Self-monitoring of Blood Glucose in Type 2 Diabetes: Cost-effectiveness in the United States

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Objective: This study was designed to model the cost-effectiveness of self-monitoring of blood glucose (SMBG) at frequencies of 1 or 3 times per day for patients with type 2 diabetes mellitus (T2DM) who are treated with oral antidiabetic (OAD) medications within the United States.

Study Design: Based on a Kaiser Permanente study showing glycosylated hemoglobin (HbA1C) improvements related to SMBG frequency, a validated model was used to project 40-year clinical and economic outcomes for SMBG at 1 or 3 times per day vs no SMBG.

Methods: Baseline mean HbA1C (8.6%), age, and sex of the simulated cohort came from the Kaiser analysis of new SMBG users of OAD agents for T2DM. Other cohort characteristics, transition probabilities, utilities, and direct costs (from a US public payer perspective) were derived from relevant literature. Outcomes were discounted at 3% per annum, with sensitivity analyses performed on discount rates and time horizons.

Results: Compared with no SMBG, quality-adjusted life expectancy increased with SMBG frequency. Increases were 0.103 and 0.327 quality-adjusted life-years (QALYs) for SMBG at 1 and 3 times per day, respectively. Corresponding incremental cost-effective ratios (ICERs) were $7856 and $6601 per QALY gained. Results indicate that SMBG at both 1 and 3 times per day in this cohort of patients with T2DM taking OADs would represent good value for money in the United States, with ICERs being most sensitive to the time horizon.

Conclusions: Longer time horizons generally led to greater SMBG cost-effectiveness. The ICER for SMBG 3 times per day was $518 per QALY over a 10-year time horizon, indicating very good value.

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The contribution of cost-effectiveness analyses in assessing the long-term value of healthcare interventions and management tools is increasing for a large number of disease states, including diabetes mellitus. The extremely large and growing economic burden of this chronic disease has been well documented. According to the Centers for Disease Control and Prevention, approximately 14.7 million people in the United States had been diagnosed with diabetes through 2004, with type 2 diabetes mellitus (T2DM) accounting for about 90% of those cases.[1] Individuals with diabetes are commonly treated for concomitant neurological disease, peripheral vascular disease, cardiovascular disease, renal disease, endocrine/metabolic complications, and ophthalmic complications.[2,3] A total of $92 billion in direct medical expenditures were attributable to diabetes for 2002, and the projected increase in the diabetes population suggests that annual direct costs could reach $138 billion by 2020.[2] Identifying cost-effective technologies for diabetes management is therefore crucial for optimizing the use of healthcare dollars in the United States.

Benefit of Glycemic Control

Glycemic control is fundamental to diabetes management, and has a well-established role in preventing, delaying, and/or reducing diabetes-related complications.[4,5] The widely cited United Kingdom Prospective Diabetes Study (UKPDS) showed that each 1% reduction in glycosylated hemoglobin (HbA1C) corresponded to a 37% reduction in microvascular complication risk in T2DM.[4] Decreases in complications, in turn, have demonstrated short- and long-term economic benefits.[6-8]

Self-monitoring of Blood Glucose

One management tool repeatedly shown to aid in the improvement of glycemic control for insulin-using patients is self-monitoring of blood glucose (SMBG).[9-12] Additionally, increased SMBG *frequency* has been linked to lower HbA1C values for this population.[13-15] Consequently, clinical guidelines recommend SMBG at least 3 times daily for patients with diabetes who use insulin.[3,16]

In this issue
Take-away Points / p139
www.ajmc.com
Full text and PDF

SMBG for Patients With T2DM Taking Oral Antidiabetic Medications

For patients with T2DM who are treated with oral antidiabetic (OAD) agents (and not using insulin), findings (as well as subsequent recommendations) regarding SMBG have been more inconsistent. Some researchers have failed to find a clear benefit of SMBG for individuals with T2DM who are being treated with OADs.[17,18] However, recent meta-analyses of randomized trials have led to conclusions that SMBG in this patient population is generally associated with a statistically significant improvement in HbA1C.[19-21]

Additional evidence regarding the effect of SMBG frequency on patients with T2DM taking OADs comes from a large-scale (n >30,000), 3-year observational study by the Kaiser Permanente Healthcare Group. Glycemic control was evaluated for patients with T2DM grouped according to current treatment and history of SMBG use.[13,15] Patients with T2DM taking OADs were defined as either "new users" (newly initiating SMBG) or "prevalent users" (had practiced SMBG within the prior year).

