

The NEW ENGLAND JOURNAL of MEDICINE

ESTABLISHED IN 1812

APRIL 24, 2008

VOL. 358 NO. 17

Stents versus Coronary-Artery Bypass Grafting for Left Main Coronary Artery Disease

Ki Bae Seung, M.D., Duk-Woo Park, M.D., Young-Hak Kim, M.D., Seung-Whan Lee, M.D., Cheol Whan Lee, M.D., Myeong-Ki Hong, M.D., Seong-Wook Park, M.D., Sung-Cheol Yun, Ph.D., Hyeon-Cheol Gwon, M.D., Myung-Ho Jeong, M.D., Yangsoo Jang, M.D., Hyo-Soo Kim, M.D., Pum Joon Kim, M.D., In-Whan Seong, M.D., Hun Sik Park, M.D., Taehoon Ahn, M.D., In-Ho Chae, M.D., Seung-Jea Tahk, M.D., Wook-Sung Chung, M.D., and Seung-Jung Park, M.D.

ABSTRACT

BACKGROUND

Several studies have compared the treatment effects of coronary stenting and coronary-artery bypass grafting (CABG). However, there are limited data regarding the long-term outcomes of these two interventions for patients with unprotected left main coronary artery disease.

METHODS

We evaluated 1102 patients with unprotected left main coronary artery disease who underwent stent implantation and 1138 patients who underwent CABG in Korea between January 2000 and June 2006. We compared adverse outcomes (death; a composite outcome of death, Q-wave myocardial infarction, or stroke; and target-vessel revascularization) with the use of propensity-score matching in the overall cohort and in separate subgroups according to type of stent.

RESULTS

In the overall matched cohort, there was no significant difference between the stenting and CABG groups in the risk of death (hazard ratio for the stenting group, 1.18; 95% confidence interval [CI], 0.77 to 1.80) or the risk of the composite outcome (hazard ratio for the stenting group, 1.10; 95% CI, 0.75 to 1.62). The rates of target-vessel revascularization were significantly higher in the group that received stents than in the group that underwent CABG (hazard ratio, 4.76; 95% CI, 2.80 to 8.11). Comparisons of the group that received bare-metal stents with the group that underwent CABG and of the group that received drug-eluting stents with the group that underwent CABG produced similar results, although there was a trend toward higher rates of death and the composite end point in the group that received drug-eluting stents.

CONCLUSIONS

In a cohort of patients with unprotected left main coronary artery disease, we found no significant difference in rates of death or of the composite end point of death, Q-wave myocardial infarction, or stroke between patients receiving stents and those undergoing CABG. However, stenting, even with drug-eluting stents, was associated with higher rates of target-vessel revascularization than was CABG.

From the Catholic University of Korea, St. Mary's Hospital, Gangnam (K.B.S., P.J.K.) and Yeoido (W.-S.C.), Seoul; the Department of Cardiology (D.-W.P., Y.-H.K., S.-W.L., C.W.L., M.-K.H., S.-W.P., S.-J.P.) and Division of Biostatistics (S.-C.Y.), Center for Medical Research and Information, University of Ulsan College of Medicine, Asan Medical Center, Seoul; Samsung Medical Center, Seoul (H.-C.G.); Chonnam National University Hospital, Gwangju (M.-H.J.); Yonsei University Severance Hospital, Seoul (Y.J.); Seoul National University Hospital, Seoul (H.-S.K.) and Bundang (I.-H.C.); Chungnam National University Hospital, Daejeon (I.-W.S.); Kyung Pook National University Hospital, Daegu (H.-S.P.); Gachon University Gil Medical Center, Incheon (T.A.); and Ajou University Medical Center, Suwon (S.-J.T.) — all in Korea. Address reprint requests to Dr. Seung-Jung Park at the Department of Cardiology, University of Ulsan College of Medicine, Cardiac Center, Asan Medical Center, 388-1 Poongnap-dong, Songpa-gu, Seoul, 138-736, Korea, or at sjpark@amc.seoul.kr.

Drs. K.B. Seung and D.-W. Park contributed equally to this article.

This article (10.1056/NEJMoa0801441) was published at www.nejm.org on March 31, 2008.

N Engl J Med 2008;358:1781-92.
Copyright © 2008 Massachusetts Medical Society.

SIGNIFICANT NARROWING OF THE LEFT main coronary artery puts a patient at high risk, since it can jeopardize the entire myocardium of the left ventricle, and it has the worst prognosis of any form of coronary artery disease.¹ On the basis of clinical trials that show a survival benefit with bypass surgery as compared with medical treatment,¹⁻⁴ coronary-artery bypass grafting (CABG) has been considered standard therapy for patients with left main coronary artery disease and is recommended by current practice guidelines.^{5,6} Because of concern about procedural risk and long-term durability, percutaneous coronary intervention (PCI) usually has been restricted to patients who are poor candidates for surgery or have left main coronary artery disease that is “protected” by a patent bypass graft to the left anterior descending or circumflex artery.

The development of coronary-artery stenting has led to a reevaluation of the role of PCI for left main coronary artery disease, and several studies have reported on the midterm safety and feasibility of stenting.⁷⁻⁹ Interest in stenting of the left main coronary artery has increased further with the availability of drug-eluting stents that significantly reduce the rates of restenosis and repeat revascularization.¹⁰⁻¹² However, there are limited data on the long-term safety and effectiveness of PCI with bare-metal or drug-eluting stents, as compared with CABG, in patients with unprotected left main coronary artery disease. We therefore compared the long-term outcomes of the implantation of coronary stents and CABG among patients with unprotected left main coronary artery disease in Korea, where stenting of the left main coronary artery has been a more common practice than in Western countries, as recorded in the MAIN-COMPARE (Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty versus Surgical Revascularization) registry.

METHODS

STUDY POPULATION

The MAIN-COMPARE registry holds data on consecutive patients from 12 major cardiac centers in Korea that performed PCI or CABG for unprotected left main coronary artery disease (defined as stenosis of more than 50%) between January 2000 and June 2006. We excluded patients who

had undergone previous CABG, those who underwent concomitant valvular or aortic surgery, and those who had myocardial infarction with ST-segment elevation or presented with cardiogenic shock. The registry is sponsored by the Korean Society of Interventional Cardiology. There was no industry involvement in the design, conduct, or analysis of the study. The local ethics committee at each hospital approved the use of clinical data for this study, and all patients provided written informed consent.

