

An Economic Analysis of Interventions for Diabetes

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The objective of this article is to stratify interventions for diabetes according to their economic impact. We conducted a review of the literature to select articles that performed a cost-benefit analysis for 17 widely practiced interventions for diabetes. A scale for categorizing interventions according to their economic impact was defined. The 17 interventions were classified as follows: 1) clearly cost-saving, 2) clearly cost-effective, 3) possibly cost-effective, 4) non-cost-effective, or 5) unclear. Clearly cost-saving interventions included eye care and pre-conception care. Clearly cost-effective interventions included nephropathy prevention in type 1 diabetes and improved glycemic control. Possibly cost-effective interventions included nephropathy prevention in type 2 diabetes and self-management training. Non-cost-effective interventions were not identified. Interventions with unclear economic impact included case management, medical nutrition therapy, self-monitoring of blood glucose, foot care, blood pressure control, blood lipid control, smoking cessation, exercise, weight loss, HbA_{1c} measurement, influenza vaccination, and pneumococcus vaccination. Widely practiced interventions for patients with diabetes can be clearly cost-saving and clearly cost-effective. These practices are attractive from both a medical and an economic perspective.

Diabetes Care 23:390-404, 2000

Interventions for diabetes use current economic resources to obtain future benefits. Cost-saving or cost-effective interventions can prevent the economic impact of long-term complications, such as blindness, end-stage renal disease (ESRD), and lower-extremity amputation (LEA), as well as short-term complications, such as hospitalizations for poor glycemic control. Is preventive care of diabetes a prudent allocation of society's assets?

We conducted a review of the literature and performed a limited economic analysis of the costs and benefits of 17 widely practiced interventions for diabetes. These interventions included the following: 1) eye care, 2) pre-conception care, 3) nephropathy prevention in type 1 and type 2 diabetes, 4) improved glycemic control, 5) self-management, 6) case management, 7) medical nutrition therapy,

8) self-monitoring of blood glucose, 9) foot care, 10) blood pressure control, 11) blood lipid control, 12) smoking cessation, 13) exercise, 14) weight loss, 15) HbA_{1c} measurement, 16) influenza vaccination, and 17) pneumococcus vaccination.

Data in the literature on the cost and benefit of an intervention are derived from either empirical studies of experimental populations (1) or from modeling studies of simulated populations (2). Modeling uses a set of formulas or a computer program based on assumptions about the accuracy of screening methods, rates of disease progression to end-stage complications or death with and without a particular treatment, and treatment costs. In chronic diseases, empirical studies of interventions, for which outcomes will not be evident for many years, are seldom per-

formed because of high costs and time delays. The relatively inexpensive and rapid results generated by modeling studies are highly influenced by assumptions and represent predictions rather than observations. Nonetheless, such studies have supplied most of the existing data about the economic impact of interventions for diabetes.

The purpose of this review article is to stratify interventions for diabetes according to their economic impact. In an era where only limited resources are available for health care measures, we sought to identify, by way of a literature review, the most economically attractive interventions for diabetes.

RESEARCH DESIGN AND METHODS

Literature review

Articles documenting or modeling the achievement of a desired outcome or benefit along with an economic analysis for 17 widely practiced interventions for diabetes were identified through the following: 1) a Medline search using the keywords "diabetes mellitus" and either "cost" or "cost-effective" from January 1984 to December 1997; 2) volume-by-volume scrutiny of six diabetes journals over this time period, including *Diabetes*, *Diabetes Care*, *Diabetes Educator*, *Diabetes Research and Clinical Practice*, *Diabetic Medicine*, and *Diabetologia*; and 3) review of bibliographies of relevant articles. The 17 interventions that we selected were identified from a review of the medical literature (3), from the 1998 American Diabetes Association standards of medical care for patients with diabetes mellitus (4), from the Diabetes Coalition of California guidelines for diabetes care (5), and from textbook recommendations (6,7).

Definitions

The definition of terms that we used to describe concepts of health economics are presented in the APPENDIX.

Study elements

For each of the 17 interventions, we determined if there were data on 14 study elements that are standard criteria used in economic analyses of medical practices

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Abbreviations: ACEI, ACE inhibitor; BC, basic nutrition care; CDAPP, California Diabetes and Pregnancy Program; DCCT, Diabetes Control and Complications Trial; DNCSG, Diabetic Nephropathy Collaborative Study Group; ESRD, end-stage renal disease; LEA, lower-extremity amputation; ME, macular edema; MNT, medical nutrition therapy; PDR, proliferative diabetic retinopathy; PGC, practice guidelines for nutrition care; QALY, quality-adjusted life-year; SMBG, self-monitoring of blood glucose.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

Table 1—List and definitions of study elements that were examined for each diabetes intervention

Target population: the patients screened for eligibility to receive an intervention.
Screening method: the procedure used to detect a condition selected for intervention.
Screening schedule: the time interval between repeated screening procedures.
Treatment population: the patients receiving the intervention.
Treatment method: the treatment intended to provide future benefits in exchange for current economic resources.
Baseline program: the standard treatment, or lack of any treatment, to which the treatment method is compared.
Types of costs: the categories of expenses associated with an intervention and its outcome, which may include direct costs, indirect costs, disability payments, and rehabilitation services.
Year of costs: the year in which costs were incurred or the final year of an intervention whose costs were incurred over multiple years.
Discount rate: the devaluation rate for future costs or benefits.
Costs or savings: the net costs or savings of an intervention compared with the baseline program.
Benefits: the health outcomes of an intervention compared with the baseline program.
Cost-benefit ratio: the cost of an intervention divided by the benefit gained.
Sensitivity analysis: a recalculation of the cost-benefit ratio that substitutes an estimate of a cost or benefit with an alternate estimate in a modeling study.
Perspective: the party, such as society or a health insurer, that pays the costs and accrues the benefits of an intervention.

Modified from References 8–10.

(8–10). The elements are listed and defined in Table 1. If cost-benefit data for an intervention was available from five or more articles, then the data are presented in sections (according to the 14 elements) along with a discussion. Otherwise, the data are presented without such sections.

Classification of interventions

We stratified interventions into five categories according to their economic impact as follows: 1) clearly cost-saving (if at least one well-controlled study, comparing intervention and nonintervention patients, or if a modeling analysis demonstrated benefits associated with eventual savings exceeding the cost of the intervention); 2) clearly cost-effective (if at least one well-controlled study or modeling analysis demonstrated benefits that cost no more than equivalent benefits

produced by generally accepted interventions for other diseases, i.e., \leq \$25,000 spent per year of life or quality-adjusted life-year [QALY] gained); 3) possibly cost-effective (if there were at least three independent studies of the economic impact of the intervention that either failed to isolate the intervention or incompletely identified the costs or benefits but concluded the intervention to be cost-saving or cost-effective); 4) non-cost-effective (producing benefits that cost more than equivalent benefits produced by generally accepted interventions for other diseases, defined as $>$ \$25,000 spent per year of life or QALY gained); or 5) unclear (if there were fewer than three studies describing the economic impact of the intervention and none were randomized controlled reports).

The classification of interventions according to their cost-utility was derived

from the literature. Proposed programs costing no more than currently funded programs are generally considered to be attractive, and those costing more than currently funded programs are generally considered to be unattractive. Cost-utility classifications have been proposed by the following: 1) The University of California, San Diego Health Policy Project in 1982 (11); 2) a Canadian multicenter group of epidemiologists in 1992 (12); and 3) a National Heart, Lung and Blood Institute Conference in 1995 (13) (Table 2). We used the same dollar boundaries for cost-utility and cost-effectiveness stratification.

