Insulin Resistance and Maximal Oxygen Uptake

MARIE SEIBÆK, M.D., PH.D., HENRIK VESTERGAARD, M.D., D.M.SCI.,* HANS BURCHARDT, M.D., PH.D., CARSTEN SLOTH, M.D., CHRISTIAN TORP-PEDERSEN, M.D., D.M.SCI.,† STEEN LEVIN NIELSEN, M.D., D.M.SCI.,‡ PER HILDEBRANDT, M.D., D.M.SCI.,§ OLUF PEDERSEN, M.D., D.M.SCI.*

Gentofte University Hospital, *Steno Diabetes Centre, †H:S Bispebjerg University Hospital, ‡Herlev University Hospital, §Frederiksberg University Hospital, Copenhagen, Denmark

Summary

Background: Type 2 diabetes, coronary atherosclerosis, and physical fitness all correlate with insulin resistance, but the relative importance of each component is unknown.

Hypothesis: This study was undertaken to determine the relationship between insulin resistance, maximal oxygen uptake, and the presence of either diabetes or ischemic heart disease.

Methods: The study population comprised 33 patients with and without diabetes and ischemic heart disease. Insulin resistance was measured by a hyperinsulinemic euglycemic clamp; maximal oxygen uptake was measured during a bicycle exercise test.

Results: There was a strong correlation between maximal oxygen uptake and insulin-stimulated glucose uptake ($r = 0.7$, $p = 0.001$), and maximal oxygen uptake was the only factor of importance for determining insulin sensitivity in a model, which also included the presence of diabetes and ischemic heart disease.

Conclusion: Maximal oxygen uptake may be a more important determinant for insulin sensitivity than ischemic heart disease and type 2 diabetes.

Key words: insulin resistance, maximal oxygen uptake

Introduction

Insulin resistance is defined as reduced insulin-stimulated, whole-body glucose uptake. Insulin resistance is a key feature of type 2 diabetes, but has also been described in patients with obesity, lipid disorders, hypertension, and impaired glucose tolerance, all conditions that are associated with an increased prevalence of ischemic heart disease. Based on this clustering of abnormalities, Reaven¹ suggested in the late 1980s the hypothesis of insulin resistance as the common denominator of conditions leading to ischemic heart disease. This hypothesis has generated an intense search for a fundamental understanding of insulin resistance.¹ In studies of athletes and in patients with type 2 diabetes and their first-degree relatives, a close relationship has been demonstrated between maximal oxygen uptake and whole-body, insulin-stimulated glucose uptake.^{2,3} It is also well known that insulin sensitivity is improved by physical training.⁴ Ischemic heart disease and diabetes are frequently found in the same patient, and in this situation the importance of diabetes, atherosclerosis, and physical fitness for insulin resistance is unknown.

In the light of this background it is important to know whether physical capability in general is the major determinant of insulin resistance or whether patients with ischemic heart disease have other key features that correlate with insulin resistance. Therefore, we studied four groups of patients, with and without type 2 diabetes and with and without ischemic heart disease. In each of these four groups we studied insulin-stimulated, whole-body glucose uptake, maximal oxygen uptake, and demographic features in order to describe the contribution of ischemic heart disease, physical fitness, and diabetes to insulin resistance.

Methods

The study population was prospectively defined to include four equally sized groups of subjects.

Group 1 ($n = 8$) were patients with type 2 diabetes, treated with diet or oral hypoglycemic agents, and an enzyme-confirmed acute myocardial infarction within the preceding year.

Dr. Vestergaard is presently affiliated with Herlev University Hospital.

The study was supported by grants from The Danish Heart Association and The Danish Diabetes Association.

