

Effect of Improved Glycemic Control on Health Care Costs and Utilization

Edward H. Wagner, MD, MPH

Nirmala Sandhu, MPH

Katherine M. Newton, PhD

David K. McCulloch, MD

Scott D. Ramsey, MD, PhD

Louis C. Grothaus, MS

COST MODELS HAVE SUGGESTED that better glycemic control will lead to reductions in the longer-term economic burden of diabetes by preventing expensive complications.¹⁻³ Unfortunately, payers and policymakers often demand evidence of more immediate returns on investments before attempting to improve the quality of diabetes care. Two recent studies^{4,5} suggest that better glycemic control among type 2 diabetic patients may be followed by health care cost savings within a short time. Gilmer et al,⁴ in a staff-model health maintenance organization (HMO), examined the relationship between baseline levels of hemoglobin A_{1c} (HbA_{1c}) among type 2 diabetic patients and health care costs over the ensuing 3 years. For every 1% increase in HbA_{1c}, they found that health care costs rose significantly over the next 3 years. The authors then used these data to estimate the reduction in health care costs associated with reductions in HbA_{1c} of 1%. Their model suggests health care cost savings of approximately \$400 to \$4000 per patient over the ensuing 3 years, with the savings increasing with the level of baseline HbA_{1c} and the presence of vascular diseases. These relative cost savings are estimates and do not reflect the actual experience of individual patients. Therefore, these data cannot an-

Context Because of the additional costs associated with improving diabetes management, there is interest in whether improved glycemic control leads to reductions in health care costs, and, if so, when such cost savings occur.

Objective To determine whether sustained improvements in hemoglobin A_{1c} (HbA_{1c}) levels among diabetic patients are followed by reductions in health care utilization and costs.

Design and Setting Historical cohort study conducted in 1992-1997 in a staff-model health maintenance organization (HMO) in western Washington State.

Participants All diabetic patients aged 18 years or older who were continuously enrolled between January 1992 and March 1996 and had HbA_{1c} measured at least once per year in 1992-1994 (n=4744). Patients whose HbA_{1c} decreased 1% or more between 1992 and 1993 and sustained the decline through 1994 were considered to be improved (n=732). All others were classified as unimproved (n=4012).

Main Outcome Measures Total health care costs, percentage hospitalized, and number of primary care and specialty visits among the improved vs unimproved cohorts in 1992-1997.

Results Diabetic patients whose HbA_{1c} measurements improved were similar demographically to those whose levels did not improve but had higher baseline HbA_{1c} measurements (10.0% vs 7.7%; $P<.001$). Mean total health care costs were \$685 to \$950 less each year in the improved cohort for 1994 ($P=.09$), 1995 ($P=.003$), 1996 ($P=.002$), and 1997 ($P=.01$). Cost savings in the improved cohort were statistically significant only among those with the highest baseline HbA_{1c} levels ($\geq 10\%$) for these years but appeared to be unaffected by presence of complications at baseline. Beginning in the year following improvement (1994), utilization was consistently lower in the improved cohort, reaching statistical significance for primary care visits in 1994 ($P=.001$), 1995 ($P<.001$), 1996 ($P=.005$), and 1997 ($P=.004$) and for specialty visits in 1997 ($P=.02$). Differences in hospitalization rates were not statistically significant in any year.

Conclusion Our data suggest that a sustained reduction in HbA_{1c} level among adult diabetic patients is associated with significant cost savings within 1 to 2 years of improvement.

JAMA. 2001;285:182-189

www.jama.com

swer 2 critical questions: (1) Will subsequent health care costs decrease if patients achieve better glycemic control? and (2) If so, how long does it take before cost savings are demonstrated?

Demonstration that better glycemic control results in early cost savings would provide stronger support for more aggressive management of type 2 diabetes⁶ and for investment in system improvements, such as computerized diabetes registries^{7,8} and nurse case management programs.^{8,9} A recent article by Testa and Simonson⁵ provides

some evidence that short-term cost savings are possible. They compared short-term effect on symptoms, quality of life,

Author Affiliations: MacColl Institute for Healthcare Innovation (Drs Wagner and McCulloch and Ms Sandhu), Center for Health Studies (Dr Newton and Mr Grothaus), Group Health Cooperative of Puget Sound, and the Departments of Epidemiology (Dr Newton) and Health Services (Drs Wagner and Ramsey), School of Public Health and Community Medicine, and the Department of Medicine (Dr Ramsey), School of Medicine, University of Washington, Seattle.

Corresponding Author and Reprints: Edward H. Wagner, MD, MPH, MacColl Institute for Healthcare Innovation, Center for Health Studies, Group Health Cooperative, 1730 Minor Ave, Suite 1290, Seattle, WA 98101 (e-mail: wagner.e@ghc.org).

work productivity, and health care use of active hypoglycemic therapy (glipizide) vs placebo in a randomized trial. At 15 weeks, patients taking glipizide reported better health and work productivity and less use of ambulatory care. Whether these changes would persist or be evident in a less-controlled context is uncertain.