Patients underwent PCI, instead of CABG, because of either the patient's or physician's preference or the high risk associated with CABG (see the Supplementary Appendix, available with the full text of this article at www.nejm.org). From January 2000 through May 2003, coronary stenting was performed exclusively with bare-metal stents, whereas from May 2003 through June 2006, exclusively drug-eluting stents were used. Methods of stent implantation for patients with left main coronary artery disease have been described previously^{10,13,14} (see the Supplementary Appendix). Interventions for other clinically important types of coronary artery disease were performed according to current practice guidelines.⁶ All patients undergoing PCI were prescribed aspirin plus clopidogrel (loading dose, 300 mg or 600 mg) or ticlopidine (loading dose, 500 mg) before or during the coronary intervention. After the procedure, aspirin was continued indefinitely. Patients treated with bare-metal stents were prescribed clopidogrel or ticlopidine for at least 1 month, and patients treated with drug-eluting stents were prescribed clopidogrel for at least 6 months. Surgical revascularization was performed with the use of standard bypass techniques.⁵ Whenever possible, the internal thoracic artery was used preferentially for revascularization of the left anterior descending artery.

FOLLOW-UP AND END POINTS

Clinical, angiographic, procedural or operative, and outcome data were collected with the use of a dedicated Internet-based reporting system. All outcomes of interest were confirmed by source documentation collected at each hospital and were centrally adjudicated by the local events committee at the University of Ulsan College of Medicine, Asan Medical Center, Seoul. For validation of complete follow-up data, information about vital sta-

Table 1. Baseline Characteristics of the Patients.*

Variable	Stent Group (N = 1102)	CABG Group (N = 1138)	P Value
Demographic characteristics			
Age (yr)			<0.001
Median	62	64	
Interquartile range	52–70	57–70	
Male sex (%)	70.7	72.9	0.24
Cardiac or coexisting conditions			
Diabetes mellitus (% of patients)			
Any diabetes	29.7	34.7	0.01
Insulin-dependent	6.8	8.2	0.22
Hypertension (% of patients)	49.5	49.4	0.94
Hyperlipidemia (% of patients)	28.5	32.6	0.04
Current smoker (% of patients)	25.6	29.8	0.03
Previous coronary angioplasty (% of patients)	18.1	11.0	<0.001
Previous myocardial infarction (% of patients)	8.1	11.6	0.005
Previous congestive heart failure (% of patients)	2.5	3.3	0.21
Chronic obstructive pulmonary disease (% of patients)	2.0	2.0	0.97
Cerebrovascular disease (% of patients)	7.1	7.3	0.84
Peripheral vascular disease (% of patients)	1.5	5.4	<0.001
Renal failure (% of patients)	2.7	3.0	0.71
Ejection fraction (%)			<0.001
Median	62	60	
Interquartile range	57–67	52–66	
Electrocardiographic findings (% of patients)			0.53
Sinus rhythm	97.8	97.1	
Atrial fibrillation	2.0	2.7	
Other	0.2	0.2	
Clinical indication (% of patients)			<0.001
Silent ischemia	3.0	2.2	
Chronic stable angina	32.0	19.9	
Unstable angina	55.2	68.1	
Non–ST-elevation myocardial infarction	9.8	9.8	
Angiographic characteristics			
Involved location (% of patients)			0.04
Ostium, midshaft, or both	50.6	46.2	
Distal bifurcation	49.4	53.8	
Extent of diseased vessel (% of patients)			<0.001
Left main only	25.2	6.2	
Left main plus single-vessel disease	24.0	10.5	
Left main plus double-vessel disease	26.0	26.3	
Left main plus triple-vessel disease	24.8	57.0	
Right coronary artery disease (% of patients)	35.9	70.7	<0.001
Restenotic lesion (% of patients)	2.9	1.2	0.005

* CABG denotes coronary-artery bypass grafting. Percentages may not total 100 because of rounding.

Table 2. Baseline Characteristics of the Propensity-Matched Patients.*

Variable	Overall Cohort			Wave 1†		Wave 2‡		
	Stents (N = 542)	CABG (N = 542)	P Value§	Bare-Metal Stents (N = 207)	CABG (N = 207)	Drug-Eluting Stents (N = 396)	CABG (N = 396)	P Value§
Age (yr)			0.41			0.57		0.23
Median	64	64		61	61	66	66	
Interquartile range	56–71	56–70		51–69	53–67	57–72	58–70	
Male sex (% of patients)	71.6	71.2	0.95	72.0	71.0	0.91	71.5	0.99
Diabetes mellitus (% of patients)								
Any diabetes	32.7	33.0	0.95	26.1	26.6	0.99	36.1	0.86
Insulin-dependent	7.6	7.9	0.91	4.8	5.3	0.99	10.1	0.77
Hypertension (% of patients)	49.4	50.0	0.90	44.9	45.4	0.99	52.3	0.81
Hyperlipidemia (% of patients)	29.3	30.1	0.84	27.1	27.1	0.99	32.6	0.81
Current smoker (% of patients)	27.7	27.1	0.89	28.5	28.0	0.99	26.3	0.87
Previous coronary angioplasty (% of patients)	14.8	15.1	0.93	14.0	14.5	0.99	15.4	0.99
Previous myocardial infarction (% of patients)	9.0	10.0	0.68	9.7	10.6	0.87	8.8	0.90
Previous congestive heart failure (% of patients)	2.8	3.0	0.99	2.4	2.9	0.99	3.0	0.99
Chronic obstructive pulmonary disease (% of patients)	2.6	2.2	0.85	2.4	1.9	0.99	2.8	0.99
Cerebrovascular disease (% of patients)	7.4	6.6	0.72	6.8	6.3	0.99	8.1	0.76
Peripheral vascular disease (% of patients)	2.0	2.0	0.99	1.0	1.0	0.99	2.5	0.79
Renal failure (% of patients)	3.7	3.9	0.99	1.9	2.4	0.99	5.3	0.83
Ejection fraction (%)			0.62			0.67		0.53
Median	61	61		61	61	60	60	
Interquartile range	54–66	55–66		57–67	56–66	55–66	56–66	
Electrocardiographic findings (% of patients)			0.80			0.99		0.62
Sinus rhythm	97.6	96.7		97.6	97.1	97.7	96.5	
Atrial fibrillation	2.4	3.1		2.4	2.9	2.3	3.0	
Other	0.0	0.2		0	0	0	0.5	
Clinical indication (% of patients)			0.97			0.78		0.41
Silent ischemia	2.8	2.6		2.9	3.4	2.3	2.8	
Chronic stable angina	29.2	28.4		16.4	16.4	30.1	28.8	
Unstable angina	57.4	57.9		69.6	69.6	57.8	57.8	
Non-ST-elevation myocardial infarction	10.7	11.1		11.1	10.6	9.8	10.6	