Costs were converted from historic dollars to 1997 dollars with the U.S. Department of Labor Statistics U.S. city average Consumer Price Indices for medical care (14) (Table 3). Foreign currency was converted to U.S. dollars with foreign exchange rates published in the Federal Reserve Bulletin (15) (Table 4). We used a conversion factor of 1.5 to convert units of microalbumin excretion from micrograms per minute to milligrams per 24 h.

EYE CARE — Diabetic retinopathy screening and treatment programs prevent blindness by detecting proliferative diabetic retinopathy (PDR) and macular edema (ME), and administering laser photocoagulation therapy. More economic studies have been reported on retinopathy prevention than on any other intervention for diabetes.

Target population

A cost-effectiveness analysis of intervention for diabetic retinopathy has been conducted in 10 studies from the perspective of a single payer in which all economic costs are paid by, and all savings accrue to, a single repository such as the government (15–25). There were 12 simulated target populations modeled in the 10 studies (Table 5). One study was modeled separately for one type 1

Table 2—Guidelines for adoption of medical interventions according to cost-utility

Cost-utility	UCSD (11)		Canada (12)		NHLBI (13)	
	1982 dollars	1998 dollars	1990 dollars	1998 dollars	1992 dollars	1998 dollars
Very attractive	<20,000	<52,346	<17,141	<25,491	<20,000	<25,471
Attractive	NR	NR	NR	NR	20,000–40,000	25,471–50,942
Possibly attractive	20,000–100,000	52,346–261,728	17,141–85,704	25,491–127,453	40,000–60,000	50,942–76,412
Possibly unattractive	NR	NR	NR	NR	60,000–100,000	76,412–127,354
Unattractive	>100,000	>261,728	>85,704	>127,453	>100,000	>127,354

Data are expressed as historic (or 1998) U.S. dollars per QALY gained and are modified from References 11–13. UCSD, University of California, San Diego; NHLBI, National Heart, Lung and Blood Institute; NR, not reported.

Table 3—U.S. Department of Labor Statistics U.S. city average Consumer Price Indices for medical care

Year	Average Consumer Price Index
1981	82.9
1982	92.5
1983	100.6
1984	106.8
1985	113.5
1986	122.0
1987	130.1
1988*	138.2
1988	138.6
1989	149.3
1990	162.8
1991	177.0
1992	190.1
1993	201.4
1994	211.0
1995	220.5
1996	228.2
1997	234.6
1998	242.1

Modified from Reference 14. *June, 1998.

diabetic population and two type 2 diabetic populations (20). The simulated study populations included the entire U.S. (24,25,27,29,30), 10,000 patients with diabetes in southern Wisconsin (20), 3,848, 999 patients with diabetic retinopathy in the U.S. (23), two regions north of the River Thames in the U.K. (16), all of Sweden (22), the west of Scotland (17), and the federal state of Tyrol in Austria (25).

Screening method

The screening method used to detect diabetic retinopathy was a dilated fundus examination by an ophthalmologist in six of the 10 studies (18,19,21,23–25). Alternate screening protocols in four studies included funduscopy by a nonophthalmologist physician (16,17) or fundus photography by a nonphysician (20,22).

Screening schedule

The screening frequency was yearly in 9 of the 10 studies (16–22,24,25) and a single time only in 1 study (23). The presence of any background diabetic retinopathy necessitated rescreening at intervals ranging from 3 to 6 months (18,19,21,22,24,25). Screening was delayed in the five populations containing only type 1 diabetic patients until 5 years after the onset of diabetes (18–22).

Treatment population

PDR was screened for and treated in all 10 studies. ME was also screened for and treated in eight of the ten studies (16–19, 21,22,24,25).

Treatment method

The treatment for PDR was panretinal photocoagulation. In one study, 30% of patients with PDR also underwent bilateral vitrectomies (25). The treatment for ME in all studies was focal photocoagulation.

Baseline program

The baseline program to which all 10 retinopathy screening and treatment efforts were compared was no screening or treatment. The compliance rate for completing screening and treatment was assumed to be 100% in seven studies (16–19,22,23,25), 60% in two studies (21,24), and 51% in one study (20).

Types of costs

The costs of intervention included direct costs in all ten studies plus disability payments in eight studies (16,17,19,21–25) and rehabilitation services for blindness in five studies (16,17,20,22,23). Indirect costs were incorporated into the total costs in two studies (16,22) and presented separately from the total costs (Table 5) in two other studies (17,23).

Year of costs

The year of costs of each study is listed in Table 5.

Discount rate

In 6 of the 10 retinopathy intervention studies, future costs were discounted (19–24). In three of these six studies, future benefits were also discounted (20,23,24). The discount rate for costs and benefits was always assumed to be 5%.

Costs or savings

The economic benefits produced by these 10 retinopathy screening studies, expressed as costs or savings per sight-year gained, are shown in Table 5. Type 1 diabetic patients were modeled in 5 of the 12 populations studied (18–22). In four of these five populations, there was a net savings associated with each sight-year gained (19–22) (Table 5). In the population with a net cost, the model did not account for savings from decreased lost earnings or from decreased disability and rehabilitation payments due to a decreased incidence of blindness (18).

The author of that report later incorporated some or all of these types of savings (in addition to costs) into his model, thereby demonstrating a net savings associated with retinopathy intervention for type 1 diabetic patients (19,21,22).

Type 2 patients were modeled in 3 of the 12 populations studied (20,24). In one of these three populations, there was a net savings associated with each sight-year gained (24) (Table 5). The other two populations were both modeled in another study and included an insulin-treated and a non-insulin-treated population (20). In both of these populations, there was a net cost required to attain an additional sight-year (Table 5). The non-insulin-treated population of type 2 diabetic patients had a higher cost per sight-year gained than any type 1 diabetic, mixed type 1/type 2 diabetic, or undivided type 2 diabetic population. A weakness in this study was the assumption that only PDR, but not ME, would be screened for and treated. This conservative assumption unnecessarily devalued the benefit of screening because most of the visual loss in diabetes is due to ME (24,26).

Mixed groups containing both type 1 and type 2 diabetic patients were modeled in 4 of the 12 populations studied (16,17,23,25). In all four populations, there was a net savings associated with each sight-year gained (Table 5).

Benefits

The benefits of laser therapy for PDR were defined as sight-years gained in all 10 studies. The benefits of laser therapy for ME (in the eight studies where ME was screened for) were also defined as sight-years gained in six studies (16,17,21,22,24,25) and as reading vision-years gained in two studies (18,19). Sight savings associated with treat-

Table 4—Federal Reserve Bulletin foreign exchange rates

Country	Currency	Year	Currency units per U.S. dollar
Austria	Schilling	1995	10.076
Canada	Dollar	1990	1.1668
Italy	Lira	1993	1,573.41
U.K.	Pound	1982	1.7480
U.K.	Pound	1983	1.5159
U.K.	Pound	1994	1.5319
U.K.	Pound	1995	1.5285

Modified from Reference 15.

Table 5—Cost-effectiveness and cost-utility analysis of diabetic retinopathy intervention studies from the perspective of a single payer

Author	Year of costs	Diabetes type	Sight-years gained	Savings (or cost) per		
				Sight-year gained (in historic dollars)	QALY gained (in historic dollars)	QALY gained (in 1998 dollars)
Savolainen and Lee (16)	1982	1,2	13,178	4,721	15,737*	41,188
Foulds et al. (17)	1983	1,2	90	2,274	7,580*	18,242
Javitt et al. (18)	1986	1	92,700	(966)	(3,220)*	(6,390)
Javitt et al. (19)	1986	1	84,367	1,222	4,073*	8,083
Dasbach et al. (20)	1989	1	319	3,201	10,669*	17,301
		2i	62	(530)	(10,000)	(16,215)
		2ni	21	(6,540)	(20,000)	(32,432)
Javitt et al. (21)	1990	1	79,236	2,108	7,025*	10,447
Fendrick et al. (22)	1992	1	3,168	1,947	6,488*	8,263
Drummond et al. (23)	1982	1,2	279,000	828	2,760*	7,224
Javitt et al. (24)	1990	2	94,304	5,006	16,687*	24,815
Matz et al. (25)	1995	1,2	179	2,162	7,208*	7,914

*Assigned utility for preventing blindness: 0.3 (27). i, insulin-treated; ni, non-insulin-treated.

ing retinopathy were apportioned as follows. PDR 68% and ME 32% in a type 1 diabetic population (21); PDR 29% and ME 71% in a type 2 diabetic population (24); and PDR 69% and ME 31% in a mixed type 1/type 2 diabetic population (25).

