Emerging Treatments and Technologies
ORIGINAL ARTICLE

Benefits of Information Technology–Enabled Diabetes Management

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OBJECTIVE — To determine the financial and clinical benefits of implementing information technology (IT)-enabled disease management systems.

RESEARCH DESIGN AND METHODS — A computer model was created to project the impact of IT-enabled disease management on care processes, clinical outcomes, and medical costs for patients with type 2 diabetes aged >25 years in the U.S. Several ITs were modeled (e.g., diabetes registries, computerized decision support, remote monitoring, patient self-management systems, and payer-based systems). Estimates of care process improvements were derived from published literature. Simulations projected outcomes for both payer and provider organizations, scaled to the national level. The primary outcome was medical cost savings, in 2004 U.S. dollars discounted at 5%. Secondary measures include reduction of cardiovascular, cerebrovascular, neuropathy, nephropathy, and retinopathy clinical outcomes.

RESULTS — All forms of IT-enabled disease management improved the health of patients with diabetes and reduced health care expenditures. Over 10 years, diabetes registries saved $14.5 billion, computerized decision support saved $10.7 billion, payer-centered technologies saved $7.10 billion, remote monitoring saved $326 million, self-management saved $285 million, and integrated provider-patient systems saved $16.9 billion.

CONCLUSIONS — IT-enabled diabetes management has the potential to improve care processes, delay diabetes complications, and save health care dollars. Of existing systems, provider-centered technologies such as diabetes registries currently show the most potential for benefit. Fully integrated provider-patient systems would have even greater potential for benefit. These benefits must be weighed against the implementation costs.

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Diabetes afflicts an estimated 20.8 million people in the U.S. and in 2005 was the fifth leading cause of death by disease (1). The American Diabetes Association (ADA) estimates that total diabetes-associated costs were $132 billion in 2002 and will increase to $156 billion by 2010 (2). Although advances in medicine can improve diabetes health outcomes and potentially help control these costs, recommendations for care are often neglected (3). As a result, diabetes often is poorly controlled despite adequate access to health care resources. Over 58% of patients with diabetes have an A1C $>7.0\%$ and over 15% have levels $>10.0\%$ (4). Many reasons may help explain this poor control, including inadequate support for patient self-care (4).

Diabetes disease management, which promotes patient involvement and care coordination, may increase compliance with recommended guidelines. Information technology (IT) represents a key tool in these programs. Effective diabetes management requires proper identification of patients with diabetes, data synthesis for population health snapshots and patient health summaries that promote care coordination, and knowledge delivery that gives patients the skills and resources for effective self-care. The National Institutes of Health's Behavioral Research and Diabetes Conference acknowledged that effective information technology is an integral component of successful diabetes management (5).

However, the evidence supporting IT-enabled diabetes management (ITDM) is relatively thin. Although a recent literature review (6) of IT in diabetes care found evidence for improved care processes, much of the existing literature is limited. Studies often fail to report costs or financial end points, have durations <1 year, fail to address issues such as patient recruitment, or have other limitations that prevent generalizations of cost-benefit or cost-effectiveness. The Congressional Budget Office noted many similar limitations in their review of the general disease management cost-benefit literature (7).

An understanding of the benefits of ITDM is essential to make informed investment decisions. For this reason, we developed computer simulations based on the best available evidence and projected the benefits of various forms of ITDM. This article reports the clinical and financial benefits of provider-based diabetes registries, computerized clinical decision support, remote monitoring and self-management technologies, and payer-sponsored technologies for diabetes management.

RESEARCH DESIGN AND METHODS

Diabetes management technologies

We examined three broad categories of diabetes management technologies, cate-

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Abbreviations: ADA, American Diabetes Association; CDSS, clinical decision support system; IT, information technology; ITDM, IT-enabled diabetes management.

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

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gorized by most commonly targeted users: *1*) clinicians and other providers, 2) patients, and *3*) payers or disease management companies on behalf of payers. We also propose a fourth category that would integrate patient and provider technologies into a single system.

Technologies used by providers

Diabetes registries track patients and their diabetes-specific information to enable several functions. Registries generate report card summaries, such as the proportion of patients with A1C levels >9%. These report cards may trigger communications, such as reminders about diabetes education sessions, and may interface with administrative systems to facilitate scheduling. Registries also can compare diabetes status with guidelines to display point-of-care reminders.

