Simulated Physician Learning Program Improves Glucose Control in Adults With Diabetes

OBJECTIVE — Inexpensive and standardized methods to deliver medical education to primary care physicians (PCPs) are desirable. Our objective was to assess the impact of an individualized simulated learning intervention on diabetes care provided by PCPs.

RESEARCH DESIGN AND METHODS — Eleven clinics with 41 consenting PCPs in a Minnesota medical group were randomized to receive or not receive the learning intervention. Each intervention PCP was assigned 12 simulated type 2 diabetes cases that took about 15 min each to complete. Cases were designed to remedy specific physician deficits found in their electronic medical record observed practice patterns. General linear mixed models that accommodated the cluster randomized study design were used to assess patient-level change from preintervention to 12-month postintervention in HbA1c, blood pressure, and LDL cholesterol. The relationship between the study arm and the total of intervention and patient health care costs was also analyzed.

RESULTS — Intervention clinic patients with baseline HbA1c ≥7% significantly improved glycemic control at the last postintervention HbA1c measurement, intervention effect of −0.19% mean HbA1c (P = 0.034) and +6.7% in HbA1c <7% goal achievement (P = 0.0099). Costs trended lower, with the cost per patient −$71 (SE = 142, P = 0.63) relative to nonintervention clinic patients. The intervention did not significantly improve blood pressure or LDL control. Models adjusting for age, sex, and comorbidity showed similar results. PCPs reported high satisfaction.

CONCLUSIONS — A brief individualized case-based simulated learning intervention for PCPs led to modest but significant glucose control improvement in adults with type 2 diabetes without increasing costs.

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Although continuing medical education (CME) is required for physician licensure in many states, there is a paucity of evidence that traditional methods change physician behavior or improve clinical care (1). The Association of American Medical Colleges has called for increased study of CME approaches that incorporate adult learning principles, including tailored curricula and interactive experiences (e.g., simulated activities, self-directed learning, immediate feedback) (2). Of particular importance is emphasis on case-based context-dependent learning situations that address the complexity of specific clinical domains and focus on transfer of knowledge and skills beyond the specific learning situation (3). Personalized outreach visit approaches such as opinion leader interventions and academic detailing may influence some aspects of clinical care (4, 5), including increased use of aspirin and β-blockers for acute myocardial infarction (5), antibiotic choices (6), and HIV prevention practices (7). However, associated drawbacks include costs, teaching nonuniformity, and difficulty finding quality opinion leaders in nonacademic settings.

Simulated case-based learning offers an efficient and less expensive personalized physician learning alternative. It has been successful in aviation and chemical engineering and is increasingly used in health care training programs (8, 9) to teach Advanced Cardiac Life Support (8), various surgical skills (10), and airway management (11). Furthermore, our previously published evaluation of a brief prototype of the learning intervention used in this trial was encouraging (12). Therefore, development and rigorous evaluation of simulation approaches to teach the cognitive skills of chronic disease care management are warranted.

RESEARCH DESIGN AND METHODS

Hypothesis

This group-randomized trial was designed to test whether a personalized simulated learning intervention for physicians would improve care delivered to adults with uncontrolled diabetes.

Study setting, subjects, and design

The study was conducted from October 2006 to May 2007 at HealthPartners Medical Group (HPMG), a large medical group in Minnesota that serves about 230,000 patients. Eleven HPMG clinics were randomly selected and block randomized on the basis of baseline quality of diabetes care and number of consenting primary care physicians (PCPs) to either receive or not receive the intervention.

PCPs were eligible for the study if they practiced in one of the study clinics, provided care to at least 10 adult patients with diabetes, and signed a consent form. Patients were classified as having diabetes if they had two or more outpatient diabetes ICD-9 codes or used a diabetes-specific medication in the year before randomization (see Fig. 1 for the detailed consort description).
Intervention design

A group of PCP experts actively involved in diabetes guideline development identified and reached consensus on 25 essential clinical practices for the successful management of type 2 diabetes in adults (Table 1). The goal of the learning program was to promote mastery of these essential clinical practices.