Patients who develop diabetes at a younger age might be expected to benefit preferentially from retinopathy prevention because the potential savings from avoiding rehabilitation costs for blindness are proportionate to the number of salvageable future working years. Such lower cost per sight-year gained ratios for younger patients were reported in two studies. In a type 1 diabetic population, younger-onset patients (age at diagnosis <30 years) constituted 46% of the population and accrued 98% of the savings (21). In a type 2 diabetic population, younger-onset patients (age at diagnosis <45 years) constituted 33% of the population and accrued 100% of the savings (24).

Cost-benefit ratio

Cost-utility analyses were performed on two retinopathy intervention populations by translating costs per sight-years gained into costs per QALYs gained. When sight-years gained and QALYs gained by a population were both presented, the implied utility was derived by dividing the sight-years gained by the QALYs gained. Utilities of 0.053 (20) and 0.327 (20) were so derived and then applied to two (20) of the three (18,20) retinopathy intervention populations for which costs exceeded savings (Table 5). For the third such population (18), sight-years gained were not converted

into QALYs gained; however, a cost per QALY gained could have been calculated with a published utility.

For the nine populations whose savings exceeded costs, no utilities converting sight-years gained into QALYs gained were proposed (16,17,19–25). A savings associated with each QALY gained (instead of a cost per QALY gained) could have also been calculated for these populations with a published utility. We assigned a utility of 0.3 to the quality-of-life increment gained by preventing blindness, based on an analysis of the quality-of-life increment gained from cataract surgery (27). We applied this utility to the 10 retinopathy intervention populations (including the 1 whose cost exceeded savings and the 9 whose savings exceeded costs) where cost-effectiveness results were not already translated into cost-utility results. The cost per QALY gained or savings associated with each QALY gained for all 10 retinopathy studies are presented in Table 5.

Sensitivity analysis

Sensitivity analysis was performed in 8 of the 10 studies (18–25). In three studies, sensitivity analysis included a determination of the economic impact of alternative screening strategies (19,20,24). For each of these three studies, the lowest cost per sight-year gained strategy is reported in Table 5.

For a type 1 diabetic population that was modeled to receive five retinopathy prevention protocols, the most sight-years were gained with routine screening every year combined with rescreening every 6 months in the presence of diabetic retinopathy. How-

ever, the most sight-years gained per dollar spent were achieved with routine screening every 2 years (19). For a type 2 diabetic population that was modeled to receive eight protocols, the most sight-years were gained with routine screening every 2 years combined with rescreening every 6 months in the presence of any diabetic retinopathy. These were the shortest time intervals for screening and rescreening that were tested in the study (24). For a mixed type 1/type 2 diabetic population that was modeled to receive six protocols, the most sight-years were gained with annual screening (20).

Sensitivity analysis was performed on other assumptions rather than alternative screening strategies in five studies (18,21–23,25). For a mixed type 1/type 2 diabetic population, sensitivity analysis presented ranges of probability (from most pessimistic to most optimistic) for six assumptions and then substituted the most pessimistic assumptions for all six best-guess (but not necessarily most optimistic) assumptions. In 1982 dollars, the direct cost per sight-year gained increased from a net savings of \$828 to a net cost of \$15,917 (or \$2,167 and \$41,660, respectively, in 1998 dollars), and the combined direct and indirect costs per sight-year gained increased from a net savings of \$10,093 to a net cost of \$8,333 (or \$26,416 and \$21,810, respectively, in 1998 dollars) (23).

Sensitivity analysis of alternative rates of compliance with screening (22), sensitivity of ophthalmoscopy for detecting retinopathy (21,22), development of retinopathy (31), and progression of retinopathy to blindness (18,22) produced no significant

alteration in the economic impact of retinopathy intervention. Sensitivity analysis of the 5% discount rate for future costs demonstrated that a lower discount rate increased savings and a higher discount rate decreased savings (19,21,22,24).

Perspective

In the single-payer perspective of the aforementioned 10 diabetic retinopathy studies (16–25), society paid all the costs and accrued all the benefits. One additional economic analysis of a retinopathy screening and treatment program was performed strictly from the perspective of a health insurer (28).

In this thorough report, the savings achieved by preventing blindness were not considered because they accrued to the government rather than to the health insurer. A simulated target population of all the diabetic patients in the U.S. was studied. A screening program consisting of a dilated fundus examination by an ophthalmologist was compared with no screening or treatment. The screening frequency was yearly, and the presence of background diabetic retinopathy resulted in rescreening every 6 months. Patients with PDR received panretinal photocoagulation. Patients with ME received focal photocoagulation. Direct medical costs of screening and treatment, but not direct government costs of disability and rehabilitation or indirect societal costs of lost productivity, were considered. The year of costs was 1990. Future costs and benefits were both discounted at a 5% rate in this study performed from the perspective of a health insurer. The medical benefit of laser therapy for both PDR and ME was defined as sight-years gained.

The quality-of-life increment gained by preventing blindness was assigned a utility of 0.55. The cost-effectiveness and cost-utility of this intervention are presented in Table 6. A sensitivity analysis calculated the cost per QALY gained with alternate quality-of-life increments. For an intervention for which costs exceeded savings (such as a retinopathy program from the perspective of a health insurer), increasing the QALY increment gained decreased the cost per QALY gained. For an intervention for which savings exceeded costs (such as a retinopathy program from the perspective of society), increasing the QALY increment gained decreased the savings associated with each QALY gained.

In 1 of the 10 retinopathy studies with a single-payer perspective, assumptions

Table 6—Cost-effectiveness and cost-utility of a diabetic retinopathy intervention study from the perspective of a health insurer

	Cost per sight-year gained (in dollars)		Cost per QALY gained* (in dollars)	
	1990	1998	1990	1998
All patients	1,757	2,613	3,190	4,744
All type 1 diabetic patients	1,099	1,635	1,996	2,968
All type 2 diabetic patients	1,839	2,735	3,339	4,966
Insulin-treated type 2 diabetic patients	1,616	2,403	2,933	4,361
Non-insulin-treated type 2 diabetic patients	1,944	2,891	3,530	5,250

Modified from Reference 28. *Assigned utility for preventing blindness: 0.55.

about costs for particular services were revised to present cost and benefit data from the perspective of a health maintenance organization. The cost per sight-year gained was estimated to range from \$2,900 to \$3,600 in patients with type 1 diabetes and was “significantly higher” for patients with type 2 diabetes (20).

Discussion

Diabetic retinopathy screening and treatment programs have been shown to be clearly cost-saving interventions. The costs to society of such interventions are outweighed by the savings for type 1 diabetic patients as well as for type 2 diabetic patients not requiring insulin. For type 2 diabetic patients requiring insulin, the economic impact of such interventions is clearly cost-effective.

From the perspective of a single payer, diabetic retinopathy interventions have generally been demonstrated to be clearly cost-saving. From the perspective of a health insurer, these interventions have been no less costly for the benefits gained than generally accepted interventions for other diseases. Thus, from both a medical and an economic perspective, diabetes retinopathy screening and treatment is eminently worthwhile.