Involved location (% of patients)	0.90	0.99	0.93
Ostium, midshaft, or both	48.3	47.8	38.9
Distal bifurcation	51.7	52.2	61.1
Extent of diseased vessel (% of patients)	0.81	0.99	0.63
Left main only	11.8	11.1	5.8
Left main plus single-vessel disease	17.0	16.2	11.6
Left main plus double-vessel disease	31.7	33.9	29.5
Left main plus triple-vessel disease	39.5	38.7	53.0
Right coronary artery disease (% of patients)	53.7	53.7	66.9
Restenotic lesion (% of patients)	1.8	1.8	1.3

* CABG denotes coronary-artery bypass grafting. Percentages may not total 100 because of rounding.

† Wave 1 shows comparisons between bare-metal stents and CABG.

‡ Wave 2 shows comparisons between drug-eluting stents and CABG.

§ P values are based on the paired t-test or the Wilcoxon signed-rank test for continuous variables and on the McNemar's test or marginal homogeneity test for categorical variables.

tus was obtained through July 15, 2007, from the National Population Registry of the Korea National Statistical Office with the use of a unique personal identification number.

Clinical follow-up after PCI and after CABG was recommended at 1 month, 6 months, and 1 year and then annually thereafter. Routine angiographic follow-up for all patients treated with PCI was recommended 6 to 10 months after the procedure. However, patients who were at high risk for procedural complications of angiography and had no symptoms or signs of ischemia, as well as patients who declined the recommendation, did not undergo routine follow-up angiography. For patients who underwent CABG, angiographic follow-up was recommended only if there were ischemic symptoms or signs during follow-up.

The end points of the study were death; the composite of death, Q-wave myocardial infarction, or stroke; and target-vessel revascularization. All events were based on clinical diagnoses assigned by the patient's physician and were centrally adjudicated by an independent group of clinicians. Death was defined as death from any cause. Q-wave myocardial infarction was defined as documentation of a new abnormal Q wave after the index treatment. Stroke, as indicated by neurologic deficits, was confirmed by a neurologist on the basis of imaging studies. Target-vessel revascularization was defined as repeat revascularization of the treated vessel, including any segments of the left anterior descending artery and the left circumflex artery.¹⁵

STATISTICAL ANALYSIS

Among patients who had unprotected left main coronary artery disease, we compared long-term outcomes for those who underwent PCI, irrespective of stent type, with the outcomes for those who underwent CABG. In addition, we compared the long-term outcomes of patients who received bare-metal or drug-eluting stents with patients who underwent CABG. Patients who received bare-metal stents were compared with patients who underwent CABG between January 2000 and May 2003 (Wave 1 of the registry). Patients who received drug-eluting stents were compared with patients who underwent CABG between May 2003 and June 2006 (Wave 2 of the registry).

To reduce the effect of treatment-selection bias and potential confounding in this observational study, we performed rigorous adjustment for sig-