In this article, we compare health care utilization and costs for a 5-year period between 2 cohorts of diabetic patients—a group whose glycemic control improved and a group in whom it did not improve—receiving care from the same HMO.

METHODS

Study Setting

The study cohorts were selected from the enrollee population of Group Health Cooperative of Puget Sound (GHC), Seattle, Wash. During the study period of 1992-1997, GHC was a staff/network-model HMO serving about 500 000 individuals in western Washington State. The study population was restricted to diabetic enrollees receiving care from staff-model physicians (>90% of all enrollees).

Sample Selection

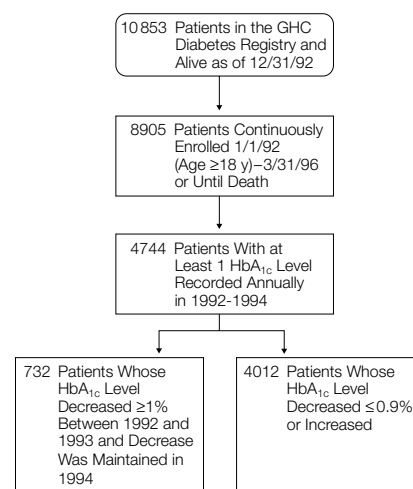
Study subjects were chosen as part of a larger study of the complications and costs of diabetes.¹⁰ Selection of the study sample is depicted in FIGURE 1. Staff-model enrollees with diabetes mellitus at the end of 1992 were identified from an automated diabetes registry.^{7,10} Patients were entered into the diabetes registry on the basis of receiving prescriptions for insulin or oral agents, having a hospital discharge diagnosis of diabetes mellitus, or having elevated HbA_{1c} or blood glucose levels. All patients included in the diabetes registry as of December 31, 1992, who were continuously enrolled in GHC from January 1, 1992, until March 31, 1996, or until their death were considered. Enrollees younger than 18 years as of January 31, 1992, and those who died in 1992 were excluded. These criteria were met by 8905 continuously enrolled diabetic persons.

To evaluate the effects of glycemic control on health care costs and utilization, we limited the study sample to continuously enrolled diabetic patients who had at least 1 HbA_{1c} measurement recorded in GHC's laboratory data system in 1992, 1993, and 1994. During this period, total glycohemoglobin levels were measured, and those values have been converted to HbA_{1c} levels for this analysis.¹⁰ Of the 8905 patients, 4744 (53%) had at least 1 HbA_{1c} result recorded during each year in 1992-1994. For those with more than 1 test in a given year, the last recorded value was used to assess change in comparison with other years. Patients whose HbA_{1c} level decreased 1% or more between 1992 and 1993 and who maintained this 1% or greater decrease from baseline (1992) through their last test in 1994 were designated as improved (n=732 [15%]). Individuals whose HbA_{1c} levels decreased 0.9% or less or increased were designated as unimproved (n=4012).

Data Collection

We collected data on demographic characteristics, HbA_{1c} results, treatment, diabetes complications, costs, and health care utilization solely from administrative data systems. Presence at baseline (any mention in 1992 or 1993) of 6 major diabetic complications (foot ulcer, retinopathy or macular edema, hypertension, ischemic heart disease, myocardial infarction, and stroke) was derived from inpatient and outpatient diagnostic codes.¹¹ To assess changes in glycemic therapy, we considered a patient's baseline period to be 365 days prior to their 1992 HbA_{1c} test date and their follow-up period to be the period between the 1992 HbA_{1c} test date and their 1993 HbA_{1c} test date. If a patient did not fill a prescription for any diabetes medication (insulin or oral agents) in the baseline period but had at least 1 prescription filled in the follow-up period, they were considered to have started medications. Patients with a record of at least 1 filled prescription of an oral agent and none for insulin in the baseline period who had a filled

Figure 1. Selection of Study Sample



GHC indicates Group Health Cooperative of Puget Sound; HbA_{1c}, hemoglobin A_{1c}. Patients were entered into the diabetes registry on the basis of receiving prescriptions for insulin or oral agents, having a hospital discharge diagnosis of diabetes mellitus, or having elevated HbA_{1c} or blood glucose levels.

prescription for insulin in the follow-up period were considered to have added insulin therapy. Remaining patients included those who decreased or did not change their medication regimen or who changed only dosages and those who never started a medication regimen. In 1992-1994, the only available oral agents were sulfonylureas.