Clinical decision support systems (CDSSs) compare patient information from electronic medical records against a set of rules and generate alerts about potential errors and present treatment options to providers. Unlike disease-specific registries, the electronic medical records that underpin CDSS maintain and use comprehensive health information about patients. Also, in contrast to registries, electronic medical records generally are not designed for population-level reporting, though they may include database tools to create such reports.

Technologies used by patients

Patient self-management technologies use educational resources and data-gathering systems to improve patients' management of their own care between provider visits. Self-management technologies include automated phone systems that push reminders or educational content to patients, electronic diary tools that collect information to be taken to a visit, and online resources such as peer support groups.

Remote monitoring technologies transmit clinical data from patients' homes to providers' offices so that providers can modify care plans between visits. Whereas older technologies transmit data by phone keypad or modem, newer technologies upload data directly from glucometers and other home devices. Such data may be monitored for abnormalities that trigger provider feedback. The technologies may connect patients to resources such as their own health data, endorsed educational materials, and interactive self-care tools.

Technologies used by payers

Payer systems interface with electronic claims systems to track and monitor diabetes-specific information. The systems compare patient data with recommended guidelines, identify opportunities for improved management, and provide feedback to patients and providers by telephone, e-mail, or postal mail. Payer systems also can focus on behavior change, using trained health coaches to push educational and motivational information to patients. Payer interventions have no point-of-care component.

Integrated diabetes management system

We assume that an integrated system would provide a suite of technologies to support a full range of diabetes management activities. This system would allow providers to make effective decisions, both at the point of care and across the entire diabetic population, and empower patients to actively participate in those decisions. It would contain the registry, self-management, and remote monitoring technologies discussed above. Although we could find no published articles that show the effect of such a system, we include this platform to demonstrate its potential.

Model development

We built a computer simulation model to project the impact of ITDM on health and economic outcomes. Four software engines interact to project the impact of ITDM on processes of care, the impact those process changes have on disease progression, the dilution of ITDM effects from patient movement between health care organizations and programs, and the scaling of results to the national level. A range of methods were used to inform each of these components.

The Intervention Impacts Engine estimates the impact of ITDM on physiologic measures and processes of care informed by systematic review of the U.S. academic literature, trade publications, and general press. We used standard techniques and systematic review methodologies adapted from Stanford University's Evidence-Based Practice Center (8). Using a uniform instrument, the evidence was graded on study design quality and exemplification of the modeled technology. From this grading process, single best estimates of the impact of ITDM on the following measures were chosen: control of A1C, systolic blood pressure, and cholesterol, as well as compliance with foot, eye, and microalbuminuria screening. To estimate the impact of the integrated platform, the benefits of each component technology (registry, self-management, and remote monitoring) were combined assuming independence of effect.

The Disease Burden Engine, an extension of a disease simulation model previously published by the Centers for Disease Control and Prevention (9), estimates the effect process changes have on coronary artery disease, cerebrovascular disease, neuropathy, nephropathy, and retinopathy. This engine is a Markov model that identifies diabetes disease states, such as diabetic retinopathy, treated retinopathy, and blindness, and characterizes how patients transition through these states. Transition probabilities were derived from the results of major clinical trials and epidemiologic studies (9,10). The engine incorporates the Intervention Impacts Engine to predict how process changes due to ITDM influence progression through these disease states. The unweighted 2001–2002 National Health and Nutrition Examination Survey dataset provided epidemiologic data (11).

The Population Selection Engine projects how patients' decisions to enter and leave provider panels, payer plans, and associated management programs dilute the effect of ITDM. Estimates for the rates at which patients move between plans and programs were derived from focused literature searches (12–21).

The Benefit Projection Engine aggregates organizational benefits to produce national results. This engine relies on estimates of the distribution of organizational sizes and assumptions regarding the national rollout of ITDM. These estimates were derived from the U.S. Census, the American Medical Association, and Community Tracking Study data (22–24). The model was created as an influence diagram using Analytica software from Lumina Decision Systems (25) and leveraged functions of the software program and Monte Carlo simulation to incorporate uncertainty.