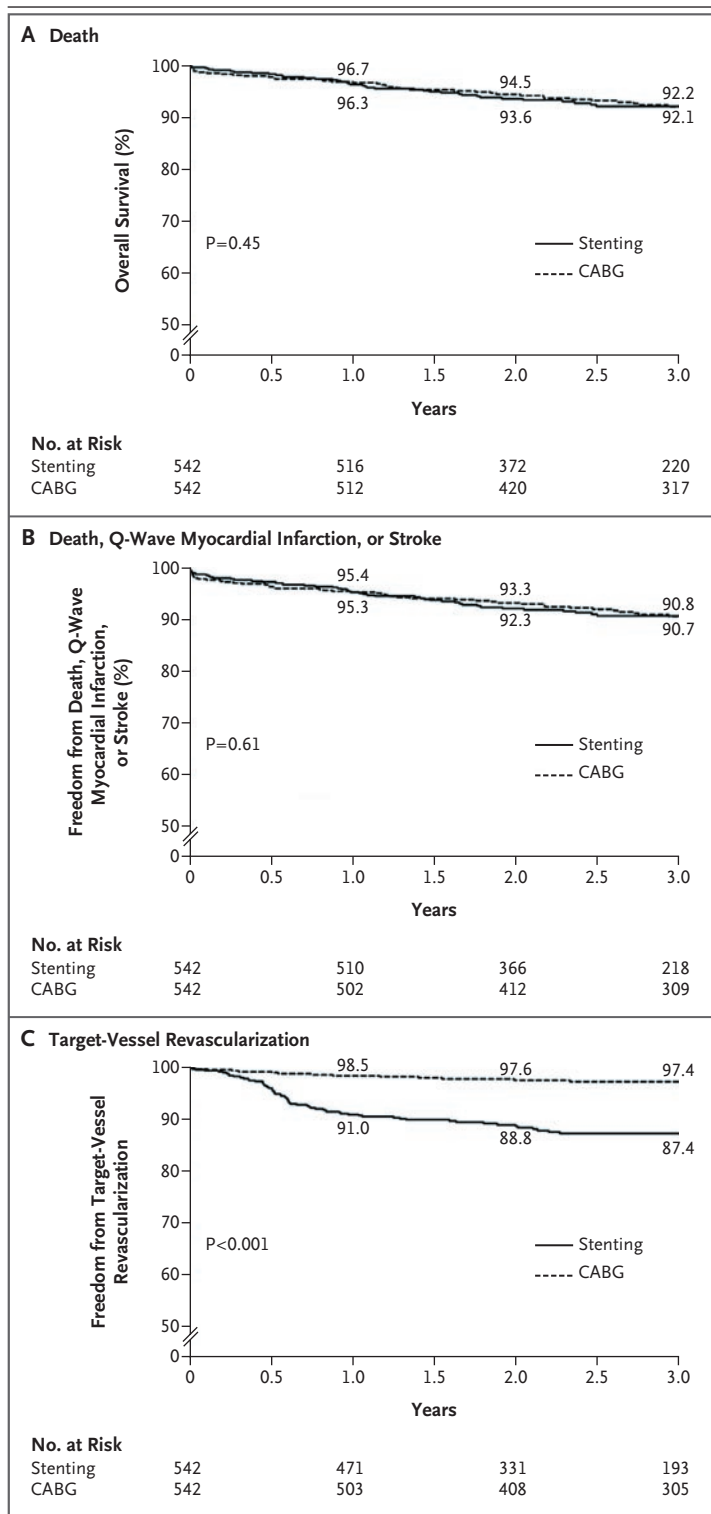


Figure 1. Kaplan–Meier Curves for Outcomes in a Cohort of Patients Matched for Propensity Scores Who Underwent Stent Implantation or Bypass Surgery.

Propensity matching for the entire cohort created 542 matched pairs of patients. Panel A shows the outcomes for overall survival; Panel B, outcomes for freedom from death, Q-wave myocardial infarction, or stroke; and Panel C, outcomes for freedom from target-vessel revascularization. Event-free survival rates (at 1, 2, and 3 years) were derived from paired Kaplan–Meier curves. CABG denotes coronary-artery bypass grafting.

Wave 1, and Wave 2), a separate propensity score for PCI versus CABG was derived. The details of the propensity-score method, with the resulting models and their predictive characteristics, are described in the Supplementary Appendix.

After all the propensity-score matches were performed, we compared the baseline covariates between the two intervention groups. Continuous variables were compared with the use of the paired t-test or the Wilcoxon signed-rank test, as appropriate, and categorical variables were compared with the use of McNemar's test. Statistical significance and the effect of treatment on outcomes were estimated with the use of appropriate statistical methods for matched data.^{18,19} In the propensity-score-matched cohort, the risks of each outcome were compared with the use of Cox regression models, with robust standard errors that accounted for the clustering of matched pairs. Survival curves were constructed with Kaplan–Meier estimates and compared with the use of methods described by Klein and Moeschberger.¹⁹

All reported P values are two-sided, and P values of less than 0.05 were considered to indicate statistical significance. SAS software, version 9.1, and the R programming language were used for statistical analyses.

RESULTS

CHARACTERISTICS OF THE STUDY POPULATION

Between January 2000 and June 2006, a total of 2240 patients with unprotected left main coronary artery disease met the criteria for inclusion. Of these, 1102 were treated with PCI and 1138 with CABG. Of the patients who underwent PCI, 1073 (97.4%) had clinical and angiographic conditions that made them eligible for either PCI or CABG, but they underwent PCI because of the patient's

nificant differences in the baseline characteristics of patients with the use of propensity-score matching.^{16,17} For each comparison (the entire cohort,

or physician's preference. The remaining 29 patients (2.6%) had underlying conditions that made them poor candidates for surgery (8 were ≥ 80 years of age and had a poor performance status, 3 had limited life expectancy, 2 had a current malignant condition, 12 had a concomitant severe medical illness, and 4 had no suitable bypass conduits).

In the PCI group, 318 patients (28.9%) received bare-metal stents and 784 (71.1%) received drug-eluting stents. Of the patients treated with drug-eluting stents, 607 (77.4%) received sirolimus-eluting stents and 177 (22.6%) received paclitaxel-eluting stents. The mean (\pm SD) number of stents implanted in a patient's left main coronary lesions was 1.2 ± 0.5 , the mean total length of the stents was 28.0 ± 20.7 mm, and the mean stent diameter was 3.5 ± 0.4 mm. The mean total number of stents implanted in a patient (including left main and other vessels) was 1.9 ± 1.1 .

In the CABG group, 478 patients (42.0%) underwent off-pump surgery and 1120 (98.4%) received at least one arterial conduit that, in 1096 patients (97.9%), was used in revascularization of the left anterior descending artery. The mean number of grafts used was 2.9 ± 1.0 (2.2 ± 0.9 arterial grafts and 0.7 ± 0.8 venous grafts).

The baseline characteristics of the study patients according to the revascularization procedure are shown in Table 1. Patients undergoing CABG were significantly older and had a higher prevalence of diabetes, hyperlipidemia, smoking, and history of myocardial infarction or peripheral vascular disease than those receiving stents. Patients undergoing CABG were also more likely to have lower ejection fractions, to present with unstable angina, and to have distal-bifurcation stenosis, three-vessel disease, and involvement of the right coronary artery. More patients in the PCI group than in the CABG group had undergone previous coronary angioplasty and had restenotic left main coronary lesions.

FOLLOW-UP

The median follow-up was 1017 days (interquartile range, 688 to 1451) in the PCI group and 1152 days (interquartile range, 681 to 1590) in the CABG group. Complete follow-up data for major clinical events were obtained in 98.9% of the overall cohort. During follow-up, 187 patients (8.3%) died, of whom 127 (67.9%, or 5.7% of the overall co-

hort) died of a cardiovascular cause. Twenty patients (0.9%) had a Q-wave myocardial infarction, and 35 (1.6%) had a stroke. Target-vessel revascularization was performed in 141 patients (6.3%).