Health care costs and utilization were also obtained from administrative data, which have been used extensively for research.^{10,12,13} The source of the cost estimates was the Decision Support System (DSS), implemented at GHC in 1989 to provide standardized, automated, step-down cost accounting for health care provided to members. The DSS uses data from 15 separate feeder systems, including clinical information, units of service, and costs from the general ledger. Monthly processing involves verifying and editing data from the feeder systems, calculating the precise cost for each unit of service delivered, and assigning costs to patients based on the units of service used. The objective of the cost accounting method is to identify the full cost of patient care services at the unit of service level. Key characteristics of this

Table 1. Baseline (1992) Characteristics of Diabetic Patients*

Characteristics	HbA _{1c} Level		P Value†
	Improved (n = 732)	Did Not Improve (n = 4012)	
Age, mean (SD), y	60.2 (13.6)	60.7 (13.0)	.33
Sex, male, %	50.8	49.2	.43
HbA _{1c} level, mean (SD), %	10.0 (1.7)	7.7 (1.5)	<.001
Foot ulcer, %	7.8	4.8	.001
Retinopathy or macular edema, %	32.5	26.5	.001
Myocardial infarction, %	5.3	3.2	.005
Cerebrovascular accident, %	8.1	5.0	.001
Ischemic heart disease, %	28.8	26.0	.11
Baseline utilization			
Eye examination, %	62.6	61.4	.86
Hospital admission, %	16.5	16.3	.86
Primary care visits, mean (SD), No.	7.5 (5.8)	7.3 (5.3)	.22
Specialty care visits, mean (SD), No.	3.9 (4.8)	3.9 (4.6)	.99
Total costs in 1992, adjusted \$	4733	5247	.66

*HbA_{1c} indicates hemoglobin A_{1c}. Improved patients had a decrease of $\geq 1\%$ in HbA_{1c}.
 †P values were computed using *t* tests for continuous variables and χ^2 tests for categorical variables.

method are that it uses actual costs from the general ledger and overhead costs are fully allocated to patient care departments. This means that all GHC costs have been identified as either a direct patient care cost (such as nurse salaries for a family practice nursing department) or an overhead cost (such as accounting, administration, and information system costs, which are shared by more than 1 department). Departments captured in the database include medical staff, nursing, pharmacy, laboratory, radiology, hospital inpatient, and community health services. Units of service are weighted as relative value units for ancillary departments, such as physical therapy, technical relative value units for radiology, College of Anatomical Pathology units for laboratory, and by visit length for outpatient visits for medical staff. The cost per unit that results from this cost accounting system reflects the actual costs of medical personnel and supplies to provide the service as well as overhead costs, such as administration, charting, and automated information systems. Independent audits of DSS records are conducted periodically.

Data Analysis

We compared the baseline unadjusted means of characteristics of the 2 cohorts using *t* tests for continuous vari-

ables and χ^2 tests for categorical variables. Annual utilization rates and total health care costs for each cohort were compared for each year from 1992-1997. All costs were inflated to 1997 dollars. We conducted the analysis in 2 ways to assess the effect of death and disenrollment on the results. Since deaths occurred somewhat more frequently among the improved cohort (16% vs 13.5%; $P=.06$), we were concerned that the larger proportion of individuals dying in that cohort might bias the results. As stated herein, individuals who disenrolled in 1992-1995 were not included in the study. Disenrollment in 1996 and 1997 was about 2% annually and did not differ between cohorts. In the first analysis, we included the experience of all individuals who were alive and enrolled for any part of the year. In the second analysis, the utilization and costs of those who died or disenrolled in the course of a given year were excluded. The results of the 2 analyses were very similar, and we report the results of the first, more inclusive analysis.

Multiple linear regression analysis was used to estimate the relationship between glycemic control and the cost and intensity of care for patients with diabetes. Cost and utilization estimates were adjusted for age, sex, base-

line HbA_{1c} level, and baseline presence of any of the 6 complications. The cost data were highly skewed. To make the distribution of the data more normal and to ensure more equal variances between groups, we logarithmically transformed the cost data prior to analysis. Regression analysis (analysis of covariance) was then used to adjust for covariates and to calculate *P* values to compare adjusted means (on the log scale) for each group. To derive unbiased estimates of mean costs on the original scale, the adjusted log means were then transformed back to a dollar scale using a smearing estimate.^{14,15} Smearing estimates give unbiased estimates on the original scale without making any assumptions regarding the cost distribution (ie, need not assume log normality). These estimates are presented in the tables and figures. All cost data presented are mean costs per person.

RESULTS

TABLE 1 shows the unadjusted demographic, health, and health care characteristics of the 2 cohorts at baseline. There were no significant differences by age or sex. The average age was approximately 60 years, indicative of the heavy preponderance of type 2 diabetic patients in the cohorts. As expected, improved patients had substantially higher baseline HbA_{1c} levels than patients who did not improve. The improved cohort also had significantly higher baseline rates of diabetic retinopathy, stroke, myocardial infarction, and foot ulcer. Group Health Cooperative diabetic patients are cared for in 25 different outpatient clinics. The distribution of the 2 cohorts among the sites of care did not differ ($P=.17$), suggesting no major differences in physicians. We also looked at an indicator of good diabetes care (eye checkups) and found no baseline difference between cohorts ($P=.86$).