The research team then used existing electronic medical record data to profile individual PCP performance on the essential clinical practices. If a physician performed below average compared with his or her physician peers on a clinical practice, a simulated case initialized with clinical parameters designed to teach the specific clinical practice was assigned.

Initialization parameters for the set of learning cases were defined to represent the wide range of complex clinical scenarios a PCP could encounter. Each case encompassed a different mix of baseline patient demographics (age, sex, duration of diabetes), medical history and comorbidities (congestive heart failure, renal insufficiency, coronary artery disease), pharmacologic use (active medications for glycemia, blood pressure [BP], lipids, depression, aspirin), clinical states (A1C, BP, lipid, creatinine, and self-monitoring of blood glucose results), and other subjective patient characteristics (hypoglycemia symptoms, medication adherence, lifestyle habits, and depressive symptoms). An automated case generator was developed to create distinct simulated learning cases.

A detailed description of the simulation software has been previously published (13). The patient model embedded in the software uses prespecified formulas derived from dose-response curves for drugs, lifestyle advice, and referrals. This allowed calculation changes in the patient state at each encounter on the basis of physician treatment actions. The interface mimics electronic medical record screens that permit the learner to prescribe drugs, order labs or diagnostic tests, make referrals, give patient advice, change frequency of recommended self-monitoring of blood glucose testing, view self-monitoring of blood glucose results, start or adjust insulin with each meal and at bedtime, and see the patient at any desired frequency for phone or office visits.

A key strategy of the learning intervention was the individualization embedded in the intervention at multiple levels. First, the PCPs received a customized set of simulated cases selected to address their assessed learning needs. Second, feedback resulted from a multitude of individual provider actions, yielding a unique trajectory to each case in response to the learner’s specific treatment decisions. Learning feedback occurred through seeing the clinical effects of treatment moves at subsequent encounters, seeing graphic displays of the projected results of accumulated treatment actions, and direct textual feedback after each encounter consisting of a critique of past actions and suggestions for future ones.

| 6 CLINICS ALLOCATED TO INTERVENTION | 5 CLINICS ALLOCATED TO USUAL CARE |
|-------------------------------------|----------------------------------|
| -20 consented PCPs                  | -21 consented PCPs               |
| -17 PCPs did not consent            | -20 PCPs did not consent         |
| -5 PCPs did not meet inclusion criteria*| -3 PCPs did not meet inclusion criteria* |
| 2,710 patients with diabetes linked to consented study PCPs** | 2,438 patients with diabetes linked to consented study PCPs** |
| 0 PCPs lost to follow-up            | 0 PCPs lost to follow-up         |
|                                    | 1 PCP transferred to an administrative position |

Included in analysis:
- 6 clinics
- 20 PCPs
- 1,847 patients with diabetes linked to study PCPs, with exclusions for:
  - 423 age out of range
  - 408 not consistently assigned to provider
  - 32 patients died

Included in the analysis:
- 5 clinics
- 20 PCPs
- 1,570 patients with diabetes linked to study PCPs, with exclusions for:
  - 566 age out of range
  - 270 not consistently assigned to provider
  - 32 patients died

*Eligible PCPs worked ≥60% of a full time equivalent and had ≥10 patients with diabetes. **Patients were linked to the study-consented last-assigned PCP during the preintervention period and study-consented first-assigned PCP during the postintervention period. Patients lacking an assigned PCP were linked to the provider seen most during the study period. PCP, primary care physician.
Intervention implementation

PCPs were sent an email link to the program, accessed through a secure login page housed on an internal server. Clicking on the name of one of the 12 assigned cases started the simulation. The physician was challenged to achieve the American Diabetes Association–recommended treatment goals for BP, lipids, and A1C within 6 months of simulated time. Each case took about 15 min to complete.

Physicians received financial compensation ($600) and up to 6 h of CME credit for completing the program, which had to be done on their own time. The average number of days to complete the 12 cases was 5.5. At the end of the intervention, physicians also were sent an evaluation of the learning program.

