Educating Resident Physicians Using Virtual Case-Based Simulation Improves Diabetes Management: A Randomized Controlled Trial

JoAnn Sperl-Hillen, MD, Patrick J. O'Connor, MD, MA, MPH, Heidi L. Ekstrom, MA, William A. Rush, PhD, Stephen E. Asche, MA, Omar D. Fernandes, MPH, Deepika Apana, Gerald H. Amundson, Paul E. Johnson, PhD, and Debra M. Curran, MA, RN

Abstract

Purpose
To test a virtual case-based Simulated Diabetes Education intervention (SimDE) developed to teach primary care residents how to manage diabetes.

Method
Nineteen primary care residency programs, with 341 volunteer residents in all postgraduate years (PGY), were randomly assigned to a SimDE intervention group or control group (CG). The Web-based interactive educational intervention used computerized virtual patients who responded to provider actions through programmed simulation models. Eighteen distinct learning cases (L-cases) were assigned to SimDE residents over six months from 2010 to 2011. Impact was assessed using performance on four virtual assessment cases (A-cases), an objective knowledge test, and pre–post changes in self-assessed diabetes knowledge and confidence. Group comparisons were analyzed using generalized linear mixed models, controlling for clustering of residents within residency programs and differences in baseline knowledge.

Results
The percentages of residents appropriately achieving A-case composite clinical goals for glucose, blood pressure, and lipids were as follows: A-case 1: SimDE = 21.2%, CG = 1.8%, $P = .002$; A-case 2: SimDE = 15.7%, CG = 4.7%, $P = .02$; A-case 3: SimDE = 48.0%, CG = 10.4%, $P < .001$; and A-case 4: SimDE = 42.1%, CG = 18.7%, $P = .004$. The mean knowledge score and pre–post changes in self-assessed knowledge and confidence were significantly better for SimDE group than CG participants.

Conclusions
A virtual case-based simulated diabetes education intervention improved diabetes management skills, knowledge, and confidence for primary care residents.

The safety and quality of diabetes care in the United States is suboptimal, with less than 20% of diabetes patients simultaneously achieving recommended levels of glycated hemoglobin (A1c), blood pressure (BP), and low-density lipoprotein cholesterol (LDL).[1–3] In support of the need for provider education, several studies suggest that lack of timely intensification of treatment when patients are not at recommended clinical goals is a major obstacle to better diabetes care in the United States.[4–6] Some data suggest that problems related to timely and appropriate treatment are especially pronounced among resident physicians, with appropriate medication intensification occurring in only 21% of diabetes visits managed by residents.[7]

Inadequate longitudinal outpatient training experience with diabetes patients in residency clinics may contribute to suboptimal outpatient diabetes care quality among practicing physicians.[8,9] Restriction of resident work hours by the Accreditation Council for Graduate Medical Education (ACGME) may further decrease resident physicians' outpatient chronic disease management experience.[10] Accordingly, the Education Committee of the American College of Physicians has recommended substantial reforms to improve resident training in outpatient chronic disease care.[11] Simulation experiences are increasingly viewed as the most prominent innovation in medical education for improving patient care and safety.[12,13]

Virtual simulation is a method of training widely used in nonmedical industries that need high reliability and safety, such as aviation, engineering, and the military.[14,15] Medical simulation training began out of similar safety and quality concerns in the 1960s with Resusci-Anne,[16] and now numerous applications use partial or full human mannequins for training in emergency management, procedural skills, obstetrics, and surgery.[17–22] However, medical simulation could be adapted for teaching the cognitive tasks of chronic disease care management, either in postgraduate training or as a continuing medical educational activity for practicing providers to focus on the frequent changes in guidelines and therapy observed in recent years. A literature and Internet search revealed no other interactive simulated diabetes educational activities as defined by the ability of the learner to be immersed in cognitive tasks such as pharmacologic prescribing over consecutive patient encounters as if it were a real-world experience.[23]

Two previous randomized trials of prototypes of this virtual case-based simulated diabetes education in practicing primary care physicians demonstrated a modest but significant 0.2% improvement in actual patient A1c levels in intervention versus control patients ($P = .04$), and a 10% reduction in metformin use in patients with

Please see the end of this article for information about the authors.

Correspondence should be addressed to Dr. Sperl-Hillen, HealthPartners Institute for Education and Research, 8170 33rd Ave. S., Minneapolis, MN 55440; telephone: (952) 967-5009; fax: (952) 967-5022; e-mail: joann.m.sperlhillen@healthpartners.com.