Despite the differences in glycemic control and morbidity, baseline utilization and costs were similar between the 2 cohorts. Sixteen percent of those whose glycemic control improved

started taking hypoglycemic medications after their baseline HbA_{1c} measurement and an additional 19% had insulin added to their regimen, compared with 6% and 3% of the unimproved cohort, respectively. The data systems do not permit assessment of changes in diet or exercise or increases in dosages of either oral agents or insulin, which also may have accounted for improvements in glyceemic control. Because of the large difference in baseline HbA_{1c} values between the 2 cohorts, all subsequent analyses either control for or stratify baseline HbA_{1c} level.

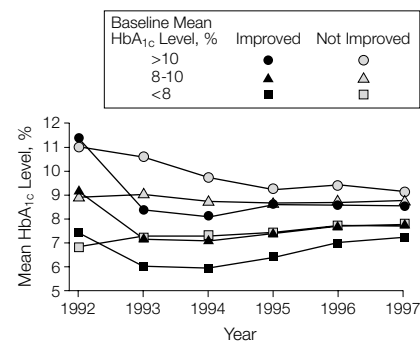
The total mortality rates in the 2 cohorts from 1994-1997 were 16% in the improved cohort and 13.5% in the unimproved cohort (*P* = .06). The difference in mortality rates is largely explained by the differences in prevalences of diabetes complications at baseline (adjusted *P* = .45).

To assess whether the differences in HbA_{1c} levels between cohorts persisted throughout the follow-up period, we examined the annual cohort means within strata based on baseline HbA_{1c} level (<8%, 8%-10%, or >10%). FIGURE 2 shows that there was initially substantial reduction in each improved subcohort and that the differences between cohorts narrowed but continued throughout the follow-up period.

FIGURE 3 shows mean utilization rates for the 2 cohorts during the 6 years of follow-up. TABLE 2 shows the adjusted differences between the 2 cohorts (the mean in the improved cohort minus the

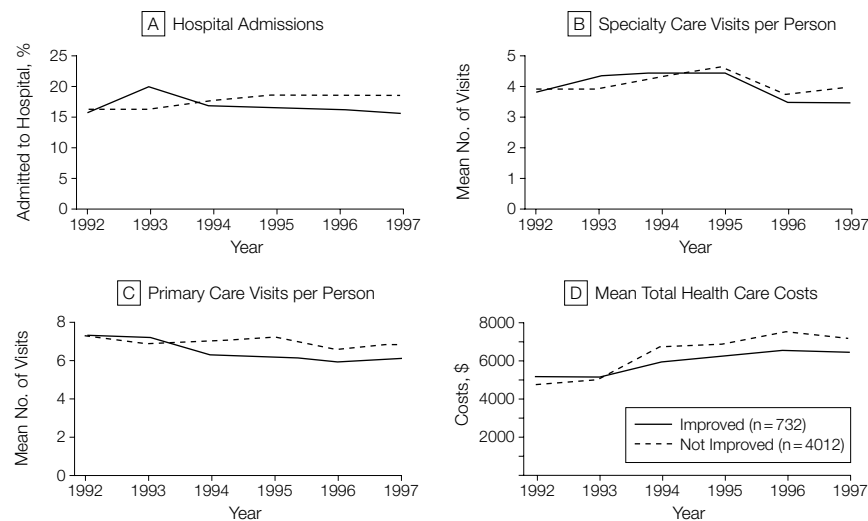
mean in the unimproved cohort) and the *P* values. After adjustment for covariates, there were no significant differences in any utilization measure at baseline (1992). Hospitalization rates were significantly higher in the improved cohort during the period in which their HbA_{1c} declined (1993), were no different in 1994, and then became lower in the improved cohort, but the differences were not statistically significant. Patients with improved HbA_{1c} levels experienced a somewhat lower rate of emergency department use, which was statistically significant only for 1995. Specialty care and primary care visits showed

Figure 2. HbA_{1c} Levels by Improvement, Baseline HbA_{1c} Level, and Year



HbA_{1c} indicates hemoglobin A_{1c}.

Figure 3. Annual Utilization and Costs Among Diabetic Patients by Improvement in HbA_{1c} Levels



HbA_{1c} indicates hemoglobin A_{1c}. Data are adjusted for age, sex, baseline HbA_{1c} levels, and complications.