While both groups showed a graded improvement in HbA1C related to SMBG frequency (up to 3 times per day), response to increasing frequency was greatest among new users. When new users began SMBG at 1, 2, or 3 times per day, reductions in HbA1C were 0.32%, 0.77%, and 1.02%, respectively.

Despite these findings, the long-term value of SMBG for T2DM patient populations treated with OADs has yet to be firmly established. Published recommendations currently vary widely and lack specificity.[3] Compounding the issue is that in this era of cost containment, SMBG represents a relatively costly management tool when viewed solely within short-term time horizons. The direct costs associated with the use of SMBG have recently been estimated to represent 58.8% of Medicare B program expenditures for treating patients with T2DM who are not taking insulin.[22] Clinical and policy stakeholders in the United States are therefore interested in obtaining additional information with which to assess the long-term clinical and economic outcomes associated with SMBG frequency for this large and growing patient population.

Study Objectives

The present study was designed to model the cost-effectiveness of SMBG (at frequencies of 1 or 3 times daily) compared with no SMBG for patients with T2DM taking OAD medications. We addressed the extent to which increased costs associated with SMBG could be offset by fewer complications and increased quality-adjusted life-years (QALYs), so that SMBG would represent a cost-effective management tool for this patient population. An additional goal was to enumerate the comparative risks of several complications of diabetes for the 2 SMBG simulated groups, relative to patients not using SMBG.

METHODS

A computer-based diabetes model was used to project the long-term (40-year) clinical and economic outcomes associated with SMBG by patients with T2DM treated with OADs in the US payer setting. Outcomes included estimated gains in life expectancy and in QALYs, long-term costs of treatment and complications, cumulative risk of specific complications, and incremental cost-effectiveness ratios (ICERs).

Model Design and Validation

The CORE Diabetes Model was designed to predict the development and progression of type 1 or type 2 diabetes over long-term time horizons (≥5 years), using the best available clinical and cost data. The model is based on 15 interdependent submodels, each having a Markov structure. Monte Carlo simulation and tracker variables can account for multiple complications (cardiovascular, neuropathy, renal and eye disease) at the individual patient level. Described and validated in peer-reviewed publications, the model is consistent with recently published American Diabetes Association (ADA) modeling guidelines and principles.[23,24] This ADA consensus document also provides support for the 40-year time horizon in the base case scenario. Because diabetes complications (eg, end-stage renal disease) may take years or even decades to occur, time horizons that cover "a patient's lifetime" such as 30 to 40 years are commonly incorporated for cost-effectiveness analyses.[25]

Simulation Cohorts and Treatment Effects

Cohort characteristics and magnitude of treatment effects were based on patient samples and study outcomes from the longitudinal study by Karter et al described above.[15] Detailed information was available for the "new user" cohort, and in the present analysis only results for subsets of patients within this large group (n >16,000) were included. The inclusion of this cohort, according to the investigators, reduces chronology bias and case-mix confounding associated with studies that pool data for "new" vs "ongoing" users of SMBG.

A simulation cohort was defined using mean baseline HbA1C, age, smoking status, and sex corresponding to patients with T2DM taking oral agents and newly initiating SMBG.[13] Information on race/ethnicity came from an earlier observational study of similar patients with T2DM,[15] and key clinical parameters were based on the diabetes-specific substudy of the National Health and Nutrition Examination

Survey (NHANES),[26] as well as from 5 other published papers[27-31] (Table 1).

Among new users treated with OADs in the Karter et al study,[13] use of SMBG at a frequency of 0.51 to 1.00 strips per day (n = 2611) or 2.51 to 3.00 strips per day (n = 318) was associated with reductions in HbA1C of –0.32% ± 2.56% and –1.02% ± 1.7%, respectively. Standard deviations necessary for this analysis were supplied by the Kaiser Permanente study group. The reference group (referred to here as the no SMBG group) consisted of the 5313 patients taking OADs who did not use SMBG or who (on average) self-monitored at a frequency of no more than 0.5 times per day. The mean change in HbA1C for this group was +0.13% ± 2.38%.

