oxygen extraction, was significantly lower postoperatively, the myocardial oxygen consumption did not change postoperatively. Because of significantly higher rate pressure product postoperatively and unchanged myocardial oxygen consumption at maximum pacing rate, myocardial efficiency appeared to be improving following bypass surgery. Global lactate extraction in some patients markedly improved following surgery. In the majority of patients, there was an improved lactate extraction at maximum pacing rate postoperatively. However, global oxygen delivery, that is the product of coronary sinus blood flow and the arterial oxygen content, was similar to the preoperative values. Improved lactate extraction in the presence of unchanged global oxygen delivery suggests that relief of hypoxia was probably related to more uniform, even distribution of oxygen for the relatively ischemic and nonischemic myocardium following revascularization. To test this hypothesis, both the global and regional myocardial metabolism were studied in seven patients by selective cannulation of the coronary sinus and anterior interventricular vein. The anterior interventricular vein drains most of the left ventricular anterior wall and the coronary sinus drains almost all of the left ventricular muscle mass. All seven patients had severe obstructive lesions of the major coronary arteries, including left anterior descending.

Postoperative studies were performed 2 weeks to 6 months following successful aortocoronary artery bypass surgery. All grafts, including the aorto-left anterior descending artery grafts, were patent. Preoperatively, in three of the seven patients, anterior wall lactate extraction was negative at rest. The average anterior wall lactate extraction at rest was normal, but was negative at a maximum ventricular pacing rate of 137 beats per minute (*Table 2*). Postoperatively, not only was resting anterior wall lactate extraction normal, but it remained normal during atrial pacing, even though a postoperative maximum pacing rate was much higher. Anterior wall (i.e., regional myocardial oxygen extraction) was less postoperatively and PO_2 and anterior interventricular venous blood and directly determined oxygen saturation both at rest and the maximum pacing rate tended to be higher postoperatively. In five of the seven patients in whom the preoperative and postoperative left ventricular angiograms could be compared, systolic wall motion of the left ventricular anterior wall improved markedly postoperatively. The average global myocardial lactate extraction preoperatively was normal at rest, but was negative at maximum pacing rate. Postoperatively, however, global lactate extraction both at rest and at maximum pacing rate was normal. Coronary sinus due to oxygen saturation was also higher postoperatively compared to the preoperative values. Overall left ventricular performance indicated by increase in ejection frac-

Table 2. Postoperative changes in global myocardial metabolism

Parameters	Preop resting	Postop resting	p<	Preop angina	Postop MPR	p<
Heart rate (beats/min)	69.4 ± 3.4	89.2 ± 2.9	0.01	124.9 ± 4.9	159 ± 3.5	0.01
PSP × HR × 10^3 (mm Hg/min)	10.2 ± 0.63	11.7 ± 0.38	0.01	18.8 ± 0.92	21.5 ± 0.89	0.01
CS pO_2 (mm Hg)	19.9 ± 0.69	22.1 ± 1.4	0.05	19.0 ± 0.96	22.7 ± 1.7	0.05
CSO_2 saturation (vol %)	31.2 ± 1.3	33.0 ± 1.8	NS	30.4 ± 1.8	33.4 ± 0.99	0.05
Art.-CSO_2 content (ml/100 ml)	12.7 ± 0.40	8.9 ± 0.37	0.01	12.4 ± 0.38	9.1 ± 0.44	0.01
Global O_2 delivery (ml/min)	20.4 ± 2.0	20.5 ± 2.4	NS	37.5 ± 4.0	36.3 ± 3.8	NS
MVO_2 (ml/min)	13.7 ± 1.3	13.9 ± 1.6	NS	23.4 ± 2.4	23.5 ± 2.4	NS
Lactate extraction (%)	24.3 ± 3.4	28.0 ± 3.7	NS	−3.6 ± 7.1	17.4 ± 5.2	0.05
Hb (g%)	14.5 ± 0.32	11.1 ± 0.48				0.01

MPR = postoperative maximum pacing rate, PSP = peak systolic pressure, HR = heart rate, CS = coronary sinus, NS = not significant, Art. = arterial, MVO_2 = myocardial oxygen consumption, Hb = hemoglobin.

tion also improved postoperatively.

This improvement was not associated with increased coronary sinus flow. Postoperative coronary sinus flow, both at rest and at maximum pacing rate, was relatively less than the preoperative values. There was also no increase in global oxygen delivery and oxygen consumption despite higher heart rate and pressure product achieved during postoperative pacing stress. Despite lack of increasing oxygen delivery, regional as well as global lactate extraction improved markedly in all patients, including relief of hypoxia. These findings strongly suggest that improved regional and global metabolism that occur in at least some patients after successful aortocoronary bypass surgery is most likely due to redistribution of blood flow to the ischemic and nonischemic myocardium.