PRE-CONCEPTION

CARE — Pre-conception care for women with established diabetes reduces the incidence of fetal malformations and spontaneous abortions (29,30). An economic analysis of two programs, which included education and intensive blood glucose management, has been conducted in two studies in which a pre-conception care program was added to a standard prenatal care program (31,32).

A case-control cost-benefit analysis of a pre-conception care intervention for type 1

diabetic women was conducted by the California Diabetes and Pregnancy Program (CDAPP)—also known as the “Sweet Success” program (31). In the study, 90 CDAPP participants with diabetes before conception participated in a pre-conception care program and subsequently received standard prenatal care after conception. They were matched with 90 control patients who received only standard prenatal care without the pre-conception program. The matching criteria were the mother’s age, race, and severity and duration of diabetes according to White’s classification system (29). For each mother, charges were included through delivery. For each infant, costs were included from birth through discharge. Long-term medical costs of adverse neonatal and maternal outcomes, which are potential savings of the CDAPP, were not included. Charges were adjusted to June 1988 dollars and normalized with a hospital wage index to account for geographic differences in charges between three CDAPP hospitals and five control hospitals. An 8% discount was applied to costs but not benefits. A comparison of program costs and discounted savings demonstrated pre-conception costs of \$1,171 and net savings of \$6,072 per live infant (or \$2,051 and \$10,637, respectively, in 1998 dollars). The benefit-cost ratio was 5.19. Thus, for every \$1 spent on the CDAPP, there was a net savings of \$5.19 (31).

A second cost-benefit analysis of a pre-conception care intervention for pregestational diabetes was conducted as a modeling study on a simulated population that was not screened for eligibility to receive the intervention (32). The direct costs of a combined pre-conception/prenatal care program and a prenatal-only care program were compared. Information about costs and consequences of both pro-

grams was obtained from a literature review, a consensus of expert physicians, and surveys of other health care professionals. Costs were calculated in 1989 dollars. Discounting was not performed. The addition of a pre-conception care program to standard prenatal care resulted in net cost savings, even when sensitivity analysis testing substituted a wide range of best-guess assumptions with alternative assumptions about program costs and outcomes. From the perspective of a health insurer, costs were specified to include only pregnancy and the initial hospitalization of the mother and infant, as was the case in the CDAPP study. The cost savings per mother was \$480 (or \$754 in 1997 dollars), and the benefit-cost ratio was 1.24 (33). From the perspective of a single payer, potential savings of pre-conception care for the child were specified to additionally include the following: 1) medical care for 3 years after discharge from a neonatal intensive care unit; and 2) lifetime medical care, residential care, and community services in the event of a severe congenital malformation. The cost savings per mother then increased to \$1,720 (or \$2,702 in 1997 dollars) and the benefit-cost ratio increased to 1.86 (32).

Pre-conception care for women with established diabetes is clearly cost-saving for society when charges for long-term care for malformed offspring are paid by society. Pre-conception care for such women is also clearly cost-saving for health insurers, even if they are responsible only for costs accrued during pregnancy and the initial hospitalization of the mother and child, but not responsible for long-term costs.

NEPHROPATHY

PREVENTION — Diabetic nephropathy screening and treatment programs prevent ESRD by 1) detecting microalbuminuria or clinical nephropathy, and 2) controlling blood pressure or administering ACE inhibitor (ACEI) therapy. ACEI medications preserve renal function, independent of their antihypertensive effects, in microalbuminuric and proteinuric patients with diabetes (34,35). The economic impact of a diabetic nephropathy intervention program can be determined by comparing program costs with savings associated with delaying or deferring dialysis or transplantation for ESRD.

Target population

Economic analyses of nephropathy intervention programs have been reported for

1) simulated type 1 diabetic populations from the U.S. in 1992 (36), Europe in 1993 (37), Canada in 1995 (38), the U.K. in 1997 (39), and Italy in 1997 (40); and 2) a combined type 1/type 2 diabetic population from both the U.S. and Canada (also known as the Collaborative Study Group trial) in 1996 (41). Type 1 diabetic populations consisted of patients aged 18–49 years with diabetes for at least 7 years (39,40), newly diagnosed 15-year-old patients (36), or patients of unspecified age with a disease duration of at least 5 years (37,38). Ages in the combined population ranged from 20 to 54 years in type 1 diabetic patients and 55 to 74 years in type 2 diabetic patients (41).

Screening method

The screening method in three type 1 diabetes studies (36–38) was a random urine assay for microalbuminuria (defined as a protein concentration of ≥ 30 mg/24 h). In two other type 1 diabetes studies (39,40) and in the combined type 1/type 2 diabetes study (39), a single urine assay for proteinuria (defined as ≥ 500 mg/24 h) was performed.

Screening schedule

The screening frequency was once yearly in two studies (37,38), twice yearly in two studies (36,40), and once only in two studies (39,41).

Treatment population

All patients with microalbuminuria or proteinuria (defined as nephropathy) were treated.

Treatment method

Treatment for nephropathy consisted of ACEI therapy and was initiated in each program after either two of three consecutive assays were positive (36–38) or a single assay was positive (39–41). Enalapril (10 mg once daily [36]) or captopril (25 mg three times [39,41] a day) was specified in three studies. An agent “equivalent to” 25 mg captopril three times a day was specified in two studies (38,40). An unspecified ACEI was used in another study (37).

In three studies of type 1 diabetes, the authors used previously published epidemiologic data to estimate the time necessary to progress from the onset of type 1 diabetes, to microalbuminuria, to various stages of proteinuria, to ESRD, and to death from renal disease (36–38) or coronary artery disease (36). One study of type 1 diabetes applied

an economic model to empirical outcome data for progression rates from proteinuria to ESRD and death (39). These data were collected by the Diabetic Nephropathy Collaborative Study Group (DNCSG) during a 4-year study of the outcomes but not costs of ACEI therapy for nephropathy in type 1 diabetes (34). The Italian study of type 1 diabetic patients (40) and the study of type 1/type 2 diabetic patients (41) both used modeled economic data and (after the 4th year) modeled outcome data either for 6 additional years (40) or for patients' estimated remaining life spans (31 years for type 1 diabetic patients and 12 years for type 2 diabetic patients) (41). These two studies (40,41) used empirical outcome DNCSG data for years 1–4. The rate of progression for type 2 diabetes in the type 1/type 2 diabetes study was assumed to be equal to that of type 1 diabetes (41).

ACEI therapy was assumed to either slow the median transition time per stage by 50% but not affect the maximum end of the range of transition time per stage (a worst-case effect), or else slow the median transition time per stage by 75% and also increase the maximum end of the range of transition time per stage by 50% (a best-case effect) in one study (36). ACEI therapy was assumed to slow the annual increase in microalbumin excretion either at worst by 33% (from 20 to 13.4%) or at best by 67% (from 20 to 6.6%) in one study (37). ACEI therapy was assumed to slow the transition from microalbuminuria to proteinuria (>300 mg/24 h) by 25% and from proteinuria to ESRD by 50% in one study (38) and from proteinuria (≥ 500 mg/24 h) to ESRD or death by 50% in three other studies (39–41).

Baseline program

The above nephropathy interventions were compared with screening for both hypertension and proteinuria (defined as >300 mg/24 h [38], ≥ 450 mg/24 h [36], or ≥ 500 mg/24 h [40,41]) combined with treatment for either hypertension or proteinuria in two studies (36,38) and for hypertension only in two studies (40,41). Nephropathy interventions were compared with no screening or treatment in two studies (37,39).