The simulated mean change in HbA1C was maintained over the course of the simulation (40 years). Based on the progressive nature of diabetes as documented through the UKPDS, it was assumed that after 5 years, patients switched to insulin treatment.[32] Furthermore, it was conservatively assumed that although patients continued to use SMBG (testing frequency 3 times per day) when treated with insulin, no further improvements in HbA1C were associated with its use.[25] In the base case, compliance was modeled to be 100%.

Table 1. Baseline Characteristics of the Simulated Patient Cohort

Characteristic	Value	Reference
HbA1C, %	8.6 (SD 2.0)	Karter et al[13]
Age, y	62.8 (SD 11.8)	Karter et al[13]
Male, %	57.5	Karter et al[13]
Ethnicity		Karter et al[15]
Non-Hispanic White	0.67	
Asian/Pacific Islander	0.11	
African American	0.08	
Hispanic	0.07	
Other/Multi-ethnic/Native American	0.08	
Duration of diabetes, y	12	NHANES[26]
Current smokers, %	20.7	NHANES[26]
Baseline total cholesterol, mg/dL	210	NHANES[26]
Baseline HDL-C, mg/dL	44	NHANES[26]
Baseline LDL-C, mg/dL	122	NHANES[26]
Baseline triglycerides, mg/dL	237	NHANES[26]
Body mass index, kg/m^2	32	NHANES[26]
Prevalence of		
Myocardial infarction, %	10.8	NHANES[26]
PVD, %	14.0	Miller et al[27]
Stroke, %	8.8	NHANES[26]
CHF, %	8.2	NHANES[26]
GPR, %	7.6	Harris[28]
BDR, %	39	Harris et al[29]
PDR, %	3	Harris et al[29]
Foot ulcer, %	10.5	Moss et al[30]
Neuropathy, %	40.0	Brändle et al[31]
Amputation, %	2.6	Moss et al[30]

BDR indicates background diabetic retinopathy; CHF, congestive heart failure; GPR, gross proteinuria; HbA1C, glycosylated hemoglobin; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; PDR, proliferative diabetic retinopathy; PVD, peripheral vascular disease.

Costs, Utility Values, and Complications

Analyses were conducted from a public payer perspective in the US healthcare system and thus included only direct medical (treatment and complication) costs. Costs of treating diabetes-related complications were extracted from published sources[33-39] and inflated to 2006 US dollars using the Consumer Price Index (Table 2).[40]

Acquisition costs for strips and lancets required for monitoring were based on Medicare reimbursement values (as supplied by LifeScan, a Johnson & Johnson Company) and were $0.74 and $0.12 per unit, respectively). The SMBG monitor itself was considered to be cost-free in the model. Patient education and training costs were based on the assumption that patients receive a 1-hour course from a nurse at the initiation of SMBG during year 1 only, at a cost of $108.77.

Discounting rates of 3% were applied to both clinical and economic outcomes.[41] Utility values used to calculate QALYs were based on data from the UKPDS, and from other published studies,[42-46] with no "dis-utility" assumed for the SMBG use. Finally, the examination of diabetes-related complications included the calculation of cumulative incidence, as well as relative risk for SMBG at 1 and 3 times per day compared to no SMBG.