CHARACTERISTICS OF PATIENTS MATCHED FOR PROPENSITY SCORES

Details of the propensity-score analysis are provided in the Supplementary Appendix. After propensity-score matching was performed for the entire population, there were 542 matched pairs of patients (Table 2). In this matched cohort, 25.5% of the PCI group received bare-metal stents and 74.5% received drug-eluting stents. After propensity-score matching was performed separately in the Wave 1 and Wave 2 cohorts, there were 207 matched pairs of patients who received bare-metal stents and concurrent control patients who underwent CABG, and 396 matched pairs of patients who received drug-eluting stents and concurrent control patients who underwent CABG. In the matched cohorts, there was no longer any significant difference between the PCI group and the CABG group for any covariate, according to the use of statistical methods appropriate for matched data (Table 2).

OUTCOMES FOR THE MATCHED COHORTS

Figure 1 and Table 3 show the long-term rates of clinical outcomes according to the treatment approach in the overall matched cohort. For the 542 matched pairs, there was no significant difference between the PCI and CABG groups in the risk of death during the 3-year follow-up period. The rates of major adverse cardiovascular events (death, Q-wave myocardial infarction, or stroke) were also similar. However, the rate of target-vessel revascularization was significantly higher in the PCI group than in the CABG group. Of the patients with initial PCI treatment who underwent target-vessel revascularization during the study period, 82.1% underwent repeat PCI (stenting or balloon angioplasty) and 17.9% underwent CABG. Of the patients with initial CABG treatment who underwent target-vessel revascularization, all underwent PCI, not repeat CABG. The risk of target-lesion revascularization specifically for restenosis of the left main coronary artery was also significantly higher in the PCI group than in the CABG group (hazard ratio, 2.72; 95% confidence interval [CI], 1.51 to 4.91).

Table 3. Hazard Ratios for Clinical Outcomes after Stenting as Compared with after CABG among Propensity-Matched Patients.*

Outcome	Overall Cohort (N = 542 pairs)		Wave 1 (N = 207 pairs)		Wave 2 (N = 396 pairs)	
	Hazard Ratio (95% CI)	P Value	Hazard Ratio (95% CI)	P Value	Hazard Ratio (95% CI)	P Value
Death	1.18 (0.77–1.80)	0.45	1.04 (0.59–1.83)	0.90	1.36 (0.80–2.30)	0.26
Composite outcome of death, Q-wave myocardial infarction, or stroke	1.10 (0.75–1.62)	0.61	0.86 (0.50–1.49)	0.59	1.40 (0.88–2.22)	0.15
Target-vessel revascularization	4.76 (2.80–8.11)	<0.001	10.70 (3.80–29.90)	<0.001	5.96 (2.51–14.10)	<0.001

* CABG denotes coronary-artery bypass grafting. Wave 1 shows comparisons between bare-metal stents and CABG, and Wave 2 shows comparisons between drug-eluting stents and CABG. Hazard ratios are for the stenting group as compared with the CABG group.

The rates of death at 3 years of follow-up did not differ significantly between the group that received bare-metal stents and the CABG group (Fig. 2 and Table 3). There was also no significant difference between the two groups in the composite risk of death, Q-wave myocardial infarction, or stroke. However, the rate of target-vessel revascularization was significantly lower among patients who underwent CABG than among those who received bare-metal stents. Of patients with bare-metal stents who underwent target-vessel revascularization, 60.5% underwent repeat PCI and 39.5% underwent CABG. All patients with initial CABG who required target-vessel revascularization were treated with PCI. The risk of stenosis of the left main coronary artery that required target-lesion revascularization was significantly higher for patients who received bare-metal stents than for those who underwent CABG (hazard ratio, 5.86; 95% CI, 2.03 to 16.90).

No significant differences were noted for the rates of death and the composite of death, Q-wave myocardial infarction, or stroke between the group that received drug-eluting stents and the CABG group (Fig. 3 and Table 3). However, the hazard ratios for each of these end points show a non-significant trend toward higher risk among patients with stents. Despite the markedly smaller hazard ratio in Wave 2 as compared with Wave 1, CABG continued to be associated with a lower rate of target-vessel revascularization than did drug-eluting stents. Among patients with drug-eluting stents who underwent target-vessel revascularization, 90.9% underwent repeat PCI and 9.1% underwent CABG. All patients with initial CABG who underwent target-vessel revascularization were treated with PCI, not re-

peat CABG. The risk of target-lesion revascularization due to stenosis of the left main coronary artery was higher among patients who received drug-eluting stents than among those who underwent CABG (hazard ratio, 2.98; 95% CI, 1.15 to 7.75).

OUTCOMES FOR THE UNMATCHED PATIENTS

Event-free survival in the unmatched cohort was consistent with the lower-risk characteristics of the patients who underwent PCI and the higher-risk characteristics of the patients who underwent CABG (see the Supplementary Appendix). Among the patients not included in the overall match, the 3-year rates of death and the composite of death, Q-wave myocardial infarction, or stroke were significantly higher in the CABG group, whereas the rate of target-vessel revascularization was higher in the PCI group. Among unmatched patients in Wave 1, the risks of death and the composite of death, Q-wave myocardial infarction, or stroke did not differ significantly between the two groups. However, the risk of target-vessel revascularization was consistently higher among patients who received bare-metal stents. Among unmatched patients in Wave 2, CABG was associated with higher risks of death and the composite of death, Q-wave myocardial infarction, or stroke than was PCI with drug-eluting stents, whereas the risk of revascularization was higher among patients who received stents.

ACUTE COMPLICATIONS

Acute complications occurred in 2.7% of patients undergoing PCI. The details of specific acute complications are provided in the Supplementary Appendix.

Figure 2. Kaplan–Meier Curves for Outcomes in a Cohort of Patients Matched for Propensity Scores Who Received Bare-Metal Stents or Underwent Bypass Surgery.