Address for reprints:
Marie Seibæk, M.D., Ph.D.
Gyrstingevej 13
2700 Brønshøj, Denmark
e-mail ms@heart.dk

Received: June 20, 2002

Accepted with revision: November 19, 2002

Group 2 ($n = 8$) were patients with type 2 diabetes, treated with diet or oral hypoglycemic agents. They had no history of coronary artery disease (CAD), no other atherosclerotic disease, and a normal electrocardiogram (ECG) at rest, a normal exercise test, and a normal myocardial scintigram.

Group 3 ($n = 8$) were patients without a history of diabetes, with a normal glucose tolerance test, and with an enzyme-confirmed acute myocardial infarction within the preceding year.

Group 4 ($n = 9$) were persons without a history of diabetes and a normal glucose tolerance test. They had no history of CAD, a normal ECG at rest, a normal exercise test, and a normal myocardial scintigram.

Patients with prior myocardial infarction (Groups 1 and 3) were recruited from the Department of Cardiology, Gentofte University Hospital. Study subjects without CAD (Groups 2 and 4) were recruited from Steno Diabetes Centre.

All study participants were Danish Caucasians as indicated by themselves.

Euglycemic Hyperinsulinemic Clamp

All participants underwent an euglycemic hyperinsulinemic clamp after a 10-h overnight fast. Each clamp lasted for 6 h: a 2-h basal period followed by a 4-h hyperinsulinemic euglycemic clamp period.⁵ Throughout the study period 3-[3H] glucose was infused intravenously. In subjects without diabetes, 3-[3H] glucose was administered as a primed (25 μCi) continuous (0.25 $\mu\text{Ci}/\text{min}$) infusion, whereas in patients with type 2 diabetes the priming dose was increased in proportion to the fasting plasma glucose concentration. The continuous infusion of labeled glucose was the same as in the subjects without diabetes (0.25 $\mu\text{Ci}/\text{min}$). The clamp was performed by continuous infusion of 2 mU insulin/kg/min (Actrapid, Novo Nordisk, Denmark), and euglycemia was maintained by a variable infusion of 20% glucose at a rate determined by the measurement of plasma glucose levels at 5–10 min intervals.

Calculations

Total glucose disposal rate (Rd) was calculated from the plasma concentrations of tritiated glucose using Steeles non-steady state equation.⁶ Nonsteady state equations were used because plasma glucose concentrations declined in most patients with type 2 diabetes during the basal period. Glucose infusion rates were used to calculate total glucose disposal rates during the insulin-stimulated steady state.

Glucose concentration in plasma was determined using a hexokinase method. Serum-specific insulin and C-peptide were measured using ELISA and RIA, respectively.^{7,8}

Peak Oxygen Uptake

Peak oxygen uptake was measured in all participants during a bicycle exercise test using an ergometric bicycle (Ergomed 740, Siemens) and continuous ECG monitoring (Marquette Electronic, Milwaukee, Wisc., USA). The load of the exercise test was initially 25 W and was increased every 30 s by 10 W.

The subjects breathed through a nonrebreathable valve. The volume and the temperature of the expired air were registered in the computer, and a polarographic method and an infrared sensor measured the amount of oxygen and carbon dioxide, respectively. The test continued until exhaustion or severe angina. At the end of the test, peak oxygen uptake was calculated and registered with peak working load and heart rate.

Oral Glucose Tolerance Test (OGTT)

A 2-h 75 g OGTT was performed in all participants without a history of diabetes after a 12-h overnight fast (Groups 3 and 4). Plasma glucose was measured at 0, 1, and 2 h. Only subjects with a normal oral glucose tolerance test (WHO criteria, 1985)⁹ were enrolled in the study.

Scintigram

All participants without a history of CAD (Groups 2 and 4) underwent a myocardial scan with 700 MBq 99mTc.-MIBI (metoxyisobutylisonitrit, cardiolite). The 99mTc.-MIBI was infused just before the end of a bicycle stress test. After 30 min of rest the scan was performed (Siemens ZLCamera, Siemens Medical, Munich, Germany). Only subjects with a normal myocardial scan were enrolled in the study.