Assumptions

The 10-year simulations assumed that diabetes management is deployed nationally at a rate of 20% per year until full national implementation is achieved in year 5. The full impact on processes of care was applied in the year of implementation because all contributing studies re-

Table 1—*Baseline diabetic population characteristics*

	Provider-patient scenarios	Payer scenarios
Mean age (years)	52.5	52.8
Sex		
Male	45.0	45.0
Female	55.0	55.0
Ethnicity		
Non-Hispanic white	74.0	74.0
Non-Hispanic black	12.0	12.0
Hispanic	10.0	10.0
Native American	0.7	0.7
Asian	3.3	3.3
Insurance		
Commercial	67.0	66.5
Medicare	26.0	26.9
Medicaid	7.0	6.5
Comorbidities		
Hypertension prevalence	71.2	71.3
Dyslipidemia prevalence	60.7	60.6
Smoking prevalence	18.9	18.7
Mean physiological values		
A1C (%)	7.6	7.6
Systolic blood pressure (mmHg)	152.9	153.4
Total cholesterol (mg/dl)	211.7	211.8
Care process level		
Eye exam rate	14.2	14.2
Foot exam rate	44.9	44.9
Microalbuminuria screening	45.0	45.0

Data are percent, unless otherwise indicated.

ported results collected within 12 months of implementation. The effect of ITDM on processes of care remained constant, neither increasing nor decreasing in subsequent years, while a patient remained actively managed. If a patient left diabetes management, all benefits of ITDM were removed in subsequent years. All insured patients diagnosed with type 2 diabetes in the U.S. were eligible for enrollment. Patients with type 1 diabetes, those with glucose intolerance or who are undiagnosed, and those aged $<$25 years or without insurance were excluded from the model. Ten-year financial values were discounted to 2004, using a 5% real discount rate. Costs were based on the original Centers for Disease Control and Prevention model assumptions, updated to reflect changes in costs and standards of care.

RESULTS — The model produced simulated national populations that mirrored the general U.S. diabetic population in major demographic and epidemiologic characteristics (Table 1). All forms of ITDM resulted in lower health care utilization (Table 2). Of the types of ITDM in the marketplace, the provider-centered technologies showed the greatest potential savings. Diabetes registries saved \$14.5 billion (\$1,016 per enrolled patient) and CDSS saved \$10.7 billion (\$752 per enrolled patient) over 10 years. Payer-centered technologies had the next largest potential for cost savings at \$7.10 billion (\$558 per enrolled patient). Patient-centered technologies showed the most modest cost savings, with remote monitoring saving \$326 million (\$130 per enrolled patient) and self-management saving \$285 million (\$34 per enrolled patient). Integrated provider-patient systems saved \$16.9 billion (\$1,180 per enrolled patient).

These cost savings reflect the relative impacts on care processes, physiologic outcomes, and clinical outcomes (Tables 2 and 3). Although integrated systems generally resulted in the largest improvements of all technologies studied, of the forms of ITDM in the marketplace, provider-centered technologies showed the greatest potential to improve processes and outcomes.

Registries increased retinopathy screening rates from 14.2 to 61.5%, peripheral neuropathy screening rates from 45 to 80%, and microalbuminuria screening rates from 45 to 66%. The corresponding screening rates for CDSS were 24, 68, and 61%, respectively. Registries reduced A1C by 0.50%, systolic blood pressure by 1.1 mmHg, and total cholesterol by 31 mg/dl (0.31 g/l), whereas CDSS reduced A1C by 0.28% and cholesterol by 4.5 mg/dl (0.045 g/l) but increased systolic blood pressure by 4 mmHg. These improvements resulted in substantial reductions in microvascular outcomes for both registries and CDSS. However, whereas substantial reductions in macrovascular outcomes were seen with registries, the effect for CDSS was equivocal, which may reflect the projected increase in blood pressure.

Using the same population, payer technologies improved screening rates for retinopathy to 26%, peripheral neuropathy to 58%, and microalbuminuria to 53%. Improvements in A1C, systolic blood pressure, and total cholesterol were 0.24%, 5.4 mmHg, and 11 mg/dl (0.11 g/l), respectively. These process and physiologic improvements were in the middle range of ITDM technologies and resulted in improvements in both macrovascular and microvascular outcomes.

Patient-centered technologies had the most modest improvements projected by the model. These technologies had no impact on provider decisions to screen for retinopathy, neuropathy, or microalbuminuria. A1C, systolic blood pressure, and total cholesterol reductions were 0.030%, 0.56 mmHg, and 2.8 mg/dl (0.028 g/l) for remote monitoring and 0.020%, 0 mmHg, and 7.9 mg/dl (0.079 g/l) for self-management. These improvements resulted in fewer cardiovascular complications but yielded no statistically significant differences in other complications. Ten-year cumulative mortality reductions were seen for all technologies, although absolute mortality rate reductions were $<$1.0% in all cases (Table 2). Relative mortality rate reduction reached 3.4% for registries.