Types of costs

Direct costs were presented for screening, ACEI therapy, and ESRD therapy in all six studies (36–41). ESRD costs included costs of dialysis in all six studies (36–41) and transplantation in all but one study (40). Direct costs of coronary artery disease treat-

Table 7—Cost-effectiveness of the Collaborative Study Group nephropathy intervention

Patient type	Direct lifetime savings (in 1994 dollars)	Indirect lifetime savings (in 1994 dollars)	Years of life gained	Direct savings per year of life gained (in dollars)		Indirect savings per year of life gained (in dollars)	
				1994	1998	1994	1998
Type 1 diabetes*	32,500	84,390	2.15	15,140	17,371	39,251	45,036
Type 2 diabetes†	9,990	45,730	1.04	9,606	11,021	43,971	50,452

Modified from Reference 41. *Assumes a 31-year life span. †Assumes a 12-year life span.

ment were presented in one study (36). Indirect treatment costs were also presented separately in one study (41).

Year of costs

The year of costs was 1990 in the Canadian study (38), 1991 in the American (36) and European (37) studies, 1993 in the Italian study (40), and 1994 in the U.K. study (39) and Collaborative Study Group trial (41).

Discount rate

Costs and benefits were both discounted at a rate of 5% in four studies (36,38,40,41) and 6% in one study (39). Costs only were discounted at rates of either 2.5 or 6% in one study (37).

Costs or savings

Nephropathy intervention in type 1 diabetes resulted in the following: 1) undiscounted annual per patient costs increasing, in 1991 dollars, by \$4,262 with conservative assumptions and by \$3,803 with optimistic assumptions (or \$5,830 and \$5,202, respectively, in 1998 dollars) in the U.S. study (36); 2) annual per patient costs increasing, in 1990 dollars, by \$262 (or \$390 in 1998 dollars) in the Canadian study (38); 3) net lifetime savings, in 1991 dollars, of \$800 accruing for a 33% treatment effect and 6% discount rate, and \$7,700 accruing for a 67% effect and 2.5% discount rate (corresponding to \$1,094 and \$10,532 in 1998 dollars) in the European study (37); 4) net savings per patient after 4 years, in 1994 pounds, of £953 (corresponding to \$1,675 in 1998 dollars) in the U.K. study (39); and 5) net savings per patient after 10 years, in 1993 Italian lire, of L8,450,765 (corresponding to \$6,456 in 1998 dollars) in the Italian study (40). Nephropathy intervention in both type 1 and type 2 diabetes resulted in net direct and indirect savings (Table 7) in the Collaborative Study Group trial (41).

Benefits

Nephropathy intervention extended life and prevented ESRD. In the U.S. study,

which proposed screening for either hypertension or proteinuria compared with no screening, undiscounted life expectancy increased, respectively, by 0.6 or 0.4 years with worst-case assumptions and by 1.2 or 0.7 years with best-case assumptions (36). In the Canadian study, discounted life expectancy increased by 0.1 years (38). In the European study, undiscounted life expectancy increased by 2 or 5 years with worst-case or best-case assumptions, respectively (37). Furthermore, the need for kidney transplantation or dialysis decreased by 21 or 63% for a 33 or 67% treatment effect, respectively (37). In the U.K. study, after 4 years, the discounted life expectancy increased by 0.2 years (39). In the Collaborative Study Group trial, after 5 and 31 years, respectively, type 1 diabetic patients attained 0.2 and 2.15 additional years of life and delayed dialysis by 0.18 and 0.72 years. In this study, after 12 years, type 2 diabetic patients attained 1.04 additional years of life and delayed dialysis by 0.29 years (41). In the Italian study, dialysis was delayed by 0.2 years per patient (40).

Cost-benefit ratio

Nephropathy intervention extended life at a cost of \$7,935 (with best-case assumptions) or \$16,494 (with worst-case assumptions) per patient per year in 1991 dollars (or \$10,853 and \$21,561, respectively, in 1998 dollars) in the U.S. study (42). Nephropathy intervention delayed onset of ESRD at a cost of \$27,042 per QALY gained in 1990 dollars (or \$40,214 in 1998 dollars) in the Canadian study (38). In that study, the quality-of-life increment gained by preventing ESRD was assigned a utility of 0.43. Savings associated with each year of life gained over the 4-year study were, in 1994 pounds, £4,888 (or \$8,591 in 1998 dollars) in the U.K. study (39). Savings associated with each month of dialysis-free life gained over the 10-year study were, in 1993 Italian lire, L3,521,152 (or \$2,690 in 1998

dollars) (40). Savings associated with each year of life gained over the projected life spans of patients with type 1 diabetes (31 years) and type 2 diabetes (12 years) in the Collaborative Study Group trial are presented in Table 7 (41). No cost-effectiveness or cost-utility figures were reported in the European study (37).

A cost-utility study tested the substitution of an immunochemical dipstick test for the "gold standard" laboratory assay for microalbumin (42). Empirical data about the accuracy of dipstick testing were combined with assumptions about the medical cost of delaying a diagnosis of microalbuminuria to create a model. Urine dipstick testing generated annual savings, in 1994 pounds, of £6,600 (or \$11,600 in 1998 dollars) but was associated with the loss of one QALY per patient.

Sensitivity analysis

Sensitivity analysis was performed in all six studies. The U.S. study compared the cost-effectiveness of ACEI therapy combined with three alternative nephropathy screening methods, including assaying for microalbuminuria (≥ 30 mg/24 h), significant microalbuminuria (≥ 150 mg/24 h), and proteinuria (≥ 450 mg/24 h). Microalbuminuria screening and treatment produced the greatest increase in life expectancy and was the intervention selected for economic analysis. Proteinuria screening and treatment, compared with no nephropathy intervention, was interpreted to be cost-saving. Proteinuria screening and treatment was then designated as the baseline program for which costs and benefits were to be compared with those of microalbuminuria screening and ACEI therapy (36). The Canadian study sequentially replaced four best-guess assumptions with alternative pessimistic assumptions. After each substitution, the cost per QALY gained almost tripled and exceeded \$75,000 in 1990 dollars (or \$111,532 in 1998 dollars) (38). In the European study, costs

Table 8—Undiscounted benefits of improved glycemic control compared with conventional therapy in the U.S.

	Type 1 diabetes (44)	Type 2 diabetes (48)
Additional years of life	5.1	1.32
Additional years of sight	7.7	1.5
Additional years free of ESRD	5.8	0.36
Additional years free from LEA	5.6	1.1
Additional QALYs	NR	1.32

NR, not reported.

were calculated to be balanced or exceeded by savings if ACEI therapy effected a $\geq 10\%$ decline in the annual rate of increase of microalbuminuria, such that this rate would fall from an assumed 20% down to $\leq 18\%$ (37). In the Italian study, a set of three best-guess assumptions was replaced with either three best-case assumptions or three worst-case assumptions. Each sensitivity analysis resulted in cost-savings 0.75–1.26 times as many as those provided by the original intervention, and dialysis-years avoided 0.98–1.02 times as great as those provided by the original intervention (40). In the Collaborative Study Group trial, each of nine alternative assumptions for type 1 diabetes and three alternative assumptions for type 2 diabetes about costs or progression of nephropathy were incorporated into the model. Each sensitivity analysis resulted in cost savings 0.73–1.24 times as great as those provided by the original intervention (41). In the U.K. study, the originally assumed 50% reduction in the rate of developing ESRD or death with ACEI therapy was replaced with worst-case (18%) and best-case (70%) risk reduction rates. The number of life-years and dollars saved increased with best-case and decreased with worst-case assumptions. The 18% rate actually resulted in a net cost per life-year saved. Reducing the estimated costs of treating ESRD by 20% halved the savings attained in this study (39).

Perspective

The U.S. (36), Canadian (38), U.K. (39), Italian (40), and Collaborative Study Group (41) studies were conducted from a single-payer perspective. The European (37) study was conducted from the perspective of a health insurer. Economic benefits associated with a reduced incidence of ESRD may accrue to a single payer, but not to an insurer.