Table 2. Event, State, and Other Costs Used in the Model

Description of Event or State	Cost per Event or State ($)	Reference
Myocardial infarction		
Year of event	37,422	O'Brien et al[33]
Each subsequent year	2069	O'Brien et al[33]
Angina		
Year of onset	7424	O'Brien et al[33]
Each subsequent year	1917	O'Brien et al[33]
Congestive heart failure		
Year of onset	3215	O'Brien et al[33]
Each subsequent year	3215	O'Brien et al[33]
Stroke		
Year of event	49,556	O'Brien et al[33]
Each subsequent year	16,539	O'Brien et al[33]
Peripheral vascular disease, onset	4707	DRG Guidebook[34]
End-stage renal disease	45,638	O'Brien et al[33]
Retinal photocoagulation	834	O'Brien et al[33]
Severe vision loss/blindness		
Year of onset	4039	O'Brien et al[33]
Subsequent years	4039	O'Brien et al[33]
Cataract extraction	2655	DRG Guidebook[34]
Neuropathy, onset	408	O'Brien et al[33]
Uninfected ulcer	1769	Shearer et al[35]
Infected ulcer	3198	Shearer et al[35]
Gangrene	6240	Shearer et al[35]
Amputation		
Year of event	33,257	O'Brien et al[33]
Years 2+ after event	1195	O'Brien et al[33]
Ketoacidosis event	13,404	O'Brien et al[33]
Major hypoglycemic event	1191	Bullano et al[36]
Annual cost of aspirin	23	*Drug Topics Red Book*[37]
Annual cost statins (assume simvastatin 10 mg @ $238/100 tabs, inflated to $US 2006)	948	*Drug Topics Red Book*[37]
Annual cost angiotensin-converting enzyme inhibitor (based on 25 mg captopril tid)*	426	Golan et al[38]
Cost of screening for retinopathy	82	O'Brien et al[33]
Cost of screening for microalbuminuria	19	O'Brien et al[33]
Cost of screening for gross proteinuria	27	O'Brien et al[33]
Cost (monthly) of nonstandard ulcer treatment (eg, Regranex)	168	Kantor & Margolis[39]

Costs are expressed in $US, 2006 values.
*tid indicates 3 times a day.

Statistical Methods

To evaluate uncertainty in the simulated cost-effectiveness outcomes, nonparametric resampling methods were used.[23,47,48] Each probability in the model was sampled, using a first-order Monte Carlo simulation, to provide a point estimate for each parameter. Using a second-order Monte Carlo simulation, the resampling method was then applied to each parameter from the first-order Monte Carlo results. Costs and clinical outcomes were produced for 1000 theoretical patients, with each going through the model 1000 times.[48] The resulting joint distribution of mean incremental costs and effectiveness gained was used to plot a cost-effectiveness acceptability curve; that is, the percentages of joint distributions falling within a given cost-effective range (eg, ≤$50,000, ≤$20,000, etc).[49] This strategy is commonly included in cost-effectiveness analyses to illustrate how likely it is that an intervention or tool would be cost-effective for a particular willingness to pay.

Sensitivity Analyses

Sensitivity analyses were performed on 2 key assumptions used in the base case cost-effectiveness simulation: discounting rate for costs and clinical benefits (0% and 6%) and time horizon (5 and 10 years) for outcomes. To examine cost-effectiveness with less than 100% compliance, 2 additional scenarios were simulated: (1) treatment costs for SMBG 3 times per day but HbA1C effects at the 2 times per day level (representing 66% compliance), and (2) costs for SMBG 3 times per day but HbA1C effects at only the once per day level (representing 33% compliance).

RESULTS

Life Expectancy and Quality-adjusted Life-years

For patients testing once per day, undiscounted life expectancy and QALYs were improved by 0.205 and 0.103, relative to patients not using SMBG. Use of SMBG 3 times per day was associated with even greater improvements compared with not testing; the increase in undiscounted life expectancy was 0.647 years, and the increase in QALYs was 0.327 (Table 3).

Diabetes-related Complications

The cumulative incidence of 16 diabetes-related complications modeled for no SMBG patients are presented in Table 4. Also included are risk ratios (relative to no SMBG) modeled for SMBG once per day and 3 times per day. Compared with no SMBG, SMBG once per day was projected to have very slightly higher risks for 2 complications (first stroke and first amputation). Of the other 14 complications, SMBG once per day was associated with slightly lower risks for 13 (relative risks ranging from 0.921 to 0.988); for end-stage renal disease, the risk reduction was greater than 10% (relative risk 0.898). The number needed to treat (NNT) ranged from 41 for onset of neuropathy to 513 for angina.