Table 2. Adjusted Mean Difference in Utilization and Costs by Year Between Diabetic Patients Whose HbA_{1c} Levels Improved (n = 732) or Did Not Improve (n = 4012)*

	1992		1993		1994		1995		1996		1997	
	Difference	<i>P</i> Value	Difference	<i>P</i> Value	Difference	<i>P</i> Value	Difference	<i>P</i> Value	Difference	<i>P</i> Value	Difference	<i>P</i> Value
Admitted to hospital, %	-0.007	.66	0.035	.03	-0.009	.61	-0.023	.19	-0.025	.15	-0.031	.09
Specialty care visits per person, No.	-0.09	.65	0.38	.06	0.16	.48	-0.17	.49	-0.38	.06	-0.52	.02
Primary care visits per person, No.	0.04	.89	0.3	.19	-0.081	.001	-0.95	<.001	-0.75	.005	-0.83	.004
Total health care costs, \$†	-512	.68	157	.22	-772	.09	-685	.002	-950	<.001	-821	.01

*Positive differences indicate that value is higher among patients whose hemoglobin A_{1c} (HbA_{1c}) levels improved. Data are adjusted for age, sex, baseline HbA_{1c} level, and complications.
†*P* values were calculated for log costs.

Table 3. Health Care Costs by Year in Diabetic Patients*

Baseline HbA _{1c} Level, %	1992			1993			1994		
	Mean Annual Cost, \$	Difference, \$	P Value	Mean Annual Cost, \$	Difference, \$	P Value	Mean Annual Cost, \$	Difference, \$	P Value
<8									
Improved (n = 88)	5121	-279	.39	3683	-1009	.12	4475	-1885	.18
Unimproved (n = 2576)	5400			4692			6360		
8-10									
Improved (n = 295)	4211	-950	.20	6186	1640	.02	5898	-692	.32
Unimproved (n = 1138)	5161			4546			6590		
>10									
Improved (n = 349)	5047	722	.70	5893	-378	.65	8088	141	.53
Unimproved (n = 298)	4325			6271			7947		

*Positive differences indicate that value is higher among patients whose hemoglobin A_{1c} (HbA_{1c}) levels improved. Data are adjusted for age, sex, baseline HbA_{1c} level, and complications. P values were calculated for the differences in log costs.

Table 4. Adjusted Mean Differences in Total Health Care Costs by Year Between Diabetic Patients Whose HbA_{1c} Levels Improved or Did Not Improve, Stratified by Baseline Complications*

Complications (No. Improved/No. Unimproved)	1992		1993		1994		1995		1996		1997		Average Cost Savings, 1994-1997, \$
	Difference, \$	P Value	Difference, \$	P Value	Difference, \$	P Value	Difference, \$	P Value	Difference, \$	P Value	Difference, \$	P Value	
Cardiovascular disease (249/1157)	820	.17	1255	.07	-1070	>.99	-1270	.66	726	.69	-1914	.13	-882
Other complications (301/1669)	-693	.14	56	.51	-952	.01	-1088	.002	-394	.007	-774	.51	-802
No complications (182/1186)	-700	.59	-49	>.99	208	.91	225	.15	-2152	<.001	-33	.03	-438

*Positive differences indicate that value is higher among patients whose hemoglobin A_{1c} (HbA_{1c}) levels improved. Data are adjusted for age, sex, baseline HbA_{1c} level, and complications. P values were calculated for log costs.

similar temporal trends. Rates were the same in the 2 cohorts at baseline, higher in the improved group during the year in which the reduction in HbA_{1c} occurred, and then became lower in the improved cohort. Specialty visit rates were higher in the improved cohort in 1993 (P=.06), lower in 1996 (P=.06), and significantly lower in 1997 (P=.02). Primary care visit rates were slightly higher in the improved group in the year of the reduction in HbA_{1c} (1993) but then became significantly and consistently lower in the improved cohort in 1994-1997. Patients with improved glycemic control had nearly 1 less visit per year to their primary care physician.

Figure 3 also shows mean total health care costs for the 2 cohorts during the 6-year interval, and Table 2 shows the differences between cohorts in adjusted mean total costs. The mean total health care costs were approxi-

mately \$5000 annually in each cohort at baseline and slowly increased over the duration of follow-up. In 1994-1997, total costs were consistently lower in the improved group than in the unimproved group and were significantly lower in 1995, 1996, and 1997. During the last 4 years of the study, better glycemic control resulted in average cost savings to the HMO of \$685-\$950 per patient per year.

Because of the large differences in baseline HbA_{1c} levels between cohorts, we examined the impact of improved glycemic control on total costs by baseline HbA_{1c} level (TABLE 3). The results are much more variable because of the smaller numbers in each group. The cost savings associated with the reduction in HbA_{1c} were statistically significant only among those with baseline HbA_{1c} levels of at least 10% for 1995, 1996, and 1997. Cost savings were also seen con-

sistently among those with baseline HbA_{1c} levels of less than 8%, but did not reach statistical significance. In the middle stratum, median costs from 1994-1997 were consistently lower in the improved cohort, but the direction of differences in the means was inconsistent from year to year. Table 3 also shows that total costs of both cohorts increased with the level of baseline HbA_{1c} over the duration of follow-up.