Discussion

Nephropathy screening and treatment interventions for patients with type 1 diabetes provide additional years of life and QALYs. Depending on the assumptions made about the cost of ACEI therapy and its effects on nephropathy progression, such programs can be clearly cost-effective or even cost-saving. We have classified nephropathy prevention in type 1 diabetes as clearly cost-effective. The economic impact of nephropathy screening and treatment has been studied far less in type 2 than type 1 diabetic patients, but type 2 diabetic patients appear to also accrue both economic and medical benefits from this intervention. We have classified nephropathy prevention in type 2 diabetes as possibly cost-effective.

IMPROVED GLYCEMIC CONTROL

Type 1 diabetes

The Diabetes Control and Complications Trial (DCCT) demonstrated that improved glycemic control (intended to achieve near-normoglycemia), compared with standard treatment in type 1 diabetes, could delay the progression of such early microvascular complications as retinopathy, nephropathy, and neuropathy by $\sim 50\%$ (43). The study did not continue long enough to demonstrate reductions in the actual incidence of the most expensive end-stage microvascular complications of type 1 diabetes, which are blindness, ESRD, and LEA.

An economic analysis of improved glycemic control for type 1 diabetes in the U.S. has been conducted by the DCCT Research Group (44). The effectiveness of such therapy was calculated by using: 1) empirical trial data to describe the incidence of microvascular complications during the first 9 years of treatment; and 2) published epidemiologic data to model subsequent disease progression from

microvascular complications to end-stage complications. Costs of improved glycemic control were measured during the trial (45). Costs of treating end-stage complications were derived from published data. The DCCT Research Group used these outcome and cost data for type 1 diabetes to address two questions. First, what are the lifetime benefits and costs of improved glycemic control, and second, is improved glycemic control preferable to conventional therapy from the economic perspective of a single-payer health care system?

Undiscounted benefits of improved glycemic control compared with conventional therapy in type 1 diabetes are presented in Table 8. Costs of improved glycemic control in type 1 diabetes were allocated for outpatient care, inpatient care, self-care supplies, case management services, and adverse effects of therapy. Costs and cost-benefit ratios were both discounted at a rate of 3% unless otherwise specified. The lifetime per patient discounted cost, cost-effectiveness, and cost-utility of improved glycemic control for type 1 diabetes are presented in Table 9.

Sensitivity analysis was performed with alternative assumptions about the incidence and progression rates of complications, the mortality rate, costs of therapy, the medical costs of added years of life, the discount rate, and health utilities. The cost-benefit ratios were significantly affected by only a single combination of alternate assumptions. In that scenario, if the annual cost of improved glycemic control for type 1 diabetes could be decreased by at least 50% without adversely affecting outcomes, then, surprisingly, improved glycemic control would actually be cost saving. The DCCT Research Group concluded that for type 1 diabetes, the cost-effectiveness of improved glycemic control is within the range considered to represent a good value.

Another economic analysis of improved glycemic control for type 1 diabetes was conducted from the perspective of a health insurer on a simulated population in Israel (46). Published complication rates and treatment costs were used (47). Improved glycemic control was assumed to decrease the incidence of end-stage microvascular complications proportionate to the lower incidence of the corresponding early-stage complications observed in the DCCT. A 6% discount rate was assumed. Direct lifetime costs, but not benefits, of improved glycemic control compared with conventional therapy in type 1 diabetes were reported (Table 9). The

Table 9—Discounted costs, cost-effectiveness, and cost-utility of improved glyceemic control compared with conventional therapy

	Type 1 diabetes in the U.S. (44)		Type 1 diabetes in Israel (46)		Type 2 diabetes in the U.S. (48)	
	1994 dollars*	1998 dollars*	1994 dollars*	1998 dollars*	1994 dollars*	1998 dollars*
Lifetime cost of intensive therapy	99,822	114,535	151,900	166,780	76,922	88,260
Lifetime cost of conventional therapy	66,076	75,815	132,900	145,918	62,769	72,021
Excess lifetime cost of intensive therapy compared with conventional therapy	33,746	38,719	19,000	20,860	14,153	16,239
Cost per year of life gained with intensive therapy	28,661	32,886	NR		NR	
Cost per QALY gained with intensive therapy†	19,987	22,933	NR		16,002	18,360
Discount rate (%)		3		6		3

*Reported (recalculated) years of cost; †assigned utilities for preventing blindness, 0.31; ESRD, 0.39; LEA, 0.20. NR, not reported.

authors concluded that for type 1 diabetes, improved glyceemic control is not cost-saving, but they did not calculate a cost-benefit ratio for this intervention.

Type 2 diabetes

An economic analysis of improved glyceemic control for type 2 diabetes, intended to achieve normoglycemia by maintaining the HbA_{1c} level at ≤7.2%, has been conducted in the U.S. (48). The outcomes of such a regimen were predicted by using published epidemiologic data to model disease progression. It was assumed that the reduced risk gradients observed with improved glyceemic control in type 1 diabetes also apply to type 2 diabetes. Costs of this treatment were based on published figures.

Undiscounted benefits of improved glyceemic control compared with conventional therapy in type 2 diabetes are presented in Table 8. Costs of improved glyceemic control for type 2 diabetes were allocated for outpatient care, inpatient care, self-care supplies, and oral medications. Costs and cost-benefit ratios were discounted at a rate of 3% unless otherwise specified. The lifetime per patient discounted cost and cost-utility of improved glyceemic control are presented in Table 9.

Sensitivity analysis was performed with alternative assumptions about the ethnicity, mean age at diagnosis, and baseline HbA_{1c} levels of patients, as well as the incidence of complications, cost of therapy, and the discount rate. Non-Hispanic white ethnicity, age at diagnosis <36 years, or an initial HbA_{1c} of at least 9.2% were the likeliest predictors of better than average cost-effectiveness. The authors concluded that for type 2 diabetes, the cost-effectiveness of improved glyceemic control is within the range of interventions that are generally considered cost-effective.

Improved glyceemic control of diabetes is a clearly cost-effective strategy. Such intervention on simulated populations of patients with either type 1 or type 2 diabetes has resulted in increased years of life and QALYs at costs no higher than those of generally practiced interventions for other diseases.

The cost-benefit ratio of therapy for type 2 diabetes would be expected to be enhanced by substituting a less costly but equipotent oral agent for a costlier oral agent. Indeed, at a Veterans Administration clinic where acquisition cost of glipizide exceeded that of glyburide, when type 2 diabetic patients were converted from glipizide to glyburide, the result was equal control at a lower cost (49).

SELF-MANAGEMENT— An economic analysis of diabetes self-management programs that prevent hospitalizations was performed in nine empirical outpatient studies (50–60) (Table 10). Each self-management intervention reported 1) costs of

providing a self-management program, and 2) hospital costs over the subsequent year with and without the intervention. One study (53) was reported in two additional articles (54,55).

Target population

The target populations were not screened to identify a subset who were eligible for or who warranted a self-management intervention.

Screening method

No economic analysis of diabetes self-management programs used screening.

Screening schedule

No economic analysis of diabetes self-management programs used screening.

Treatment population

The treatment population consisted of patients with either type 1 or type 2 diabetes in eight studies (50–56,58–60) and only type 1 diabetes in one study (57).

Table 10—Benefit-cost analysis of outpatient diabetes self-management intervention studies

Author	Year of costs	Curriculum	Cost† (in dollars)	Benefit‡ (in dollars)	Benefit-cost ratio
Spaulding and Spaulding (50)	1974	Begin insulin	154	1,293	8.40
Laugharne and Steiner (51)	1976	Self-care	144	206	1.43
Davidson et al. (52)	1978	Primary care	434	192	0.43
Nersesian et al. (53)*	1982	Self-care	150	293	1.95
Schwartz et al. (54)*					
Zaremba et al. (55)*					
Whitehouse et al. (56)	1979	Self-care	770	1,005	1.31
Fishbein (57)	1985	Self-care	100	876	8.76
Rettig et al. (58)	1983	Home education	175	–175	—
Bruce et al. (59)	1983	Begin insulin	370	1,857	5.02
de Weerd et al. (60)	1990	Self-care	144	–144	—

*Same program; †self-management training expenses per patient; ‡self-management training expenses minus averted hospital expenses per patient.