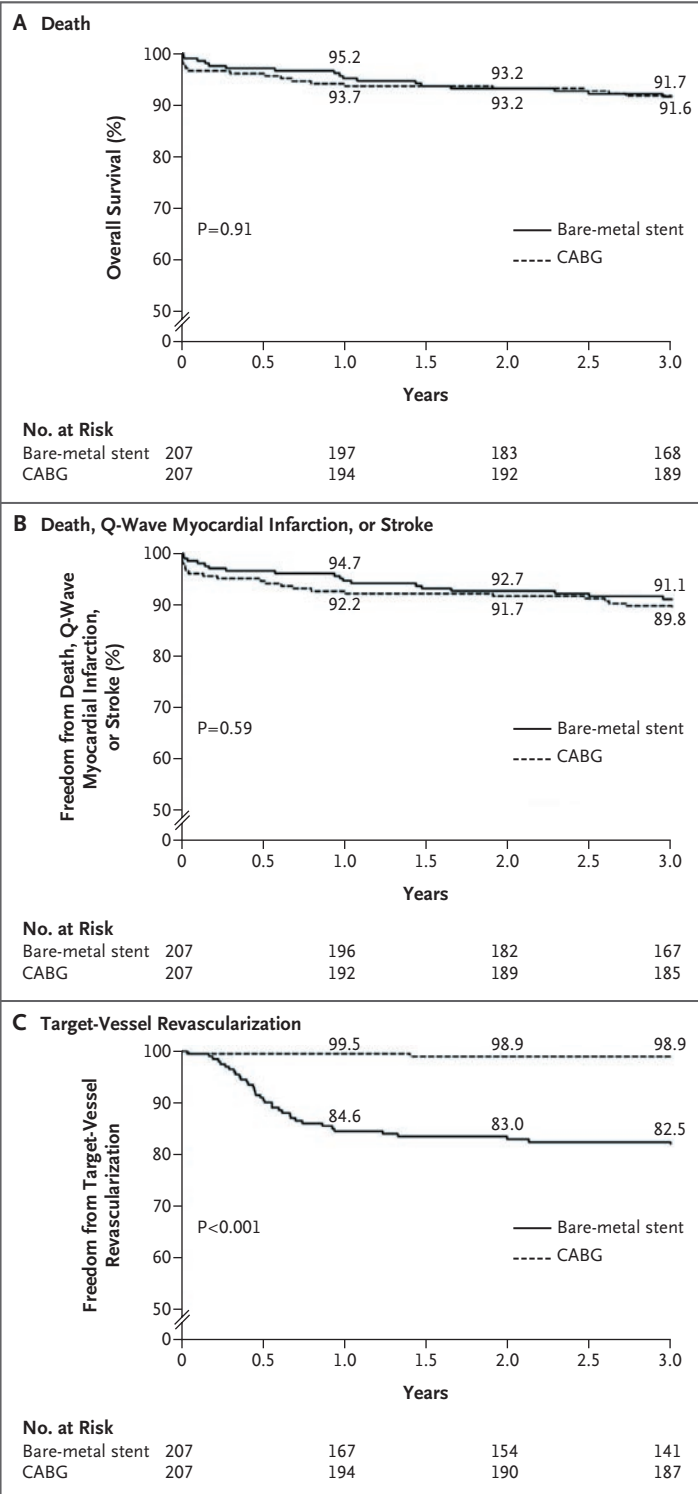
Propensity matching for Wave 1 created 207 matched pairs of patients. Panel A shows the outcomes for overall survival; Panel B, outcomes for freedom from death, Q-wave myocardial infarction, or stroke; and Panel C, outcomes for freedom from target-vessel revascularization. Event-free survival rates (at 1, 2, and 3 years) were derived from paired Kaplan–Meier curves. CABG denotes coronary-artery bypass grafting.

DISCUSSION

We compared the long-term outcomes of coronary stenting and CABG in a large cohort of patients with unprotected left main coronary artery disease. Our observational study showed that the risks of death and a composite of serious outcomes (death, Q-wave myocardial infarction, or stroke) were similar in the PCI and the CABG groups. These results were consistent when bare-metal stents or drug-eluting stents were compared with CABG, although there was a nonsignificant trend toward higher risk with drug-eluting stents. In contrast, the rate of target-vessel revascularization was significantly lower in the CABG group than in the PCI group, although hazard ratios varied depending on the type of stent.

Another large observational study, published before the development of drug-eluting stents, suggested that patients with left main coronary artery disease did significantly better with CABG than with PCI.²⁰ Although this was a risk-adjusted analysis, patient-selection factors probably contributed to the results. More recent observational studies have shown similar mortality rates and similar risks of major adverse cardiac and cerebrovascular events between patients receiving drug-eluting stents and those undergoing CABG, although patients undergoing CABG have typically had significantly lower rates of repeat revascularization.^{15,21–23} These studies have all been limited by small numbers of patients, a limited duration of follow-up, and selective performance of PCI in patients considered to be poor candidates for CABG.

In our study, despite the lower rates of repeat revascularization with drug-eluting stents than with bare-metal stents, CABG was still more effective than drug-eluting stents in reducing the



need for target-vessel revascularization. However, there was a significantly higher rate of follow-up angiography in the PCI group than in the CABG