Acad Med. 2014;XX:00–00.
First published online
doi: 10.1097/ACM.0000000000000406

Supplemental digital content for this article is available at http://links.lww.com/ACADMED/A225.

impaired renal function (P = .03).[24,25] The authors theorized that simulated diabetes education may be more potent for resident physicians who have less baseline knowledge and experience than practicing physicians. To study this theory, we developed and evaluated a comprehensive curriculum of 18 simulated interactive cases capable of teaching medical residents diabetes care management skills for a large variety of complex clinical presentations.

Method

Study objective

This cluster-randomized trial tested the primary hypothesis that an online virtual case-based Simulated Diabetes Education intervention (SimDE) would increase the ability of primary care residents to appropriately and safely achieve evidence-based diabetes clinical goals, evaluated using a set of virtual patient assessment cases.

Study setting and participant population

We conducted residency program recruitment through invitations to residency programs nationally by e-mail, phone, and listserv postings.[26] Nineteen residency programs agreed to participate and distributed study brochures to their residents to encourage voluntary study participation (our institutional review board prohibited mandatory resident participation). Subsequently, 341 of 723 eligible residents provided online informed consent and completed a baseline survey. Residency program faculty participated in an advisory board that guided us through operational aspects of recruitment and implementation. We kept the identity of participating residents confidential from residency program staff. Over the study implementation period from October 2010 through April 2011, three iPad raffles were conducted to incentivize residents to complete the learning and assessment cases. All consented residents who completed the study evaluation received a $50 gift card.

Randomization

To minimize the possibility of imbalance across study groups in key program factors, we stratified residency programs prior to randomization by specialty (family medicine or internal medicine), number of consented residents, and a composite score based on a residency program survey concerning annual frequency of diabetes-specific educational conferences and presentations and rates of resident participation in endocrinology electives. Ten residency programs with 177 consented residents were subsequently assigned using a random number generator to SimDE and 9 programs with 164 consented residents to the control group (CG). See Figure 1 for study design and participant flow.

Intervention description

SimDE residents had secure online access to a standardized set of 18 learning cases (L-cases) designed by the research team with input from local diabetes experts.[27] The curriculum was evidence based, and consistent with the American Diabetes Association and Institute of Clinical Systems Improvement (ICSI) diabetes care guidelines.[28–30] Medications were referred to by generic names and were recommended only for uses approved by the U.S. Food and Drug Administration.

The intervention used an intuitive electronic health record–like interface that allowed treatment of virtual patients over multiple encounters at any desired follow-up intervals within 180 days

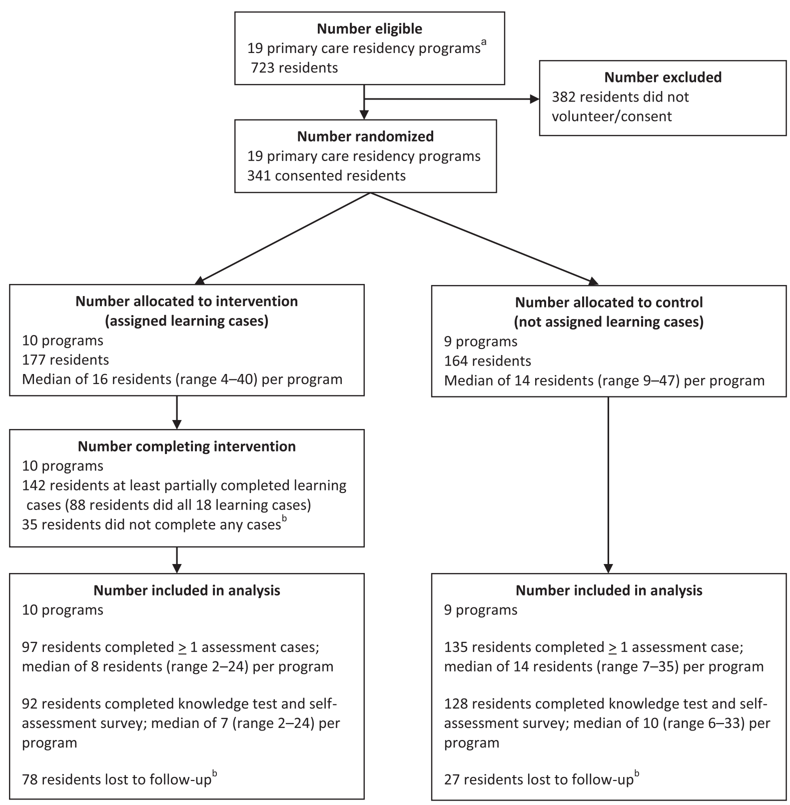

Figure 1 Consort diagram outlining residency program participation, resident subject recruitment, randomization, participation, and analysis, from a randomized study of whether virtual case-based simulation improves diabetes management, 2010–2011.