Coronary Angiography

Patients with CAD and a prior myocardial infarction underwent coronary angiography (Groups 1 and 3). Left ventricular ejection fraction was calculated from a single view (right anterior oblique, 35°) with the area-length method. Coronary angiograms were evaluated by an experienced radiologist blinded to the patient's glucose tolerance status.

The study protocol, which was in accordance with the Helsinki declaration II, was approved by the local ethical committee, and written informed consent was obtained from all study participants.

Statistical Methods

Differences between continuous variables between the four study groups were analyzed by analysis of variance (ANOVA) and differences between discrete variables by chi-square test. Correlation was studied using Pearson's correlation coefficient. The multivariate relation between various parameters and glucose disposal rate was studied with a multiple linear regression model. As for the assumptions of this model, the glucose disposal rate was found to be normally distributed; there was no significant interaction between independent variables, and plots of residuals demonstrated constant variability.

Results

Descriptive characteristics and risk factors for the development of CAD and insulin resistance in all 33 study partici-

TABLE I Descriptive data and risk factors for development of coronary artery disease (CAD) in the four groups

Group 1: Patients with Type 2 diabetes and CAD

Group 2: Patients with Type 2 diabetes without CAD

Group 3: Patients with normal glucose tolerance and CAD

Group 4: Patients with normal glucose tolerance without CAD

	Group 1 n = 8	Group 2 n = 8	Group 3 n = 8	Group 4 n = 9
Age (years)	54 ± 2.6	54 ± 1.9	53 ± 2.2	52 ± 1.7
Female/male, n	0/8	1/7	1/7	2/7
BMI, kg/m ²	26.1 ± 1.2	26.1 ± 1.0	26.3 ± 1.0	26.1 ± 0.7
Fasting blood glucose, mmol/l	8.2 ± 0.9	10.7 ± 1.3	5.0 ± 0.1	5.2 ± 0.2 ^a
HbA1c, %	6.8 ± 0.6	8.8 ± 1.0	5.3 ± 0.2	5.2 ± 0.1 ^a
Microalbuminuria, % (n) ^b	29 (2)	43 (3)	29 (2)	11 (1)
Fasting plasma cholesterol, mmol/l	6.1 ± 0.3	6.3 ± 0.5	5.8 ± 0.4	5.6 ± 0.2
Fasting plasma HDL-cholesterol, mmol/l	0.9 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.3 ± 0.1
Fasting plasma LDL-cholesterol, mmol/l	4.0 ± 0.4	3.6 ± 0.3	4.0 ± 0.3	3.7 ± 0.2
Fasting plasma triglyceride, mmol/l	3.2 ± 0.7	2.8 ± 0.5	1.2 ± 0.2	1.2 ± 0.2 ^a
Smoker, % (n)	50 (4)	75 (6)	63 (5)	56 (5)
Systolic blood pressure, mmHg	124 ± 5.1	151 ± 6.7	127 ± 9.1	120 ± 4.2 ^a
Diastolic blood pressure, mmHg	78 ± 3.5	89 ± 2.8	75 ± 5.4	78 ± 3.1
Ejection fraction ^c	48 ± 3 %	Normal	63 ± 4 %	Normal

Values are mean (± SEM) for continuous variables and percentage (n) for categorical variables.

^a P values: $p \leq 0.05$, in comparison of the four groups by analysis of variance.

^b Microalbuminuria was defined as 30–300 mg albumin/24 h in at least two consecutive bacteria-negative 24 h urine samples.

^c Estimated from ventriculography during cardiac catheterization in Groups 1 and 3 and by echocardiography in Groups 2 and 4.