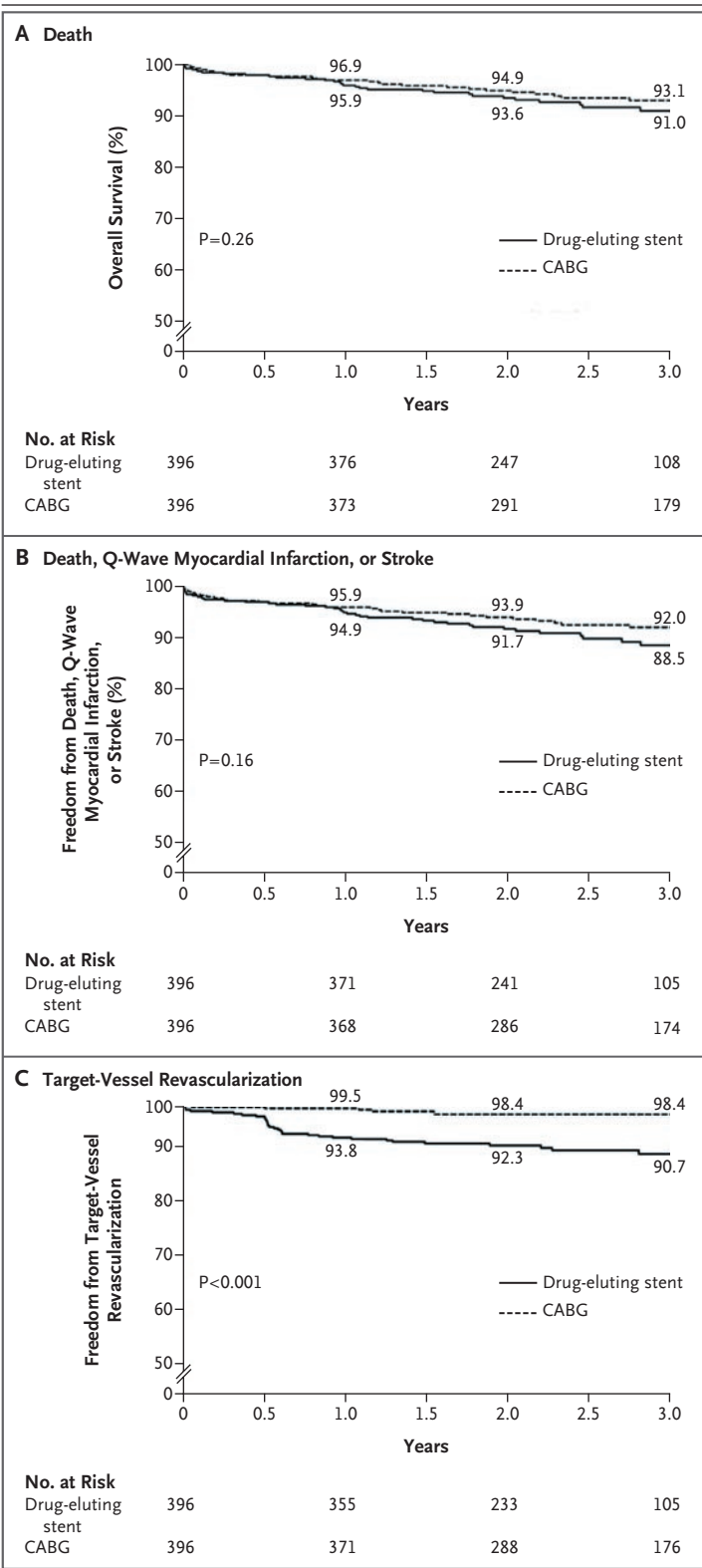


Figure 3. Kaplan–Meier Curves for Outcomes in a Cohort of Patients Matched for Propensity Scores Who Received Drug-Eluting Stents or Underwent Bypass Surgery.

Propensity matching for Wave 2 created 396 matched pairs of patients. Panel A shows outcomes for overall survival; Panel B, outcomes for freedom from death, Q-wave myocardial infarction, or stroke; and Panel C, outcomes for freedom from target-vessel revascularization. Event-free survival rates (at 1, 2, and 3 years) were derived from paired Kaplan–Meier curves. CABG denotes coronary-artery bypass grafting.

group (73.0% vs. 14.6%, $P<0.001$). Therefore, the rate of asymptomatic graft stenosis or occlusion may have been underestimated in the CABG group relative to the PCI group.

The major limitation of this study is that we evaluated observational data, and therefore the treatment strategy was not based on randomized assignment. The choice of revascularization was at the discretion of the treating physician or the patient. In the Supplementary Appendix we have attempted to provide as clear a description as possible of the factors that were likely to have influenced the selection of a procedure for individual patients. We acknowledge, however, that the particulars of clinical practice in the institutions in this trial, as well as the specific expertise of the interventional cardiologists and cardiac surgeons who performed the procedures, may differ from those of other institutions and practitioners, potentially limiting the reproducibility of these results in other settings.

From an analytical standpoint, our findings are subject to selection bias and confounding with respect to the relative severity of preprocedural risks among patients who underwent PCI and those who underwent CABG. To minimize these biases, we used propensity-score matching.^{16,17} Previous research has suggested that matching according to the propensity score eliminates a greater proportion of baseline differences between two treatments than does stratification or covariate adjustment.²⁴ Nevertheless, hidden bias may remain because of the influence of unmeasured confounders. Given these issues and the findings of our study, we believe that a randomized trial of PCI with drug-eluting stents as compared with CABG is warranted in patients with

unprotected left main coronary artery disease who are candidates for revascularization.

A final caveat is that our analysis was underpowered to detect significant differences in mortality, especially in the comparison of drug-eluting stents with CABG. More than 5500 patients would have been needed for such an analysis. Non-significant trends toward higher event rates were seen in the group that received drug-eluting stents; these trends might have been significant with a larger cohort of patients.

In conclusion, we found that in matched cohorts of patients with unprotected left main coronary artery disease, PCI with stenting and CABG were associated with similar long-term rates of death and the composite end point of death, Q-wave myocardial infarction, or stroke. Rates of target-vessel revascularization were higher among patients who underwent PCI than among those who underwent CABG.

Supported by the Korean Society of Interventional Cardiology and the Cardiovascular Research Foundation, Seoul.

Drs. Seung, Hong, and Chung report receiving lecture fees from Cordis and Boston Scientific; Dr. Y.-H. Kim, receiving lecture fees from Cordis; Dr. C.W. Lee, receiving lecture fees from Medtronic; Dr. Jeong, receiving lecture fees from Cordis, Medtronic, and Boston Scientific; Dr. Tahk, receiving lecture fees from Boston Scientific; Dr. S.-W. Park, receiving research grant support from Medtronic; Dr. Seong, receiving grant support from Boston Scientific; Dr. Gwon, receiving lecture fees from Boston Scientific and Medtronic and research grant support from Medtronic; Dr. H.-S. Kim, receiving consulting fees from Abbott Vascular; and Dr. S.-J. Park, receiving consulting fees from Cordis, lecture fees from Cordis, Medtronic, and Boston Scientific, and research grant support from Cordis and Medtronic. No other potential conflict of interest relevant to this article was reported.

We thank the staff members of the MAIN-COMPARE registry, the other members of the cardiac catheterization laboratories and the cardiac surgery departments of the participating centers, and the study coordinators for their efforts to collect the clinical data that made this study possible and to ensure the accuracy and completeness of the registry data.