[a]Residency programs that participated in the study were Good Samaritan Hospital Internal Medicine (IM), Cincinnati, Ohio; Mankato Family Medicine (FM), Mankato, Minnesota; University of Minnesota IM, Minneapolis, Minnesota; Smiley's FM, Minneapolis, Minnesota; Monmouth Medical Center IM, Long Branch, New Jersey; Baystate Medical Center IM, Springfield, Massachusetts; Drexel University College of Medicine/Hahnemann University Hospital FM, Philadelphia, Pennsylvania; Wesley FM, Wichita, Kansas; Oklahoma University, Tulsa FM, Tulsa, Oklahoma; University of Missouri FM, Columbia, Missouri; North Memorial FM, Minneapolis, Minnesota; Methodist Hospital FM, St. Louis Park, Minnesota; Banner Good Samaritan/Phoenix VA IM, Phoenix, Arizona; St. Joseph's Hospital and Medical Center IM, Phoenix, Arizona; Baptist Health System IM, Birmingham, Alabama; Sioux Falls FM, Sioux Falls, South Dakota; United FM, St. Paul, Minnesota; Fairview Hospital/Cleveland Clinic FM, Cleveland, Ohio; and Conroe FM, Conroe, Texas.

[b]Out of 28 residents who responded to phone and e-mail inquiries about reasons for not completing learning and assessment cases, reasons included lack of time due to resident duties (22), lack of time due to studying for board exams (2), lack of time due to personal/family commitments (1), lack of satisfaction with the learning program (1), being on an overseas clinical rotation (1), and battling with an illness (1).

of simulated time.[31] Training for all residents included a five-minute training video on how to order labs, medications, diagnostic tests, lifestyle interventions, SMBG (self-monitored blood glucose) testing, referrals, and follow-up visits,[32] and a sham case without diabetes educational content to practice and assess proficiency with the interface.

The 18 L-cases, which covered type 1 and type 2 diabetes, included diagnosis and pharmacologic and lifestyle management across a range of illness severity and comorbid conditions. SimDE residents were explicitly challenged to safely achieve each virtual patient's individualized A1c, BP, and LDL goals within six months of simulated time. Physiologic simulation modeling realistically predicted the clinical impact of all resident actions on SMBG, A1c, BP, and LDL over follow-up time intervals chosen by the learner. Between each L-case encounter, learners received personalized feedback automatically generated by the SimDE program using a rules engine to critique the learner's actions and guide future actions.[24] The feedback between encounters contained links to more detailed diabetes care management information that could be viewed at the discretion of the learner. Details of the feedback and other aspects of the educational intervention have been previously described.[25,31,33] We asked SimDE residents to complete three L-cases each month, and cases could be started, stopped, and returned to, or repeated as many times as desired anytime during the intervention period.

Data sources, measurement, and outcome measures

At the time of consent, all subjects completed a baseline survey for demographics, postgraduate year (PGY) level, and self-assessment questions on different diabetes management skills and confidence in managing diabetes. Subsequently, residents received their random assignment and were sent a Web site link with log-on information for all study activities. CG residents and SimDE residents received the same training on the computer interface. After the six-month intervention period, we assigned all SimDE and CG subjects four virtual assessment cases (A-cases), a 10-question case-based knowledge test (scored as a sum of correct responses from 0 to 10), and the same self-assessment questions about knowledge and confidence asked at baseline. These A-cases used the same interface as that of the L-cases but included no learning feedback between encounters. All residents were challenged on A-cases to achieve all care goals safely within six months of simulated time. For each A-case, binary variables were defined to indicate achievement of A1c, BP, and LDL goals, and cases were also scored for whether goals were achieved appropriately and safely on the basis of predetermined criteria for each A-case. The multiple-choice knowledge test consisted of complex case scenarios related to blood sugar, BP, lipids, and safety. The knowledge questions were difficult and, in addition to factual knowledge, required choosing clinical priorities for patients with multiple issues. The test was developed by the study team and tested with practicing providers and certified diabetes nurse specialists to ensure clarity. SimDE residents also rated satisfaction with the L-cases and reported the extent to which what they learned affected their actual practice.