Simulated patients utilizing 3 times daily SMBG showed greater reductions in the cumulative incidence of many (particularly microvascular) complications. The relative risk was lower for 14 of 16 complications modeled and slightly increased for 2 (first stroke and first amputation). SMBG 3 times per day resulted in relative risk improvements of at least 10% for 10 complications, with greatest risk reductions (>20%) for 2 renal-related complications (gross proteinuria 0.724, and end-stage renal disease 0.616) and for 2 complications related to the eye (proliferative retinopathy 0.739, and macular edema 0.786). The risk of peripheral vascular disease onset was also decreased by 20% with a relative risk of 0.797. The NNT ranged from 15 for microalbuminuria to 437 for angina, and NNT values were 20 or less for 4 complications.

Lifetime Direct Costs and Cost-effectiveness

For both scenarios, use of SMBG was associated with increased total direct medical costs (Table 3). Compared to no SMBG, increases in mean per patient lifetime direct medical costs were $808 for once per day and $2161 for 3 times per day SMBG. For once per day, the improvements in QALYs reported earlier partially offset the increased costs so that the projected ICER was $7856 per QALY gained. For 3 times per day, the even larger improvement in QALYs resulted in an ICER of $6601 per QALY gained. Complication costs were $66,317 for no SMBG, $65,511 for SMBG once per day, and $63,784 for SMBG 3 times per day.

Incremental Cost-effectiveness Scatter Plots/Acceptability Curves

Figure 1 shows the base case cost-effectiveness scatter plot for SMBG once per day vs no SMBG. Although more points were to the right of the grid (indicating greater effec-

Table 3. Summary of Base Case Results for SMBG at 1 or 3 Times Per Day Vs No SMBG for Patients Taking OADs

Outcomes	SMBG	No SMBG	Difference
SMBG once daily vs no SMBG			
Undiscounted life expectancy, mean (SD), y	9.633 (0.875)	9.428 (0.826)	0.205
QALYs, mean (SD)	4.954 (0.662)	4.851 (0.621)	0.103
Total lifetime costs, $ (SD)	87,408 (3635)	86,600 (3534)	808
Incremental costs per QALY gained (ICER)		$7856	
SMBG 3 times daily vs no SMBG			
Undiscounted life expectancy, mean (SD), y	10.075 (0.570)	9.428 (0.826)	0.647
QALYs, mean (SD)	5.179 (0.435)	4.851 (0.621)	0.327
Total lifetime costs, $ (SD)	88,761 (2859)	86,600 (3534)	2161
Incremental costs per QALY gained (ICER)		$6601	

ICER indicates incremental cost-effective ratio; OADs, oral antidiabetics; QALYs, quality-adjusted life-years; SMBG, self-monitoring of blood glucose; SD, standard deviation.

Table 4. Cumulative Incidence, Relative Risk, and Number Needed to Treat for Diabetes Complications for SMBG 1 and 3 Times Per Day Vs No SMBG for Patients Taking OADs

	No SMBG	SMBG Once Per Day		SMBG 3 Times Per Day	
Complication	Cumulative Incidence (%)	Relative Risk	NNT	Relative Risk	NNT
Cardiovascular disease					
Congestive heart failure	40.227	0.976	104	0.947	47
Acute myocardial infarction	35.311	0.972	101	0.926	38
First stroke	12.259	1.03	—	1.09	—
Angina	13.588	0.986	513	0.983	437
Renal disease					
Microalbuminuria	41.417	0.944	44	0.840	15
Gross proteinuria	21.149	0.922	61	0.724	17
End-stage renal	8.724	0.898	113	0.616	30
Eye complications					
Background retinopathy	25.647	0.932	58	0.805	20
Proliferative retinopathy	3.998	0.921	319	0.739	96
Severe vision loss	10.320	0.943	171	0.844	62
Macular edema	20.248	0.930	71	0.786	23
Cataract	7.600	0.964	361	0.891	121
Ulcer, neuropathy					
First ulcer	26.177	0.988	310	0.980	193
First amputation	8.357	1.002	—	1.03	—
Onset of neuropathy	50.098	0.951	41	0.872	16
PVD	20.861	0.934	73	0.797	24

NNT indicates number needed to treat; OADs, oral antidiabetics; PVD, peripheral vascular disease; SMBG, self-monitoring of blood glucose.

tiveness with SMBG once per day), the results showed wide scatter. This resulted partially from the relatively large (and therefore conservative) standard deviation used to model the clinical response (change in HbA1C). The base case cost-effectiveness scatter plot for SMBG 3 times per day vs no SMBG is shown in Figure 2. As expected, more points appear in the upper 2 quadrants, indicative of greater costs. Compared with the scatter plot for SMBG once per day, the upper right quadrant (indicating greater costs but greater effectiveness) contains a larger proportion of the points, and also shows less scatter.