TABLE 4 shows the impact of baseline complications on subsequent total health care costs. We stratified the cohorts into 3 mutually exclusive groups depending on the presence of various complications in 1992-1993: cardiovascular disease (ischemic heart disease, myocardial infarction, or stroke) with or without other complications, complications other than cardiovascular disease (hypertension, retinopathy, foot ulcer), or no compli-

1995			1996			1997		
Mean Annual Cost, \$	Difference, \$	P Value	Mean Annual Cost, \$	Difference, \$	P Value	Mean Annual Cost, \$	Difference, \$	P Value
5528	-828	.14	5005	-1837	.18	5055	-1457	.73
6356			6842			6512		
7428	538	.56	8122	1021	.35	6927	-180	.17
6890			7101			7107		
7299	-2914	<.001	7469	-4093	<.001	8404	-1779	.05
10213			11562			10183		

cations. After 1993, improvement in glycaemic control tended to reduce costs in all 3 groups, with some inconsistency from year to year. Although the differences in log costs between improved and unimproved patients reached statistical significance only in some years in the other complications and no complications subgroups, the 4-year (1994-1997) average cost savings (\$882 for cardiovascular disease, \$802 for other complications, and \$438 for no complications) suggest that the presence of complications played little role in explaining the cost savings associated with better glycaemic control.

COMMENT

The relatively high incremental costs of improving glycaemic control in the Diabetes Control and Complications Trial raised concerns that economic considerations would limit health payer enthusiasm for the more aggressive management required for better control.¹⁶ To counter these concerns, investigators have used simulation and modeling techniques to estimate the benefits of better glycaemic control.¹⁻³ Most such models postulate that cost savings would be the result of fewer long-term complications and, therefore, would take several years to manifest. More immediate effects on health care costs should make investments in efforts to improve diabetes care more attractive to employers and health insur-

ers. Gilmer et al⁴ showed that HbA_{1c} levels and diabetic complications at a specific point in time independently predict health care costs during the ensuing 3 years, and their models suggested that reductions in HbA_{1c} would be followed by substantial reductions in costs.

But their study did not test the hypothesis that lowering the HbA_{1c} level of diabetic patients leads to reductions in health care utilization and costs. We attempted to test this hypothesis by comparing the health care utilization and costs of 2 contemporaneous cohorts of diabetic patients, one cohort that had experienced a reduction in HbA_{1c} of 1% or more sustained over 2 years and a second cohort of everyone else. Comparing the utilization and costs in these 2 cohorts should provide a conservative comparison since many in the "unimproved" cohort improved their glycaemic control after 1993 and some in the "improved" group deteriorated after 1994. Nonetheless, the differences in HbA_{1c} levels between the cohorts persisted throughout the follow-up period.

As expected, the cohorts differed at baseline. The improved cohort had substantially higher HbA_{1c} levels. O'Connor et al¹⁷ studied characteristics predictive of improved glycaemic control among a cohort of type 2 diabetic patients and found that patients whose HbA_{1c} levels improved had signifi-

cantly higher baseline HbA_{1c} levels, differing especially in the proportion whose HbA_{1c} levels exceeded 10%. The improved cohort also had higher prevalences of diabetic complications at baseline. Inpatient admissions and specialty care visits increased significantly among improved patients during the year in which their glycaemic control improved. Since for many patients, increased utilization preceded the decrease in HbA_{1c}, health problems such as acute illnesses that resulted in greater health care use may have motivated patients or clinicians to pay closer attention to glucose control. Such was the case with smoking cessation, in which we found that health care utilization and costs increased during the year in which smokers successfully quit and that much of the increased utilization stemmed from illnesses that preceded and may have precipitated the patient's cessation efforts.¹⁸ However, the 1993 increases in utilization among those whose glycaemic control improved were greatest among those who started insulin therapy. This is consistent with the findings of Hayward et al,¹⁹ who found that utilization among GHC type 2 diabetic patients increased significantly after initiation of insulin therapy. This suggests that some of the increase may have been associated with more intensive management.

We defined improved glycaemic control stringently and demonstrated that the improved cohort maintained better glycaemic control throughout the follow-up period than individuals with similar baseline HbA_{1c} levels who did not improve (Figure 2). Utilization and costs in the improved cohort tended to level off or decline in 1994-1997. In comparison, utilization and costs of the unimproved cohort tended to increase during this period. Significant cost savings from better glycaemic control were apparent within a year of achieving a lower HbA_{1c} level. The cost savings were associated with reductions in all forms of utilization examined, suggesting better health status. The model of Gilmer et al⁴ predicted that baseline HbA_{1c} was a powerful pre-

dictor of subsequent health care costs and that cost savings should be greatest among those with the worst baseline glycemic control. Cost savings in our study were only statistically significant among those with the worst glycemic control at baseline (HbA_{1c} level >10%) but were also evident among those with better baseline control.