Sensitivity analysis

One-way sensitivity analysis was performed against key variables: ITDM impacts used by the Intervention Impacts Engine, patient turnover rates used by the Population Selection Engine, and discount rates used across the model. Across the range of ITDM impacts found in the literature, overall cost of care varied by up to 2.7%. Assuming a neutral effect on sys-

Table 2—*Ten-year clinical and financial outcomes*

	Payer technologies	Registries	CDSS	Remote monitoring	Self-management	Integrated system
Cardiac arrest and myocardial infarction	54 (46–61)	100 (90–110)	−4.5 (−16 to 7.4)	26 (15–37)	160 (150–170)	
Stroke	19 (18–21)	5.2 (3.0–7.3)	−12 (−14 to −9.7)	2.1 (−0.030 to 4.2)	0.48 (−1.5 to 2.4)	16 (14–18)
End-stage renal disease	3.0 (0.080–5.9)	5.6 (1.4–9.8)	2.6 (−1.4 to 6.7)	0.050 (−3.8 to 3.9)	−1.3 (−5.0 to 2.5)	7.9 (3.7–12)
Amputated	190 (180–200)	560 (550–580)	340 (330–360)	−3.9 (−21 to 13)	−13 (−30 to 3.5)	560 (550–580)
Blindness	18 (14–22)	63 (58–69)	20 (14–25)	0.60 (−4.4 to 5.6)	1.2 (−3.7 to 6.0)	64 (59–70)
Death	380 (340–420)	710 (650–770)	210 (140–270)	270 (210–330)	170 (110–230)	920 (860–980)
Savings ($ billion)	$7.10 (6.30–7.90)	$14.5 (13.2–15.8)	$10.7 (9.41–12.0)	$0.326 (−0.890 to 1.54)	$0.285 (−0.938 to 1.51)	$16.9 (15.6–18.1)
Savings ($ per enrolled patient)	$558	$1,016	$752	$130	$34	$1,180

Data are national cumulative (95% CI). Clinical outcomes in thousands of cases avoided.

tolic blood pressure by CDSS, cardiac complication rates improved by 2.1%, stroke rates improved by 0.56%, and an additional $1.2 billion cost-of-care savings was generated, for a total of $12 billion. Across a range of patient turnover rates derived from the literature, cost of care varied by <4.0%. The discount rate was varied from 3.0 to 8.5%; cost of care increased by up to 14% and fell by up to 16% across this range.

CONCLUSIONS— We found that ITDM improves processes of care, prevents development of diabetes complications, and generates cost-of-care savings. Projections of physiologic and care process improvement directly flow from our literature review. Our results, based on existing data, suggest that diabetes registries may be the most beneficial form of existing ITDM. Although, currently, self-management appears to offer the least benefit, future empirical studies may demonstrate greater benefit. Integrated systems would more closely realize the full intent of disease management and would have the greatest potential for benefit. These benefits must be weighed against implementation costs.

ITDM improves the synthesis of information, delivery of knowledge, and efficiency of communication. These improvements allow coordination of care across delivery teams that help ensure that patients receive recommended care and provide tools and information that empower patients to be more effective in their self-care. Registry-enabled diabetes management was the most effective ITDM approach. This may be due to its ability to influence behavior at three locations: at the health care system level through provider report cards, at the point of care through reminders, and at the patient's home through telephonic or mail-based reminders.

CDSS- and payer-mediated diabetes management were the next most effective. For CDSS, this may reflect the importance of decisions made at the point of care and the powerful influence CDSS can have on those decisions. For payer-mediated technologies, this may reflect a less powerful influence over a wide range of opportunities, indirectly influencing both provider and patient decision making through telephonic and mail-based interventions. Patient-oriented approaches appear to have the least effect based on the data available today. Whereas patient-oriented technologies do enhance diabetes management, they only have indirect influence on important care processes that are largely under the control of providers, such as referrals for ophthalmologic exams. However, more effective patient-centered approaches may be developed in the future.

Our approach applies the best available evidence from studies conducted under rigorous and controlled situations, while taking into account many of the real-world limitations of diabetes management. The projections account for the challenges of participant recruitment, recognizing that not all patients with diabetes would be identified, enrolled, and retained in such programs. Additionally, chronic diseases such as diabetes may take years to result in serious complications, so the value of managing such diseases takes years to become evident. Our model suggests that 10 years is sufficient for the benefit of diabetes management to have stabilized.