Dependent variables

Measures of intermediate outcomes (A1C, BP, LDL levels) of diabetes care in patients of providers extracted from the electronic medical record were the principal dependent variables. The baseline measurements were the clinical values viewable by the provider at the first encounter after completing the learning intervention. For A1C and LDL, this was the last clinical value obtained in the 1-year preintervention period. Because of point-of-care availability of blood pressure levels at encounters, the baseline measurement for BP was the first value in the 1-year postintervention period. For all measures, the last value in the postintervention period is selected as the postintervention variable. No changes in laboratory assay methods occurred during the study.

Costs were estimated from the health plan perspective and included the costs of the intervention and health care costs. Intervention costs included 1) marketing to physicians; 2) profiling physician learning needs; 3) implementing physician training, case assignment, and email reminders; and 4) physician compensation for completing cases. Health care costs included outpatient services and pharmaceuticals. Inpatient services were not included because the intervention was not expected to affect hospitalization rates. Costs were estimated using methods previously developed to assign costs of services in this medical setting (14). Services were based on relative value

Table 1—The 25 essential clinical care practices taught in the simulated program

| Glycemia practice                                                                 | Hypertension practice                                                                 | Lipid practice                          |
|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------|
| 1 Early drug initiation after medical nutrition therapy failure                   | Initiation of BP medication, new diagnosis                                          | Initiation of statin above goal          |
| 2 Initiation of additional oral drugs or exenatide beyond metformin and sulfonylureas | Appropriate use of home BP measurements                                             | Use of fibrate for high triglyceride    |
| 3 Initiation of insulin or exenatide                                             | Initiation of combo drugs for stage 2 hypertension                                   | Use of fibrate for low HDL              |
| 4 Change to updated insulin regimen (basal bolus insulin regimens)               | Adding drug classes as needed                                                        | Titrating statin or ezetimibe to achieve LDL goals |
| 5 Initiation of metformin as insulin sensitizer                                   | Initiation of fourth drug class                                                     | Titrating lipid drugs, fear of myalgias |
| 6 Initiation of thiazolidinedione as insulin sensitizer                           | Titration of drugs                                                                   | Reassessing lipids ≤3 months after adjusting lipid medications                     |
| 7 Initiation of prandial insulin                                                 | Target systolic BP                                                                   | Yearly monitoring of lipids             |
| 8 Titration of basal insulin                                                     | Importance of treatment in the elderly                                              | Monitoring liver enzymes tests          |
| 9 Titration of prandial insulin                                                  | More frequent visit intervals for patients not at goal                               |                                         |
| 10 Titration of insulin in large enough amounts                                    | Monitoring potassium and creatinine after starting or increasing an ACE inhibitor or angiotensin receptor blocker |                                         |
| 11 Use of SMBGs and pattern recognition                                          | Use of ACE inhibitor or angiotensin receptor blocker for congestive heart failure    |                                         |
| 12 Optimal metformin dosing                                                       |                                                                                      |                                         |
| 13 Optimal sulfonylurea dosing                                                    |                                                                                      |                                         |
| 14 Optimal insulin dosing                                                         |                                                                                      |                                         |
| 15 Optimal thiazolidinedione dosing                                               |                                                                                      |                                         |
| 16 Timely visit intervals                                                         |                                                                                      |                                         |
| 17 Avoid severe hypoglycemia (<60 mg/dl)                                          |                                                                                      |                                         |
| 18 Address mild hypoglycemia (60–69 mg/dl)                                       |                                                                                      |                                         |
| 19 Avoid fear of low normal glucose levels (70–89 mg/dl)                          |                                                                                      |                                         |
| 20 A1C frequency ≤3 months if not at goal                                        |                                                                                      |                                         |
| 21 A1C frequency ≤6 months at goal                                                |                                                                                      |                                         |
| 22 Metformin/creatinine contraindications                                         |                                                                                      |                                         |
| 23 Metformin/heart failure warnings                                               |                                                                                      |                                         |
| 24 Thiazolidinedione/heart failure warnings                                       |                                                                                      |                                         |
| 25 Educator referrals for patients not at goal                                    |                                                                                      |                                         |

MNT, medical nutrition therapy; TZD, thiazolidinedione; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; SMBG, self-monitored blood glucose; ACE, angiotensin-converting enzyme inhibitor; ARB, angiotensin-receptor blocker; TG, triglyceride.
A priori sample size calculations were based on 68% of the average 2009 wholesale price.