Table 11—Cost-benefit ratios, unadjusted and adjusted for medication savings, of medical nutrition therapy in type 2 diabetes

Type of medical nutrition therapy	Cost per mg/dl decline in plasma glucose		Cost per 0.1% decline in HbA _{1c}	
	1993 dollars	1998 dollars	1993 dollars	1998 dollars
Practice guidelines for nutrition care (unadjusted)	5.84	7.02	12.05	14.49
Basic care (unadjusted)	5.75	6.91	6.08	7.31
Practice guidelines for nutrition care (adjusted)	4.20	5.05	8.66	10.41
Basic care (adjusted)	5.32	6.40	5.63	6.77

Modified from Reference 70.

Treatment method

Insulin therapy was initiated in 2 programs in which curricula consisted of either 2 or 3 visits to the day care unit followed by several home visits and daily phone calls by the nurse during the first 2 weeks (50) or up to 13 visits (with a mean of 5 visits) to the outpatient center (59). In five studies, a complete self-care curriculum was provided at the outpatient center, consisting of either 10 h (53–55,57), 12 h (60), 4 days (51), or 5 days (56) of teaching. One self-management program was taught at patients' homes by visiting nurses in up to 12 sessions (58). One study was a multidisciplinary primary care clinic for patients with diabetes, where each team member provided education each visit (52) (Table 10).

Baseline program

Hospital costs over a 1-year period after the self-management intervention were compared with predicted hospital costs for 1 year without a self-management program.

Types of costs

Only direct costs of self-management programs and hospitalizations were considered.

Year of costs

The year of costs of each study is listed in Table 10.

Discount rate

Discounting was not performed because the benefits were measured within only 1 year of the intervention.

Costs or savings

The costs for each self-management program are listed in Table 10.

Benefits

The benefits for each self-management program (training expenses minus averted hospital expenses) exceeded the program costs in seven (50–57,59) of the nine studies (Table 10).

Cost-benefit ratio

In the seven studies in which benefits exceeded costs (50–57,59), the benefit-cost ratio (which is the inverse of the cost-benefit ratio) ranged from 0.44 to 8.76. Thus, for every \$1 spent on self-management training, there was a net savings of \$0.44 to \$8.76 (Table 10).

Sensitivity analysis

Sensitivity analysis testing is only performed on modeled data, not empirical data, and was therefore not performed in these nine empirical studies.

Perspective

All nine studies were conducted from the perspective of a health insurer (50–60).

Discussion

All but two of the diabetes self-management economic studies suffered from a lack of a good control group and/or randomization (58,60,61). The self-management intervention patients were compared with randomized control subjects in only two studies, and in both reports, the self-management program did not lower hospital costs (58,60). In the other seven studies, all of which were not randomized, the intervention population was compared with one of the following: the same population 1 year before the intervention (53–55,57), a retrospectively selected population that was hospitalized over the same time period (50,59), the entire population of the diabetes clinic from which the study popula-

tion was drawn (52,56), or an unspecified population (51).

An additional study demonstrated economic benefits of diabetes self-management programs. An inpatient diabetes self-management program was reported to reduce length of hospital stays, but program costs were not disclosed (62).

Flawed but consistent evidence suggests that diabetes self-management programs are possibly cost-effective. The economic analyses of diabetes self-management programs have not only been poor in terms of their methodology, but they have measured only short-term savings over 1 year. Randomized controlled studies examining the long-term costs and benefits of this intervention are definitely needed.

CASE MANAGEMENT — A diabetes case management intervention uses a team of diabetes specialists to provide individual attention, timely referrals, and intensive self-management training (63). Such an intervention is intended to reduce the number and the length of hospitalizations for diabetes.

Cost-saving case management for inpatients with diabetes can be provided by a diabetes team consisting of an endocrinologist, a diabetes nurse educator, and a registered dietitian (64). In a New York City hospital, 34 nonrandomized patients with diabetes received a diabetes team consultation from November 1991 through January 1992. The average length of stay was 3.6 days for team patients, which was shorter than the length of 5.5 days for 43 patients seen by an individual endocrine consultant from September 1990 through May 1991 ($P < 0.05$) or the length of 8.2 days for 27 no-consultation patients seen from September 1990 through May 1991 ($P < 0.0001$). Hospital costs of team patients compared with those of no-consultation patients fell by \$120,000, and team expenses were \$40,000. Each 1-day delay in consultation produced a 1-day increase in the length of stay (64).

Studies of an inpatient case management program that reduced the length of hospital stays (65), as well as one outpatient case management program that did (66) and another that did not (67) reduce hospital admissions, all did not present the added costs of providing this intervention. The economic attractiveness of case management teams to decrease costs has not been studied in randomized controlled trials. Subsets of patients with diabetes most likely to benefit long-term from this approach have not been identified. The

Table 12—The effects of SMBG compared with urine glucose testing on HbA_{1c} in randomized controlled trials of a type 1 diabetic population in Russia and a type 2 diabetic population in the U.S.

Time	Type 1 diabetic population in Russia (71)		Type 2 diabetic population in the U.S. (72)	
	SMBG	UGT	SMBG	UGT
Baseline	12.6	12.5	12.4	11.7
1/2 year	NR	NR	10.4	9.7
1 year	9.3	9.4	—	—
2 years	9.2	9.2	—	—

Data are for timed HbA_{1c} (%). NR, not reported; SMBG, self-monitoring of blood glucose; UGT, urine glucose testing.

economic impact of case management for diabetes is, therefore, unclear.

MEDICAL NUTRITION

THERAPY — The economic impact of medical nutrition therapy (MNT) for diabetes has been poorly documented. This intervention is intended to improve plasma glucose and HbA_{1c} levels to prevent complications. MNT is widely practiced as a component of programs providing intensive education or case management. The costs compared with benefits of this intervention in isolation have been reported only in a single study.

A randomized controlled trial of an MNT intervention in type 2 diabetes measured program costs and outcomes (68). Optimal MNT, using practice guidelines for nutrition care (PGC), was compared with basic nutrition care (BC). PGC was developed by a consensus panel of nutrition and diabetes experts (69). PGC consisted of three visits with a dietitian over 6 months and a measurement of HbA_{1c} level. BC consisted of a single visit with a dietitian. Serum glucose and HbA_{1c} levels fell after 6 months, in both the PGC group and the BC group (70). No long-term outcome data were collected.

Staff costs were calculated and divided by the differences between pre- and post-intervention fasting serum glucose levels and HbA_{1c} levels. The cost-benefit ratio of each intervention was adjusted (and slightly enhanced) by subtracting medication savings accrued during the intervention program from program costs (70). The unadjusted and adjusted cost-benefit ratio figures per decline in plasma glucose and HbA_{1c} levels are presented in Table 11. On an absolute scale, PGC, compared with BC, effected a greater fall in both the plasma glucose and HbA_{1c} levels. The economic impact of optimal MNT, however, was no better than that of BC.

There is no generally accepted formula for converting the cost-benefit ratio of MNT from a reduction in plasma glucose or HbA_{1c} levels into life-years or QALYs gained. MNT for diabetes is an intervention in which cost-effectiveness is unclear.