Additional benefits

The diabetes management literature reports additional benefits that could not be incorporated into our model. Such benefits may add substantially to improved outcomes projected by the model. For instance, smoking cessation guidelines are integral to many diabetes management programs. Although we could not include this effect, patients with diabetes almost certainly benefit from such interventions, probably more than those without diabetes (26,27).

Diabetes guidelines often include recommendations for vaccinations and other processes of care, such as exercise, medical nutrition therapy, and weight loss (28). Many studies have reported the effectiveness of diabetes management in improving compliance with these recommendations (12,29–31). Despite evidence that such improvement may produce health benefits (27,32,33), it was not possible to incorporate such generic process improvements into our model.

Limitations

Estimates of the impact of diabetes management are limited by the strength of the underlying evidence. Although the best available evidence for the effect of CDSS-based diabetes management on systolic blood pressure showed a detrimental effect, CDSS in other settings show a neutral effect or improvement in blood pressure control (34,35). Sensitivity analysis showed additional benefits assuming a neutral effect on blood pressure; thus,

Table 3—*Intervention Impact Engine results*

	Eye exam rate	Foot exam rate	Microalbuminuria exam rate	A1C	Systolic blood pressure (mmHg)	Total cholesterol (mg/dl)
Sample baseline	14.2	44.9	45.0	7.58	153	212
Payer technologies	25.6	57.8	52.6	7.34	148	201
Provider technologies						
Registries	61.5	80.0	66.1	7.08	152	181
CDSS	23.5	67.5	61.4	7.30	157	207
Patient technologies						
Remote monitoring	14.2	44.9	45.0	7.55	152	209
Self-management	14.2	44.9	45.0	7.56	153	204
Integrated system	61.5	80.0	66.1	6.90	149	166

Data are percent, unless otherwise indicated.

the main results may underestimate the true benefit of CDSS. Conversely, the benefit of foot screenings may be overestimated. We were able to identify only one randomized, controlled trial demonstrating the benefit of foot screening on amputation rates (36). Given the high rate and cost of amputations, the overall results may be unduly influenced by the results of this trial.

We excluded many additional potential economic benefits from the model. First, we excluded health care utilization effects due to complications not included in the original Centers for Disease Control and Prevention model, such as admissions for uncontrolled hyperglycemia or pneumonia. The ADA estimates that utilization attributed to such general medical conditions accounted for $44.1 billion, or roughly a third of total diabetes costs (2). Second, we did not model indirect costs, such as lost days from work, despite evidence that such indirect costs may be avoided (37). The ADA estimates that indirect costs accounted for $40.8 billion, again a third of total diabetes costs. Finally, the ADA estimates that >6 million people with diabetes remain undiagnosed (1), and prevalence rates are likely to increase in the future (38).

Projecting literature-derived estimates from one setting to another can be hazardous. In the case of diabetes management, there is wide variation in a number of salient features, such as the diabetes programmatic elements and the baseline quality of care. Additionally, our methodology requires a subjective assessment of how similar the studied technology is to modeled technology in our taxonomy. Others may disagree with our assessment and application of these studies, although this similarity assessment was only one factor in our study selection process.

Finally, the overall utility of diabetes management is determined not only by its benefit but also by its cost. High-benefit approaches may or may not be associated with high costs of implementation. An understanding of the ITDM cost structure is needed for a complete cost-benefit analysis and may change the relative appeal of various ITDM approaches. However, cost data are not often published (7) and may vary widely by institution and approach. Because of the complexity of these issues, we elected to present costs separately from this analysis (39). Clearly, however, organizations must consider such costs in their own analyses.

Summary

Many technologies underlie diabetes management programs, and all have varying degrees of clinical and financial benefit. Well-designed and adequately powered studies that show the comprehensive benefit of diabetes management on cost of care and clinical outcomes are unlikely to be conducted because the amount of time and money required to conduct such studies may be prohibitive. Our study estimates that the 10-year cost-of-care savings ranged from $285 million to $14.5 billion across various forms of ITDM, or ~0.30–3.2% of discounted 10-year costs of diabetes care and direct complications of diabetes. Provider-centered technologies have the greatest current potential for improving clinical and financial outcomes, although an integrated model may be the most useful in the future. These benefits must be weighed against implementation costs.

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