Independent variables
The independent variable was an indicator for study arm. The interaction of this variable with time was used to assess the differential impact of the intervention on the prespecified outcomes. Because the trial was group-randomized at the clinic level, imbalance in patient characteristics was expected. Patient-level independent variables include age, sex, race, and validated indicator variables for coronary artery disease and congestive heart failure. Adults older than 80 years and individuals with Charlson comorbidity scores of ≥3 (indicating high short-term risk of mortality) were excluded from the study because of legitimate debate about appropriate clinical goals in such scenarios (15).

Statistical analysis
Attributes of study-consented physicians and patients linked to these physicians are compared by study arm using descriptive statistics (mean, SD, proportions) and using independent samples t tests, contingency tables, and Pearson χ² tests.

General and generalized linear mixed models with a repeated time measurement (baseline and postintervention) were used to analyze continuous and binary outcomes using SAS Proc Mixed and Proc Glimmix. These models included a term for study arm, time (baseline or postintervention), a time by study arm interaction term, and random intercepts to account for multiple levels of nesting. The time-by-study-arm interaction term tested the effect of the intervention on the postintervention values from study arm, time (baseline or postintervention), a time by study arm interaction term for study arm, time (baseline or postintervention), and random intercepts to account for multiple levels of nesting. The time-by-study-arm interaction term tested the effect of the intervention arm over time. The analyses on test and control arm were generally small, with values of ICC < 0.001 for A1C and LDL value, ICC = 0.001 for SBP value, and ICC = 0.003 for DBP. Because of the low level of variance at the clinic level, three-

Table 2—Characteristics of study physicians and diabetes patients linked to those study physicians at intervention and control clinics

|                        | Intervention clinics | Control clinics | p*    |
|------------------------|----------------------|----------------|-------|
| Patients (n)           | 1,847                | 1,570          | 0.012 |
| Age (years)            | 55.9 ± 10.9          | 56.9 ± 10.4    | <0.001|
| Female (%)             | 44.6                 | 54.0           |       |
| White race (%)         | 72.2                 | 69.1           | 0.054 |
| Coronary artery disease during preintervention (%) | 11.3 | 11.3 | 0.97 |
| Congestive heart failure during preintervention (%) | 3.4 | 4.0 | 0.35 |
| Preintervention first A1C value | 7.4 ± 1.7 | 7.5 ± 1.7 | 0.18 |
| Preintervention first SBP value | 126.7 ± 17.7 | 125.8 ± 16.8 | 0.12 |
| Preintervention first DBP value | 74.0 ± 10.9 | 73.4 ± 10.6 | 0.12 |
| Preintervention first LDL value | 95.7 ± 34.1 | 96.5 ± 34.5 | 0.53 |
| PCPs (n)               | 20                   | 20             |       |
| Age (years)            | 48.5 ± 7.9           | 50.2 ± 7.3     | 0.51  |
| Family practice physicians (%) | 45.0            | 45.0           | 0.99  |
| Female (%)             | 40.0                 | 50.0           | 0.53  |
| Number of adult diabetes patients per PCP | 57.0 ± 28.7 | 55.8 ± 30.2 | 0.90  |

Data are means ± SD unless otherwise indicated. *Independent samples t test or Pearson χ².

Protection of human study subjects
The study was reviewed in advance, approved, and monitored on an ongoing basis by the HealthPartners Institutional Review Board, Project #03-083.

RESULTS—Attributes of study-eligible patients and PCPs are presented in Table 2. Diabetic patients’ age was 56.4 ± 10.7 years (mean ± SD), 24.0% were 65–74 years old, 48.9% were female, and 29.2% were nonwhite. At baseline (first preintervention value), 47.5% had A1C < 7%, 61.7% had systolic BP (SBP) < 130 mmHg, 67.3% had diastolic BP (DBP) < 80 mmHg, and 60.2% had LDL < 100 mg/dl. The number of diabetic patients per study-enrolled PCP ranged from 10 to 125, with a mean of 56.4 ± 29.1. Randomization at the clinic level resulted in an intervention arm with a higher proportion of younger and male patients.