Abbreviations: CAD = coronary artery disease, HDL = high-density lipoprotein, LDL = low-density lipoprotein, SEM = standard error of the mean.

pants, divided into the four groups, are shown in Table I. The four groups were well matched for age and body mass index (BMI). As expected, patients with type 2 diabetes had higher values of fasting blood glucose and HbA1C than patients with normal glucose tolerance ($p = 0.0001$). In ANOVA, fasting levels of lipids in plasma did not differ significantly among groups except for higher levels of plasma triglyceride in patients with type 2 diabetes ($p = 0.0001$). In the subgroup of patients with type 2 diabetes with no evidence of CAD (Group 2), systolic blood pressure was significantly higher than in the other groups.

Table II shows medications administered to the four study groups. Diabetic patients without ischemic heart disease (Group 2) were more often treated with oral hypoglycemic agents than the diabetic patients with verified CAD (Group 1).

The difference in medication reflects the fact that patients in Group 2 had a longer duration of known diabetes than patients in Group 1 (7.7 vs. 2.7 years).

Data concerning the hyperinsulinemic-euglycemic clamp study are shown in Table III and Figure 1. In the basal period, patients with type 2 diabetes (Groups 1 and 2) had higher levels of plasma glucose, serum insulin, and serum C-peptide than the normal glucose-tolerant subjects ($p < 0.05$). During the insulin clamp, plasma glucose, serum insulin, and serum C-peptide were identical in all four groups. During the clamp period, ANOVA showed a significantly different insulin-stimulated glucose disposal rate among groups. The glucose disposal rate was reduced for patients with type 2 diabetes (Groups 1 and 2) compared with normal glucose-tolerant subjects (Groups 3 and 4) ($p = 0.01$), but there was no significant

TABLE II Medical treatment in the four groups (for group description see Table I)

	Group 1 n = 8	Group 2 n = 8	Group 3 n = 8	Group 4 n = 9
ACE inhibitor, n	3	1	1	1
Thiazide, n	0	2	1	0
Beta blocker, n	3	1	2	0
Calcium antagonist, n	3	1	6	1
Nitrate, n	2	0	3	0
Oral hypoglycemic agents, n	1	6	0	0

TABLE III Data from the hyperinsulinemic-euglycemic clamp study; steady state in the basal period and in the insulin-stimulated period in relation to group (for group descriptions see Table I)

	Group 1 n = 8	Group 2 n = 8	Group 3 n = 8	Group 4 n = 9
Basal period				
Plasma glucose, mmol/l	8.3 ± 0.9	11.2 ± 1.5	5.4 ± 0.2	5.4 ± 0.2 ^a
Serum insulin, pmol/l	61 ± 9.2	39 ± 5.9	28 ± 5.9	34 ± 6.3 ^a
Serum C-peptide, pmol/l	834 ± 138	751 ± 135	420 ± 54	533 ± 74 ^a
Hepatic glucose production, mg/min/m ²	101 ± 7	82 ± 4	93 ± 3	75 ± 3 ^a
Total glucose disposal rate, mg/min/m ²	102 ± 7	89 ± 6	89 ± 4	75 ± 3 ^a
Hyperinsulinemic period				
Plasma glucose, mmol/l	5.4 ± 0.2	5.3 ± 0.1	5.4 ± 0.2	5.3 ± 0.1
Serum insulin, pmol/l	806 ± 62	894 ± 72	761 ± 61	919 ± 68
Serum C-peptide, pmol/l	408 ± 109	275 ± 46	422 ± 128	362 ± 44
Total glucose disposal rate, mg/min/m ²	286 ± 36	332 ± 28	381 ± 30	425 ± 40 ^a

Values are mean ± standard error of the mean.

^a P values, analysis of variance = < 0.05.

difference between type 2 diabetic patients with and without CAD (Groups 1 and 2). Similarly, there was no significant difference between glucose-tolerant patients with and without previous acute myocardial infarction (Groups 3 and 4).