SELF-MONITORING OF BLOOD

GLUCOSE — Self-monitoring of blood glucose (SMBG) facilitates adjustments in diabetes treatment intended to improve serum glucose and HbA_{1c} levels and prevent complications. The costs and benefits of SMBG, as a component of nonintensive therapy, have been compared with those of urine glucose testing in two randomized controlled trials. A type 1 diabetic population in Russia (71) and a type 2 diabetic population in the U.S. (72) used test results to modify their medication dosages. In both trials, SMBG was no more effective at lowering HbA_{1c} levels than urine glucose testing (Table 12), but SMBG was costlier. An economic analysis of an intensive regimen to lower fasting blood glucose levels below the threshold for measuring urinary glucose, which could compare SMBG with no SMBG, has not been reported. There is a need for good randomized controlled tri-

als of the effectiveness of SMBG as a prerequisite for cost-effectiveness analyses. SMBG is an accurate, widely practiced intervention for diabetes. However, the relationship between the medical and economic benefits of SMBG is unclear.

FOOT CARE — No economic analysis of a foot care intervention in diabetes to prevent LEA has been reported in medical literature. Controlled nonrandomized retrospective comparisons of hospital costs for LEA and revascularization have been conducted in seven cohorts of patients with diabetes (73–78) (Table 13). The costs of either procedure ranged from \$15,100 to \$92,417 in 1998 dollars. In each study, the cost of revascularization was 71–107% that of LEA. The annual incidence of LEA among patients with diabetes in the U.S. is ~0.8% (79). A foot care program consisting of podiatric care, education, and specially fitted shoes can achieve a 50% reduction in the amputation rate (80) by reversing risk factors for foot wounds (81,82). Based on these two rates and an assumed cost of \$25,000 (in 1998 dollars) for an LEA, the savings provided by a foot care program can be calculated. This intervention would lower apportioned annual LEA costs per patient from 0.8% × \$25,000, or \$200, to 0.8% × 50% × \$25,000, or \$100, which is a \$100 savings. If the cost of such a program was less than \$100 annually, then the program would be cost-saving. There is reason to predict that formal economic studies of foot care will demonstrate this intervention to be clearly cost-effective or even clearly cost-saving.

OTHER

INTERVENTIONS — Blood pressure control (83), blood lipid control (84), smoking cessation (85), and exercise (86)

Table 13—Comparison of charges for amputation and vascular reconstruction performed on cohorts

Author	Year of costs	Professional fee included	Amputation charges (in dollars)		Bypass charges (in dollars)	
			Historic	1998	Historic	1998
Mackey et al. (73)	1984	No	40,563	91,950	40,769	92,417
Raviola et al. (74)	1985	Yes	24,700	52,686	23,500	50,127
Gupta et al. (75)	1981	Yes	27,225	79,507	26,194	76,497
Cheshire et al. (76)	1989	Yes	21,726	35,230	16,725	27,121
Gibbons et al. (77)	1984	No	20,498	46,465	21,978	49,821
Gibbons et al. (77)	1990	No	18,341	27,275	19,694	29,287
Panayiotopoulos et al. (78)	1995	No	19,458	21,364	13,753	15,100

Table 14—Interventions for diabetes classified according to economic impact

Clearly cost-saving
Retinopathy screening and treatment
Pre-conception care
Clearly cost-effective
Nephropathy prevention in type 1 diabetes
Improved glycemic control
Possibly cost-effective
Neuropathy prevention in type 2 diabetes
Self-management training
Non-cost-effective
Unclear cost-effectiveness
Case management
MNT
SMBG
Foot care
Blood pressure control
Blood lipid control
Smoking cessation
Exercise
Weight loss
HbA _{1c} measurement
Influenza vaccination
Pneumococcus vaccination

are four widely practiced interventions to prevent cardiovascular disease. Economic analyses have clearly demonstrated that for the general population, such practices are clearly cost-effective (83–86). For patients with diabetes, however, an economic analysis of these interventions has not been reported, but it is not unreasonable to expect that these interventions would also be clearly cost-effective for patients with diabetes. Weight loss in type 2 diabetes decreases the risk of cardiovascular disease (87). No economic analysis of weight loss has matched the costs of a weight loss intervention with life-years gained. Furthermore, no economic analysis has been reported for patients with diabetes regarding HbA_{1c} measurement (88) or vaccinations to prevent influenza (89) and pneumococcus (90) infections.

CONCLUSIONS — The economic impact of 17 widely practiced interventions to decrease complications of diabetes can be classified as 1) clearly cost-saving, 2) clearly cost-effective, 3) possibly cost-effective, 4) non-cost-effective, or 5) unclear (Table 14). A particular enhancement in the incremental quality and/or quantity of life in diabetes can be attained at a net savings clearly by interventions that provide 1) retinopathy

screening with laser photocoagulation to prevent blindness, or 2) pre-conception care to prevent birth defects. Such a life enhancement can be attained at a cost no more than that of generally accepted interventions for other diseases clearly by interventions that provide 1) nephropathy screening with ACEI therapy to prevent ESRD in type 1 diabetes, and 2) improved glycemic control to prevent multiple end-stage microvascular complications and possibly also by interventions providing 1) nephropathy screening with ACEI therapy to prevent ESRD in type 2 diabetes, and 2) self-management training. No life enhancement in diabetes has been shown to require a cost exceeding that of generally accepted interventions for other diseases. The cost of attaining such a life enhancement in diabetes is unclear for such interventions as 1) case management, 2) MNT, 3) SMBG, 4) foot care, 5) blood pressure control, 6) blood lipid control, 7) smoking cessation, 8) exercise, 9) weight loss, 10) HbA_{1c} measurement, and 11) vaccinations against influenza and pneumococcus.

Economic resources for health care are becoming scarce. For patients with diabetes, although any effective intervention is worthwhile, the implementation of clearly cost-saving and clearly cost-effective interventions is now particularly warranted.

ADDENDUM — After this article was submitted, the U.K. Prospective Diabetes Study Group reported that the cost-effectiveness of tight blood pressure control in hypertensive patients with type 2 diabetes compared favorably with that of many accepted health care programs (91).

APPENDIX

Definition of terms used to describe concepts of health economics

Direct costs: Medical expenditures for screening and treatment (8).

Indirect costs: Lost earnings due to disease, disability, and death (8).

Utility: An estimate, on a 0–1 scale, of the quality of life associated with a state of health (92,93).

Quality-adjusted life year (QALY): A measurement of both the incremental quality and quantity of life associated with a health care intervention. QALYs are calculated by multiplying the utility for a particular state of health by the time (in years) spent in that state of health. The expression of health care benefits as QALYs allows comparison of interventions not only for

the same disease, but also for different diseases (94). For example, assuming 1) a 50% per year incidence of a complication in an untreated population, 2) a 60% risk reduction from an intervention, and 3) a utility of 0.4 for avoidance of the complication, then the intervention provides $50\% \times 60\% \times 0.4$ or 0.12 QALYs per patient per year. If the added cost of providing the intervention to the entire population minus the savings realized from the lower complication incidence amounts to \$120 per patient per year, then the cost per QALY gained is \$120 divided by 0.12 or \$1,000. Cost-effectiveness: A measurement of the cost per year of life gained, unadjusted for quality, reported as cost per year of life gained (95).

Cost-utility: A measurement of the cost per year of life gained, adjusted for quality, reported as cost per QALY gained (95).

Discounting: A practice whereby future costs, and often benefits as well, are devalued at a constant proportional rate to be expressed at their current value (96). Future costs are discounted because it is assumed that the amount of money needed for future treatment can be acquired by investing a smaller amount of current funds at a compound interest rate. Discounting of costs reduces the amount of current financial resources needed for future costs. A constant relationship between dollars and health benefits is often assumed, which necessitates discounting future benefits (along with costs) to make them comparable to current benefits (97). Discounting of benefits reduces the current value of future benefits.

Acknowledgments — We thank Richard Kahn, PhD, for many helpful suggestions; Linda Rossi for expert editorial assistance; Mavie Portman for manuscript preparation; and Ann Curry for document procurement.

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