In four-level random intercept models (measurement occasion nested within patient, provider, and clinic), ICCs at the clinic level were generally small, with values of ICC < 0.001 for A1C and LDL value, ICC = 0.001 for SBP value, and ICC = 0.003 for DBP. Because of the low level of variance at the clinic level, three-
Table 3—Rates and counts of diabetes encounters, A1C tests, cholesterol tests, BP measurements, and changes in A1C, BP, and LDL control in adult diabetes patients of intervention and control group PCPs in the pre- and postintervention periods

| Intervention clinics | Control clinics | Intervention effecta |
|---------------------|-----------------|---------------------|
|                     | Baseline Postintervention Change Baseline Postintervention Change | P (t) | Baseline Postintervention Change Baseline Postintervention Change | P (t) |
| Proportion (95% CI) of patients with one or more encounters or tests(n=3,417) | | | | |
| Diabetes encounters | 0.889 (0.866–0.908) 0.946 (0.931–0.958) 0.057* 0.886 (0.861–0.907) 0.933 (0.915–0.947) 0.047* 0.010 0.27 | | | |
| A1C test | 0.858 (0.827–0.884) 0.907 (0.884–0.926) 0.049* 0.872 (0.842–0.897) 0.906 (0.882–0.926) 0.034† 0.015 0.41 | | | |
| BP obtained | 0.992 (0.986–0.995) 0.985 (0.978–0.990) 0.007 0.985 (0.978–0.990) 0.986 (0.979–0.991) 0.001 0.008 0.13 | | | |
| LDL test | 0.849 (0.819–0.875) 0.886 (0.861–0.907) 0.037† 0.833 (0.801–0.862) 0.854 (0.824–0.880) 0.021 0.016 0.22 | | | |
| Mean (95% CI) of number of encounters or tests per patient(n=3,417) | | | | |
| Number of diabetes encounters | 4.1 (3.7–4.5) 4.3 (3.8–4.7) 0.16 4.5 (4.1–4.9) 4.8 (4.4–5.2) 0.31‡ 0.15 0.39 | | | |
| Number of A1C test | 1.9 (1.7–2.0) 2.1 (2.0–2.3) 0.24* 2.1 (1.9–2.2) 2.2 (2.1–2.4) 0.14† 0.09 0.12 | | | |
| Number of LDL tests | 1.5 (1.4–1.6) 1.6 (1.5–1.8) 0.13† 1.5 (1.3–1.6) 1.5 (1.3–1.6) 0.02 0.11 0.07 | | | |
| Mean (95% CI) of test values and proportion (95% CI) at goal | | | | |
| A1C | 8.4 (8.3–8.6) 7.9 (7.7–8.1) 0.53* 8.4 (8.3–8.6) 8.1 (7.9–8.3) 0.32* 0.14 0.19 0.034 | | | |
| 7% A1C | 0.292 (0.257–0.329) 0.225 (0.193–0.261) 0.009 | | | |
| SBP (mmHg) | 138.9 (137.2–140.7) 130.9 (129.1–132.6) 8.1* 139.5 (137.7–141.3) 131.3 (129.5–133.2) 8.2* 0.06 0.965 | | | |
| 130 (mmHg) | 0.502 (0.446–0.558) 0.529 (0.470–0.587) 0.509 | | | |
| DBP (mmHg) | 80.2 (78.9–81.5) 75.5 (74.3–76.7) 4.6* 80.2 (79.0–81.3) 76.4 (75.2–77.7) 3.8† 0.9 0.257 | | | |
| 80 (mmHg) | 0.606 (0.545–0.663) 0.590 (0.526–0.651) 0.714 | | | |
| LDL (mg/dl) | 122.0 (119.1–125.0) 103.8 (100.7–106.8) 18.3* 123.6 (120.4–126.8) 100.3 (96.9–103.7) 23.3* 0.039 | | | |
| 100 (mg/dl) or 70 mg/dl with CHD | 0.413 (0.363–0.466) 0.414 (0.359–0.470) 0.998 | | | |
| LDL (70 mg/dl) | 0.606 (0.545–0.663) 0.590 (0.526–0.651) 0.714 | | | |