Were these differences in health care costs and utilization related to better glycemic control, or were they the result of other patient or health care characteristics? The data in Table 3 confirm the relationship between future total health care costs and baseline HbA_{1c} level among both cohorts. The total costs for 1995-1997 of those patients whose baseline HbA_{1c} levels exceeded 10% were 49% and 62% higher than those whose baseline HbA_{1c} levels were less than or equal to 8% in the improved and unimproved cohorts, respectively.

We explored several alternative explanations for the findings. Patients who improved received their health care from the same clinics and physicians as those who did not and had similar baseline health care utilization and prevalences of eye examinations. Thus, we have no evidence that this group received better care that reduced utilization independent of glycemic control. The improved cohort had evidence of significantly worse glycemic control, higher prevalences of complications at baseline, and greater mortality. While we adjusted all analyses for these differences in baseline morbidity, our adjustment for covariates is likely to be incomplete. But, incomplete adjustment for baseline differences in diabetes severity should lead to differences in utilization and costs favoring the unimproved cohort. Since we found the opposite, it increases the likelihood that the observed differences are related to better glycemic control and not to other patient characteristics. To ensure that the greater proportion of deaths in the improved group did not influence the findings, we conducted the cost and utilization analysis with and without the deaths and found similar results.

Attempts to model the cost savings associated with better glucose control assume that the savings result from prevention of expensive complications several years after initiation of more stringent control.¹⁻³ Our data indicate that cost savings appear within 1 or 2 years of better control, making it unlikely that complication prevention is the major cause. Further, cost savings were no greater among those with baseline complications, a group at greater risk of subsequent complications. The work of Testa and Simonson⁵ suggests that the early effects of better glycemic control on utilization and costs may be more closely related to reduced symptom burden and greater functionality than to prevention of specific diabetes complications.

Improvements in glycemic control may also increase the comfort of the primary care physician, the patient, and the family, which may explain some of the reduction in primary care and specialty visits. Greater patient well-being and physician comfort may explain why significant cost savings associated with better glucose control were also observed among those without complications at baseline. Two additional factors may contribute to the reduction in health care utilization associated with better glycemic control. Improvements in glycemic control provide positive reinforcement for the patient's efforts in managing their illness, which may increase self-efficacy and reduce dependency on medical care for diabetes management. The fact that two thirds of the improved cohort lowered their HbA_{1c} levels without adding new drugs to their regimen may also be evidence of better self-management.

Patients with ischemic heart disease, myocardial infarction, and stroke at baseline demonstrated nonsignificant and inconsistent cost reductions with better glycemic control. Thus, we are unable to confirm the suggestion by Gilmer et al⁴ that better glycemic control may lead to even larger cost savings in diabetic patients with heart disease. It may be that the costs associated with managing these life-threatening conditions simply overwhelm any cost

savings associated with better control of diabetes.

Our results must be interpreted with caution. They were derived from an HMO population that has a smaller percentage of enrollees at the very high and very low ends of the income spectrum than the surrounding population. We considered only diabetic patients who were enrolled continuously for 4 years and had at least 1 HbA_{1c} measurement during 3 of those years. Thus, the study population includes a stable population that was being followed up regularly by their physicians. Whether a reduction in HbA_{1c} would be followed by cost savings in less advantaged populations or among those with less stable access to medical care is less certain. The majority of the individuals in our cohort whose HbA_{1c} levels improved apparently did so without adding new drugs to their regimen; but our pharmacy data do not permit us to identify increases in dosage of either insulin or sulfonylureas. The period of improvement preceded the approval of metformin. Therefore, many individuals appear to have improved without a major change in pharmacotherapy. This may reflect general lifestyle changes or random variation. Because the improved cohort's baseline glycemic control was poor, it is possible that regression to the mean accounted for some of the improvement.

These data from a staff-model HMO provide evidence that sustained improvements in glycemic control among older, predominantly type 2 diabetic patients are followed fairly closely in time by reductions in health care utilization and costs. These observations lend support to the growing evidence that older as well as younger diabetic patients benefit from better glycemic control. The cost differences of approximately \$685-\$950 per year per patient would more than pay for system enhancements^{20,21} required to achieve better glycemic control.

Author Contributions: Dr Wagner participated in study concept and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, obtaining funding, and supervision of the study.

Ms Sandhu participated in acquisition of data,

drafting of the manuscript, and provision of administrative, technical, or material support.