Analysis of correlation between insulin-stimulated glucose disposal and peak oxygen uptake is shown in Figure 2. Peak oxygen uptake during a bicycle exercise test correlated closely with the insulin-stimulated glucose disposal rate ($r = 0.7$, $p < 0.001$). Further analyses were performed in patients with and without diabetes and with and without ischemic heart disease: in patients with diabetes ($n = 16$), $r = 0.49$, $p = 0.05$, and in patients without diabetes ($n = 17$), $r = 0.73$, $p < 0.001$; in patients with ischemic heart disease ($n = 16$), $r = 0.48$, $p = 0.06$, and in patients without ischemic heart disease ($n = 17$), $r = 0.86$, $p < 0.001$.

FIG. 1 Insulin-stimulated glucose disposal rate in patient groups. Columns are mean, error bars standard error of the mean. DM = type 2 diabetes, AMI = acute myocardial infarction.

Analyses of correlation between insulin-stimulated glucose disposal and indices for degree and dissemination of CAD and left ventricular ejection fraction all came out with insignificant p values and small r values.

To study the potential influence of several parameters on insulin-stimulated glucose disposal, we developed three linear regression models shown in Table IV. In a model including all variables of potential significance, peak oxygen uptake was the only variable of independent statistical significance for insulin-stimulated glucose disposal ($p = 0.0002$) (Model A). The presence of diabetes and ischemic heart disease was maintained in the model but all other variables were gradually eliminated in a reduction to Model B. During this process, peak oxygen uptake was the only variable of statistical significance ($p = 0.0002$). In a further reduction, only the four study groups and peak oxygen uptake were maintained (Model C), and this model confirms the decisive influence of peak oxygen uptake on insulin-stimulated glucose disposal rate.

FIG. 2 Insulin-stimulated glucose disposal rate versus peak oxygen uptake during an exercise test.

TABLE IV Analyses of multiple linear regression of the influence of different variables on insulin-stimulated glucose disposal rate. Three models (A, B, C), see text

Model A	p Values
Peak oxygen uptake, ml/min/kg	0.0002
Ischemic heart disease	0.08
Type 2 diabetes	0.12
Age, years	0.11
BMI, kg/m ²	0.85
Waist-hip ratio	0.62
Plasma creatinine, µmol/l	0.23
Fasting plasma cholesterol, mmol/l	0.93
Fasting plasma HDL-cholesterol, mmol/l	0.69
Fasting plasma triglycerides, mmol/l	0.11
HbA1C, %	0.43
Microalbuminuria	0.73
Systolic blood pressure, mmHg	0.62
Diastolic blood pressure, mmHg	0.49
Model B	
Peak oxygen uptake, ml/min/kg	0.0002
Ischemic heart disease	0.36
Type 2 diabetes	0.46
Model C	
Peak oxygen uptake, ml/min/kg	0.0001
The four study groups (1–4)	0.43

Abbreviations: BMI = body mass index, HDL = high-density lipoprotein.

Discussion

This study showed that peak oxygen uptake during a bicycle exercise test is the most important variable for predicting insulin-stimulated glucose disposal rate in a population of subjects with and without type 2 diabetes and ischemic heart disease. This finding may indicate a basic relationship between insulin sensitivity and physical fitness, as the result was consistent when the population was dichotomized according to the presence of either diabetes or ischemic heart disease.

The surprising finding in this study is that peak oxygen uptake in a multivariate model leaves the presence of diabetes and ischemic heart disease without influence on insulin resistance. A larger study might have shown these factors to have influence, but the importance of peak oxygen uptake was clearly much greater than the presence of diabetes and ischemic heart disease. A number of studies have demonstrated that physical exercise is an important determinant for insulin resistance and that the development of type 2 diabetes can be deferred or even prevented by exercise in persons with impaired glucose tolerance.^{4, 10} Other studies have demonstrated that there is a relationship between insulin resistance and ischemic heart disease^{11, 12} and between insulin resistance and risk factors for ischemic heart disease.^{13–15} Such relationships include many of the variables that were analyzed in this study. However, the present study, to our knowledge, is the

first which attempts to study the importance of physical fitness in relation to other factors in a comprehensive manner.