Relative to no SMBG, acceptability at a willingness-to-pay of $50,000/QALY was 52.6% for SMBG once per day and 60.7% for SMBG 3 times per day. Compared with no SMBG, SMBG once per day would be cost-effective at the threshold of $20,000/QALY, 51.5% of the time and of $10,000/QALY, 51.3% of the time. For 3 times per day vs no SMBG, values were 56.7% and 51.6% for the $20,000/QALY and $10,000/QALY thresholds, respectively.

Sensitivity Analyses

As is commonly the case, results were sensitive to the time horizon used (Table 5). For SMBG once per day, reductions in time horizon to 5 years resulted in an ICER of $23,380/QALY. For SMBG 3 times per day, a 5-year time horizon was associated with an ICER of $29,137/QALY. With a 10-year time horizon, SMBG once per day resulted in an ICER of $9346/QALY. Finally, the ICER for SMBG 3 times per day was only $518/QALY under a 10-year time horizon, indicating very good value for money.

As expected, when compliance was modeled at 66% and at 33%, ICERs increased from the base case. For 66% compliance (SMBG 3 times per day treatment costs and 2 times clinical benefits, vs no SMBG), the difference in QALYs was

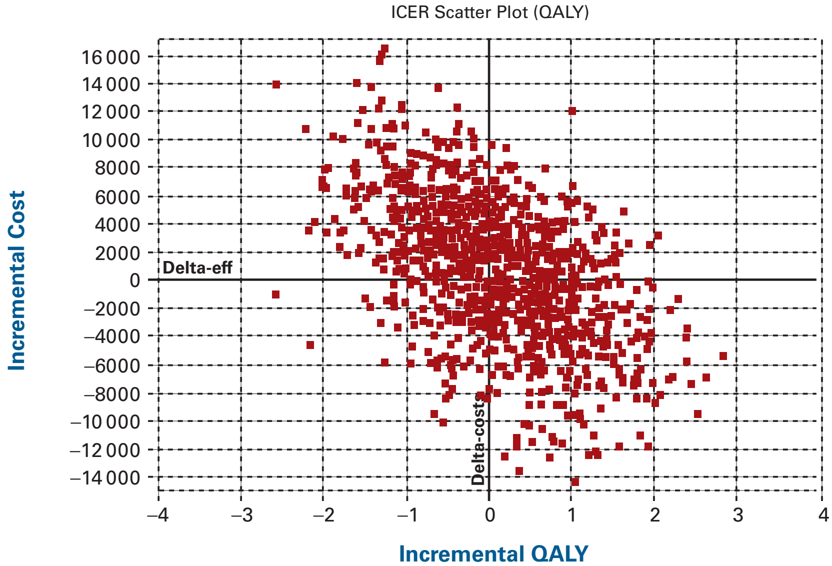
0.250, the difference in total costs was $2594, and the ICER was $10,362. For a compliance assumption of only 33% (SMBG 3 times per day treatment costs and once per day HbA1C improvement vs no SMBG), the difference in QALYs was 0.103 and the difference in total costs was $2952. These differences resulted in an ICER of $28,676 per QALY gained.