Dr Newton participated in study concept and design, acquisition of data, analysis and interpretation of data, critical revision of the manuscript for important intellectual content, provision of administrative, technical, or material support, and supervision of the study. Dr McCulloch participated in study concept and design,

analysis and interpretation of data, critical revision of the manuscript for important intellectual content, and provision of administrative, technical, or material support. Dr Ramsey participated in study concept and design, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, provision of statistical expertise, and supervision of the study.

Mr Grothaus participated in analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content, and provision of statistical expertise.

Funding/Support: This work was supported by an unrestricted grant from Parke-Davis Inc.

Acknowledgment: We appreciate the careful work of Adele Clark in preparing the manuscript.

REFERENCES

1. Diabetes Control and Complications Trial Research Group. Lifetime benefits and costs of intensive therapy as practiced in the Diabetes Control and Complications Trial. *JAMA*. 1996;276:1409-1415.
2. Eastman RC, Javitt JC, Herman WH, et al. Model of complications of NIDDM, I: model construction and assumptions. *Diabetes Care*. 1997;20:725-734.
3. Eastman RC, Javitt JC, Herman WH, et al. Model of complications of NIDDM, II: analysis of the health benefits and cost-effectiveness of treating NIDDM with the goal of normo-glycemia. *Diabetes Care*. 1997;20:735-744.
4. Gilmer TP, O'Connor PJ, Manning WG, Rush WA. The cost to health plans of poor glycemic control. *Diabetes Care*. 1997;20:1847-1853.
5. Testa MA, Simonson DC. Health economic benefits and quality of life during improved glycemic control in patients with type 2 diabetes mellitus: a randomized, controlled, double-blind trial. *JAMA*. 1998;280:1490-1496.
6. Clark CM, Fradkin JE, Hiss RG, Lorenz PA, Vinicor F, Warren-Boulton E. Promoting early diagnosis and treatment of type 2 diabetes: the National Diabetes Education Program. *JAMA*. 2000;284:363-364.
7. McCulloch KD, Price MJ, Hindmarsh M, Wagner EH. A population-based approach to diabetes management in a primary care setting: early results and lessons learned. *Effective Clin Pract*. 1998;1:12-22.
8. Aubert RE, Herman WH, Waters J, et al. Nurse case management to improve glycemic control in diabetic patients in a health maintenance organization: a randomized, controlled trial. *Ann Intern Med*. 1998;129:605-612.
9. Peters AL, Davidson MB, Ossorio RL. Management of patients with diabetes by nurses with support of subspecialists. *HMO Pract*. 1995;9:8-13.
10. Ramsey SD, Newton K, Blough D, McCulloch DK, Sandhu N, Wagner EH. Patient-level estimates of the cost of complications in diabetes in a managed-care population. *Pharmacoeconomics*. 1999;16:285-295.
11. Newton KM, Wagner EH, Ramsey SD, et al. The use of automated data to identify complications and comorbidities of diabetes: a validation study. *J Clin Epidemiol*. 1999;52:199-207.
12. Fishman P, Von Korff M, Lozano P, Hecht J. Chronic care costs in managed care: the first single-plan comparison of chronic care costs shows why cost-effective clinical approaches are critical to managed care success. *Health Aff (Millwood)*. 1997;16:239-247.
13. Ramsey SD, Newton K, Blough D, et al. Incidence, outcomes, and cost of foot ulcers in patients with diabetes. *Diabetes Care*. 1999;22:382-387.
14. Duan N. Smearing estimate: a nonparametric re-transformation method. *J Am Stat Assoc*. 1983;78:605-610.
15. Rutten-van Molken MP, van Doorslaer EK, van Vliet RC. Statistical analysis of cost outcomes in a randomized controlled clinical trial. *Health Econ*. 1994;3:333-345.
16. Diabetes Control and Complications Trial Research Group. Resource utilization and costs of care in the Diabetes Control and Complications Trial. *Diabetes Care*. 1995;18:1468-1478.
17. O'Connor PJ, Crabtree BF, Abourizk NN. Longitudinal study of a diabetes education and care intervention: predictors of improved glycemic control. *J Am Board Fam Pract*. 1992;5:381-387.
18. Wagner EH, Curry SJ, Grothaus L, Saunders KW, McBride CM. The impact of smoking and quitting on health care use. *Arch Intern Med*. 1995;155:1789-1795.
19. Hayward RA, Manning WG, Kaplan SH, Wagner EH, Greenfield S. Starting insulin therapy in patients with type 2 diabetes: effectiveness, complications, and resource utilization. *JAMA*. 1997;278:1663-1669.
20. Wagner EH, Austin BT, Von Korff M. Organizing care for patients with chronic illness. *Milbank Q*. 1996;74:511-544.
21. Wagner EH. More than a case manager. *Ann Intern Med*. 1998;129:654-656.

I am still learning.
—Michelangelo (1475-1564)