REFERENCES

1. Yusuf S, Zucker D, Peduzzi P, et al. Effect of coronary artery bypass graft surgery on survival: overview of 10-year results from randomised trials by the Coronary Artery Bypass Graft Surgery Trialists Collaboration. *Lancet* 1994;344:563-70. [Erratum, *Lancet* 1994;344:1446.]
2. Chaitman BR, Fisher LD, Bourassa MG, et al. Effect of coronary bypass surgery on survival patterns in subsets of patients with left main coronary artery disease: report of the Collaborative Study in Coronary Artery Surgery (CASS). *Am J Cardiol* 1981;48:765-77.
3. Takaro T, Peduzzi P, Detre KM, et al. Survival in subgroups of patients with left main coronary artery disease: Veterans Administration Cooperative Study of Surgery for Coronary Arterial Occlusive Disease. *Circulation* 1982;66:14-22.
4. Caracciolo EA, Davis KB, Sopko G, et al. Comparison of surgical and medical group survival in patients with left main equivalent coronary artery disease: long-term CASS experience. *Circulation* 1995;91:2335-44.
5. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA 2004 guideline update for coronary artery bypass graft surgery: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1999 Guidelines for Coronary Artery Bypass Graft Surgery). *Circulation* 2004;110(14):e340-e437. [Erratum, *Circulation* 2005;111:2014.]
6. Smith SC Jr, Feldman TE, Hirshfeld JW Jr, et al. ACC/AHA/SCAI 2005 guideline update for percutaneous coronary intervention: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/SCAI Writing Committee to Update 2001 Guidelines for Percutaneous Coronary Intervention). *Circulation* 2006;113(7):e166-e286.
7. Park SJ, Hong MK, Lee CW, et al. Elective stenting of unprotected left main coronary artery stenosis: effect of debulking before stenting and intravascular ultrasound guidance. *J Am Coll Cardiol* 2001;38:1054-60.
8. Silvestri M, Barragan P, Sainsous J, et al. Unprotected left main coronary artery stenting: immediate and medium-term outcomes of 140 elective procedures. *J Am Coll Cardiol* 2000;35:1543-50.
9. Black A, Cortina R, Bossi I, Choussat R, Fajadet J, Marco J. Unprotected left main coronary artery stenting: correlates of mid-term survival and impact of patient selection. *J Am Coll Cardiol* 2001;37:832-8.
10. Park SJ, Kim YH, Lee BK, et al. Sirolimus-eluting stent implantation for unprotected left main coronary artery stenosis: comparison with bare metal stent implantation. *J Am Coll Cardiol* 2005;45:351-6.
11. Valgimigli M, van Mieghem CA, Ong AT, et al. Short- and long-term clinical outcome after drug-eluting stent implantation for the percutaneous treatment of left main coronary artery disease: insights from the Rapamycin-Eluting and Taxus Stent Evaluated At Rotterdam Cardiology Hospital Registries (RESEARCH and T-SEARCH). *Circulation* 2005;111:1383-9.
12. Chieffo A, Stankovic G, Bonizzoni E, et al. Early and mid-term results of drug-eluting stent implantation in unprotected left main. *Circulation* 2005;111:791-5.
13. Park SJ, Park SW, Hong MK, et al. Stenting of unprotected left main coronary artery stenoses: immediate and late outcomes. *J Am Coll Cardiol* 1998;31:37-42.
14. Park SJ, Lee CW, Kim YH, et al. Technical feasibility, safety, and clinical outcome of stenting of unprotected left main coronary artery bifurcation narrowing. *Am J Cardiol* 2002;90:374-8.
15. Chieffo A, Morici N, Maisano F, et al. Percutaneous treatment with drug-eluting stent implantation versus bypass surgery for unprotected left main stenosis: a single-center experience. *Circulation* 2006;113:2542-7.
16. Rosenbaum PR, Rubin DB. The central role of the propensity score in observational studies for causal effects. *Biometrika* 1983;70:41-55.
17. D'Agostino RB Jr. Propensity score methods for bias reduction in the comparison of a treatment to a non-randomized control group. *Stat Med* 1998;17:2265-81.
18. Therneau TM, Grambsch PM. Modeling survival data: extending the Cox model. New York: Springer-Verlag, 2000.
19. Klein JP, Moeschberger ML. Survival analysis: techniques for censored and truncated data. New York: Springer-Verlag, 1997.
20. Dzavik V, Ghali WA, Norris C, et al.

Long-term survival in 11,661 patients with multivessel coronary artery disease in the era of stenting: a report from the Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease (APPROACH) Investigators. *Am Heart J* 2001;142:119-26.

21. Lee MS, Kapoor N, Jamal F, et al. Comparison of coronary artery bypass surgery with percutaneous coronary intervention with drug-eluting stents for

unprotected left main coronary artery disease. *J Am Coll Cardiol* 2006;47:864-70.

22. Palmerini T, Marzocchi A, Marrozzini C, et al. Comparison between coronary angioplasty and coronary artery bypass surgery for the treatment of unprotected left main coronary artery stenosis (the Bologna Registry). *Am J Cardiol* 2006;98:54-9.

23. Sanmartín M, Baz JA, Claro R, et al.

Comparison of drug-eluting stents versus surgery for unprotected left main coronary artery disease. *Am J Cardiol* 2007;100:970-3.

24. Austin PC, Mamdani MM. A comparison of propensity score methods: a case-study estimating the effectiveness of post-AMI statin use. *Stat Med* 2006;25:2084-106.

Copyright © 2008 Massachusetts Medical Society.

JOURNAL EDITORIAL FELLOW

The *Journal's* editorial office invites applications for a one-year research fellowship beginning in July 2009 from individuals at any stage of training. The editorial fellow will work on *Journal* projects and will participate in the day-to-day editorial activities of the *Journal* but is expected in addition to have his or her own independent projects. Please send curriculum vitae and research interests to the Editor-in-Chief, 10 Shattuck St., Boston, MA 02115 (fax, 617-739-9864), by September 30, 2008.