†P < 0.05; *P < 0.01; ‡P < 0.001.aThe intervention effect column illustrates the differential amount of change in the intervention arm relative to the control arm comparing pre- to postintervention.bP value associated with the time condition term in a generalized linear mixed model with repeated time measurements, study arm, and their interaction.cFor A1C and LDL test values, baseline is the last preintervention value. For SBP and DBP, baseline is the first postintervention test. For all test values, follow-up is the last postintervention value. Separate test value analyses consists of those with baseline A1C (n=1,403). SBP >130 and/or DBP >80 at the last preintervention test and first postintervention test (n=920), LDL >100 (70 mg/dl for CHD patients) (n=1,069). BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure; LDL, low-density lipoprotein cholesterol; CHD, coronary heart disease.
CONCLUSIONS — This personalized physician learning intervention demonstrated a modest but significant A1C lowering without increasing patient visits or total net costs. The observed A1C impact (a 0.5% improvement in A1C in the intervention group, which was 0.19% better than the control group) is of roughly the same magnitude as that reported in uncontrolled observational studies of more expensive interventions intended to improve diabetes care, such as clinical information systems (18), patient education, and disease management programs (19). The net A1C improvement is clinically significant based on the potential to reduce patient complications, as demonstrated through UK Prospective Diabetes Study results showing 37% lower microvascular complications for every 1% absolute A1C reduction (20).

PCPs reported high levels of satisfaction with the intervention, repeated learning cases voluntarily, and reported tangible changes in the way they manage diabetes. The learning effect of the computer-based intervention was present independent of PCP baseline diabetes performance and indicates an ability to transfer what was learned from the simulated cases to the care of real patients—an important challenge and desirable finding in simulation research.

There are a number of points to make about the cost of this intervention in relation to its modest clinical effectiveness. First, the intervention did not increase patient visits or testing rates in real patients and trended toward cost-saving. Second, this simulated approach to physician learning is compatible with a wide range of chronic care improvement activities designed to activate patients or develop prepared care teams (21). Finally, the simulation content can be easily adapted to accommodate changes in care guidelines, discourage unnecessary tests or treatments, and encourage use of generics and might help modulate to some degree the high costs of diabetes care. The marginal costs for ongoing use of this learning tool are relatively small and principally involve periodic updates to ensure that the simulation model remains current with evidence-based treatment strategies and newly approved drugs.

Future research should investigate issues that might increase the impact, reduce the complexity, or broaden the dissemination potential of the intervention. Our use of electronic medical record–based physician treatment patterns to assess learning needs is innovative but can be difficult. Development of simpler methods to evaluate physician learning needs (e.g., assessment on a set of prespecified simulated cases) warrants investigation. Second, the intervention needs adaptation for web distribution and to simplify addition of clinical updates when needed. Third, at the time of this study, generalized diabetes care goals, such as A1C of <7%, were widely accepted. As personalized medicine seeks to accommodate individualized treatment goals, this approach provides an opportunity to teach a systematic approach to setting clinical care goals individualized to patient characteristics such as comorbidities, polypharmacy concerns, hypoglycemia risk, and genetics (22,23).

Additional work is needed to elucidate more precisely the mechanisms responsible for the observed effects. The variable effect on clinical domains may be partially related to primary emphasis on glucose-related feedback in the learning cases relative to BP or lipid-related feedback. Recent clinical trial results (23,24) highlight the importance of directing more attention to BP- and lipid-management issues. It is notable that the study site had relatively good baseline levels of A1C, BP, and LDL (25). The impact of this learning intervention in settings with worse baseline levels of diabetes care remains to be determined. This promising care-improvement strategy might also be applied to other clinical domains.

Despite some limitations, these data demonstrate that delivery of a brief and relatively inexpensive individualized physician learning intervention improved intermediate outcomes of diabetes care without increasing costs. Experimentation with simulated personalized learning interventions in a broad range of other care or educational settings seems warranted.
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