CONCLUSIONS

The CORE Diabetes Model was used to simulate the cost effectiveness (and several related outcomes) of SMBG at frequencies of 1 and 3 times per day for patients with T2DM taking OAD medications. The strengths and limitations of the model, as well as of the studies upon which present simulations were based, have been discussed in previous publications.[13,23,50]

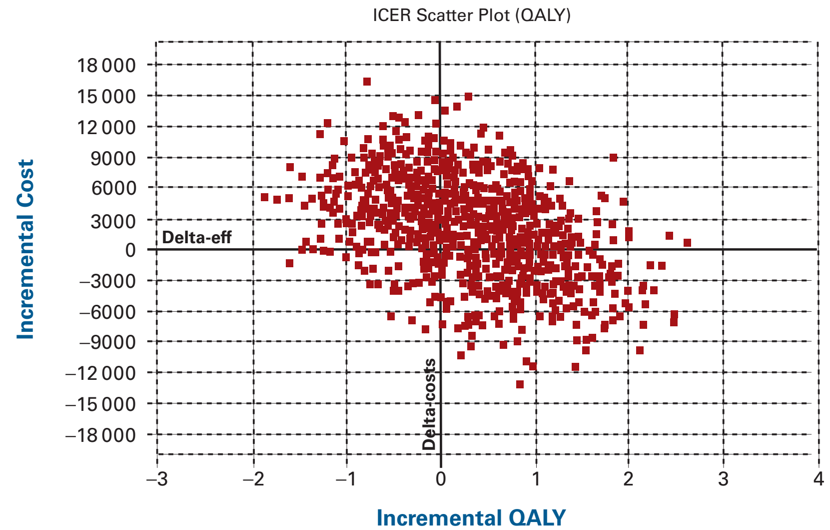
Results showed that a portion of the increased costs associated with SMBG were offset by reductions in the cumulative incidence of several diabetes-related complications and associated costs, as well as by modest increases in QALYs. The greatest reduction of risk (for 3 times per day relative to no SMBG) was associated with end-stage renal disease. The relative risk for (hypothetical) patients who monitor 3 times per day was 0.616. Although this complication had a smaller overall incidence compared with most others examined (8.724% of the simulated population at end point for no SMBG), its clinical and economic impact can be substantial.[51]

Figure 1. Base Case Analysis Scatter Plot of 1000 Samples of Mean Incremental Costs Plotted Against Mean Incremental Effectiveness (QALYs Gained)



This scatter plot was generated for 1000 patients using SMBG once per day vs SMBG 0 times per day. QALYs indicates quality-adjusted life-years; ICER, incremental cost-effectiveness ratio.

Figure 2. Base Case Analysis Scatter Plot of 1000 Samples of Mean Incremental Costs Plotted Against Mean Incremental Effectiveness (QALYs Gained)



This scatter plot was generated for 1000 patients using SMBG 3 times per day vs SMBG 0 times per day. QALYs indicates quality-adjusted life-years; ICER, incremental cost-effectiveness ratio.

As others have noted, several factors may contribute to the relatively modest effects typically found for SMBG in patients taking OADs. SMBG effects on HbA1C must be considered to be indirect, with no clear understanding of how the use of SMBG results in improved HbA1C (eg, Did patients' self-manage timing/dose of medication? Did they report monitoring results to clinicians who modified prescribed regimens?)[13,22,52] As Karter et al[13] have recently suggested, pathways are likely to vary on an individual basis, with both representing potentially important benefits of SMBG.

In both of the present comparisons, use of SMBG was associated with increased total direct costs. However, the base case ICERs, for both SMBG once per day vs no SMBG and SMBG 3 times per day vs no SMBG, were well within the range considered to represent good value for money in the United States.[49] Baseline results showed sensitivity to the time horizon considered. This finding is consistent with the nature of diabetes modeling; longer time horizons are generally necessary to capture the development of key complications and thus reflect the overall value of an intervention or a management tool.[24] Despite this, ICERs for both SMBG regimens remained below $30,000, even with the very short time horizon of 5 years. The ICER for SMBG 3 times per day was less than $600 over a 10-year time horizon. Moreover, this cost-effectiveness estimate can be considered conservative in the sense that a relatively large degree of variability in patient response was assumed.

As is the case for all studies, several limitations are relevant in interpreting present results. The patient cohort for this simulation was based on a large group of SMBG "new users" from a longitudinal study, and response to increasing SMBG frequency in that study was greatest for this subpopulation. The magnitude of present treatment effects should be interpreted within the context of this patient subpopulation.