From a clinical perspective, this study may offer part of the explanation as to why physical exercise protects patients with manifest atherosclerosis against future events. Several studies have demonstrated that regular exercise protects against atherosclerotic morbidity.¹⁶ If Reaven's hypothesis¹ of insulin resistance as a key pathophysiologic factor is correct, the most important effect of exercise may be improved insulin sensitivity. While such a line of thinking may be attractive, exercise has many physiologic effects and several of these have been associated with reduced atherosclerotic morbidity—examples are weight loss and improved endothelial function.¹⁷

In diabetes and in states of normal glucose tolerance, physical exercise increases skeletal muscle glucose uptake and induces activation of glycogen synthase, resulting in glycogen formation.¹⁸ In studies of patients with congestive heart failure, exercise improves endothelial nitric oxide (NO) formation and agonist-mediated, endothelium-dependent vasodilatation of the skeletal muscle vasculature.¹⁹ This endothelium-dependent change in peripheral blood flow was found to correlate closely with peak oxygen uptake. Insulin is an NO-dependent vasodilator, and some studies have shown that insulin resistance is associated with attenuated vasodilatation in response to insulin and other endothelium-dependent vasodilators, whereas endothelium-independent vasodilatation was most often unaffected.²⁰ In some but not all studies, a close relationship between the function of the endothelium and the glucose disposal rate has been found, leading to the hypothesis that insulin resistance and endothelial dysfunction are part of the same story.²¹ These data may suggest that alterations in endothelial function is the explanation for the findings in the current study, and it would appear relevant to study changes in endothelial function and insulin resistance in selected groups of patients with diabetes and ischemic heart disease.

Conclusion

This study suggests that physical fitness may be a more important determinant for insulin resistance than even the presence of ischemic heart disease and type 2 diabetes. Improved insulin sensitivity may in part explain the beneficial effect of exercise.

References

1. Reaven GM: Banting lecture 1988. Role of insulin resistance in human disease. *Diabetes* 1988;37:1595–1607
2. Nyholm B, Mengel A, Nielsen S, Skjaerbaek C, Møller N, Alberti KG, Schmitz O: Insulin resistance in relatives of NIDDM patients: The role of physical fitness and muscle metabolism. *Diabetologia* 1996;39(7):813–822
3. Dela F, Mikines KJ, von Linstow M, Secher NH, Galbo H: Effect of training on insulin-mediated glucose uptake in human muscle. *Am J Physiol* 1992; 263(6 Pt 1):E1134–1143
4. Helmrigh SP, Ragland DR, Leung RW, Paffenbarger RS: Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *N Engl J Med* 1991;325(3):147–152