Another factor that influences the results of any cost-effectiveness analysis is the cohort definition. For this study, the cohort had an average illness duration of 12 years and a baseline HbA1C of 8.6%. If patients had represented a "less severe" or a "more severe" clinical cohort, results could be expected to differ from those obtained in the present study. In general, SMBG has been found to be somewhat less cost-effective for patients with T2DM who are on a diet-and-exercise regimen only (ie, earlier in disease progression), and more cost-effective for individuals who require the use of insulin.[25]

Another important point is that for the base case simulations, compliance was assumed to be 100%, even for SMBG at 3 times per day. Thus, the theoretical patient population is likely to most closely resemble what has been described as motivated patients who have been appropriately educated in the use of SMBG, and who are likely to exhibit good self-care practices and relatively healthy lifestyles. It follows, then, that the benefit of SMBG in clinical settings may be increased by better integrating SMBG practice into an overall program of health education and therapeutic decision making.[13]

As expected, compliance rates less than 100% increased ICERs in the present study. However, the 66% compliance scenario ICER was only minimally higher than the ICER for the base case. Both the 66% and 33% compliance scenarios represent very conservative analyses in that they included the assumption that patients would continue to purchase enough strips to monitor 3 times per day, even though they would continue to monitor two thirds or even one third of the time. Compliance with healthcare interventions and management tools has become an important topic, and several researchers have attempted to assess SMBG compliance.[25,53] One of the

Table 5. Sensitivity Analyses for SMBG at 1 or 3 Times Per Day Vs No SMBG for Patients Taking OADs

	QALYs	ΔCosts ($)	Incremental Costs/ QALY Gained ($)
Once daily vs no SMBG			
Base Case	**0.103**	**808**	**7856**
Discount rates 0%	0.154	1242	8080
Discount rates 6%	0.072	632	8752
Time horizon 5 years	0.023	548	23 380
Time horizon 10 years	0.043	405	9346
3 times daily vs no SMBG			
Base Case	**0.327**	**2161**	**6601**
Discount rates 0%	0.469	3640	7762
Discount rates 6%	0.238	1487	6253
Time horizon 5 years	0.057	1654	29 137
Time horizon 10 years	0.149	77	518

SMBG indicates self-monitoring of blood glucose; OADs, oral antidiabetics; QALYs, quality-adjusted life-years.

most robust predictors of decreased SMBG "compliance" is the presence of environmental barriers such as lack of insurance coverage for monitoring supplies.[53,54]

A final study caveat to be mentioned is that economic outcomes were defined as direct medical expenditures. Not assessed were economic impacts of temporary incapacity, long-term disability, or mortality-related productivity losses. Regarding assessments of direct costs (for diabetes as well as other disease states), no single comprehensive source of data is available.[2] It is necessary to draw upon multiple sources having different levels of details regarding service utilization and various combinations of charges and reimbursements. Future work will benefit from efforts to standardize cost definitions and address their impact on cost-effectiveness evaluations.

This study was intended to contribute to the growing body of clinical and policy research on the long-term value of SMBG for patients with T2DM taking OADs. According to the ADA, more intensive disease management and the advent of new technologies are key factors for reducing health problems caused by diabetes, substantially improving the quality of life for patients and their families, and reducing national expenditures for healthcare services.[2]

The overall value of SMBG in the scenarios modeled was based on modest increases in glycemic control (associated with SMBG frequency), and partial offsets of SMBG expenditures through projections of complication cost reductions. Although the potential effect of acquisition costs could be nontrivial if applied to a very large patient population, the present analyses showed SMBG at both 1 and 3 times per day to be cost-effective management regimens for patients with T2DM being treated with OADs within the US payer system.

Take-away Points

Glycemic control reduces diabetes-related complications. These reductions have demonstrated short- and long-term economic benefits. Self-monitoring of blood glucose (SMBG) has been linked to improved glycemic control for insulin-using patients, and less consistently for patients with type 2 diabetes taking oral agents.

- Using data from a Kaiser Permanente "real-world" study, cost-effectiveness of SMBG 1 and 3 times per day was modeled.
- For both SMBG frequencies, relative risks (vs no SMBG) were lower for most complications.
- Although not cost saving, both SMBG frequencies showed good value. Incremental cost-effectiveness ratios were less than $8000 per quality-adjusted life-year gained.

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