5. DeFronzo RA, Tobin JD, Andres R: Glucose clamp technique: A method for quantifying insulin secretion and resistance. *Am J Physiol* 1979;6(3): E214–E223
6. Steele R: Influences of glucose loading and of injected insulin on hepatic glucose output. *NY Acad Sci* 1959;82(1):420–430
7. Andersen L, Dinesen B, Jørgensen PN, Poulsen F, Røder ME: Enzyme immunoassay for intact human insulin in serum or plasma. *Clin Chem* 1993; 39(4):578–582
8. Heding LG: Radioimmunological determination of human C-peptide in serum. *Diabetologia* 1975(11):541–548
9. WHO technical report series. In WHO, 1985
10. Pan XR, Li GW, Hu YH, Wang JX, Yang WY, An ZX, Hu ZX, Lin J, Xiao JZ, Cao HB, Liu PA, Jiang XG, Jiang YY, Wang JP, Zheng H, Zhang H, Bennett PH, Howard BV: Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance. The Da Qing IGT and Diabetes Study. *Diabetes Care* 1997;20(4):537–544
11. Bressler P, Bailey SR, Matsuda M, DeFronzo RA: Insulin resistance and coronary artery disease. *Diabetologia* 1996;39:1345–1350
12. Inchiostro S, Bertoli G, Zanette G, Donadon V: Evidence of higher insulin resistance in NIDDM patients with ischaemic heart disease. *Diabetologia* 1994;37(6):597–603
13. Haffner SM, Stern MP, Hazuda HP, Mitchell BD, Patterson JK: Cardiovascular risk factors in confirmed prediabetic individuals. Does the clock for coronary heart disease start ticking before the onset of clinical diabetes? *J Am Med Assoc* 1990;263(21):2893–2898
14. Zavaroni I, Bonora E, Pagliara M, Dall'Aglio E, Luchetti L, Buonanno G, Bonati PA, Bergonzani M, Gnudi L, Passeri M, Reaven G: Risk factors for coronary artery disease in healthy persons with hyperinsulinemia and normal glucose tolerance. *N Engl J Med* 1989;320:702–706
15. Siegel RD, Cupples A, Schaefer EJ, Wilson PW: Lipoproteins, apolipoproteins, and low-density lipoprotein size among diabetics in the Framingham offspring study. *Metabolism* 1996;45(10):1267–1272
16. Blair SN, Kohl HW III, Barlow CE, Paffenbarger RS Jr, Gibbons LW, Macera CA: Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. *J Am Med Assoc* 1995;273(14): 1093–1098
17. Lavrencic A, Salobir BG, Keber I: Physical training improves flow-mediated dilation in patients with the polymetabolic syndrome. *Arterioscler Thromb Vasc Biol* 2000;20(2):551–555
18. Goodyear LJ, Hirshman MF, King PA, Horton ED, Thompson CM, Horton ES: Skeletal muscle plasma membrane glucose transport and glucose transporters after exercise. *J Appl Physiol* 1990;68(1):193–198
19. Hambrecht R, Fiehn E, Weigl C, Gielen S, Hamann C, Kaiser R, Yu J, Adams V, Niebauer J, Schuler G: Regular physical exercise corrects endothelial dysfunction and improves exercise capacity in patients with chronic heart failure. *Circulation* 1998;98(24):2709–2715
20. Laakso M, Edelman SV, Brechtel G, Baron AD: Impaired insulin-mediated skeletal muscle blood flow in patients with NIDDM. *Diabetes* 1992;41(9): 1076–1083
21. Baron AD: Vascular reactivity. *Am J Cardiol* 1999;84(1A):25J–27J

Clin. Cardiol. 26, 520 (2003)

Images in Cardiology: Cardiac Rupture and Tamponade as Captured on Ventriculography

SEAN HANEY, M.D., DAVID WALLIS, M.D., DANIEL WOHLGELERNTER, M.D.*

Department of Family Medicine, UCLA-Santa Monica; *Cardiology Consultants of Santa Monica, Santa Monica, California, USA

A 77-year old woman presented to the emergency room with a 5-h history of acute chest pain, radiating to her back and arms and associated with nausea and diaphoresis. Electrocardiogram demonstrated acute transmural inferior wall myocardial infarction. Coronary angiography revealed a total occlusion of the dominant right coronary artery. Angioplasty successfully restored normal flow. However, the patient was severely hypotensive, requiring continuous intravenous dopamine. Left ventriculography revealed a large rupture in the posterior wall with extravasation of significant amounts of dye into the pericardial space. Right heart catheterization indicated cardiac tamponade with equalization of diastolic pressures in all four chambers.

Reference

Hochman J, Gersh B: *Textbook of Cardiovascular Medicine* (Ed. Topol E), pp. 421–449. Philadelphia: Lippincott Williams & Wilkins, 2002

FIG. 1 Ventriculography revealing dye extravasation into the patient's pericardial sac indicating rupture of the posterior left ventricular wall.