Analytic methods

We used general linear mixed models with an identity link and generalized linear mixed models with a logit link to predict binary achievement goals of A1c, BP, LDL, and composite goals for each A-case, and the total score on the objective diabetes knowledge test and correct responses to the individual knowledge items. These models included a fixed effect for study arm, a composite baseline measure of self-assessed knowledge to control for differences at baseline, and a random intercept for residency program. The analysis of the postintervention self-assessment questions about knowledge and confidence used a general linear mixed model containing a fixed effect for study arm, time (baseline or postintervention), the study-arm-by-time interaction, a random term for program, and a random term for provider to account for the repeated measurement of the self-assessment questions. We repeated analysis of the objective knowledge score and self-assessed diabetes knowledge questions after stratifying on PGY (1, 2, 3–4) to examine the patterns of effects within PGY. PGY3 and PGY4 groups were combined because of expected low numbers of eligible PGY4 residents (usually a "chief resident" position). We used Bonferroni correction for multiple comparisons for primary outcomes of goal achievement and appropriate and safe goal achievement, but not for secondary outcomes (individual knowledge and self-assessment items or specific case criteria for inappropriate treatment). The study was powered to detect a difference of 40% versus 25% in composite goal achievement at 0.8 (two-tailed alpha = 0.05) based on enrollment of 360 subjects with follow-up data on 240 subjects.

Results

Participating residency programs represented all seven regions of the American Medical Association Medical Student Section[34] and included 12 family medicine and 7 internal medicine programs. Four residency programs described themselves as community based, 7 as affiliated with academic institutions, and 8 as both. The range in number of residents per program was 12 to 130 (median = 27), and the number of ambulatory residency clinics associated with the residency programs ranged from 1 to 13 (median = 1). The estimated number of patients with diabetes on a PGY3 resident's patient panel ranged from 1 to 100 (median = 20). Study enrollment rates ranged from 22% to 94% of the total number of residents at participating residency programs (median 48%). Characteristics of consented residents are described in Table 1.

Reasonable proficiency with using the virtual interface was demonstrated by SimDE and CG residents prior to the start of the intervention and evaluation activities. Median time spent on the training and proficiency case was 8.5 minutes for SimDE residents and 9.5 minutes for CG residents ($P = .32$). Ten task activities were assigned to assess proficiency, and a score of 80% or higher on the 10 assigned tasks was demonstrated by 90/136 (67%) CG subjects and 72/97 (74%) intervention subjects.

L-cases were attempted by 80% of residents in the intervention group, and 50% completed all 18 L-cases. The median time spent per learning case was 16.8 minutes. The median time spent to complete all 18 cases was 5.2 hours, which was less than the median annual number of hours spent on diabetes-specific conferences or presentations (8 hours annually) as reported in the residency program baseline survey.

Table 1

Baseline Characteristics of 341 Consented Primary Care Resident Physicians, From a Randomized Study of Virtual Case-Based Simulation to Improve Diabetes Management, 2010–2011[a]

Characteristics	All, no. (%)	Intervention, no. (%)	Control, no. (%)
Treatment group	341 (100)	177 (51.9)	164 (48.1)
Age, median (interquartile range)	29 (4)	30 (4)	29 (4)
Women	180/341 (52.8)	89/177 (50.3)	91/164 (55.5)
Race/ethnicity[b]			
White	174/341 (51.0)	78/177 (44.1)	96/164 (58.5)
Asian	91/341 (26.7)	57/177 (32.2)	34/164 (20.7)
Black	16/341 (4.7)	9/177 (5.1)	7/164 (4.3)
Hispanic	24/341 (7.0)	9/177 (5.1)	15/164 (9.2)
Other	36/341 (10.6)	24/177 (13.6)	12/164 (7.3)
Specialty			
Internal medicine	159/339 (46.9)	89/176 (50.6)	78/163 (47.9)
Family medicine	146/339 (43.1)	68/176 (38.6)	70/163 (42.9)
Medicine–pediatrics	20/339 (5.9)	10/176 (5.7)	10/163 (6.1)
Other	14/339 (4.1)	9/176 (5.1)	5/163 (3.1)
Postgraduate year			
1	125/341 (36.7)	69/177 (39.0)	56/164 (34.2)
2	105/341 (30.8)	53/177 (29.9)	53/164 (32.3)
3	101/341 (29.6)	52/177 (29.4)	48/164 (29.3)
4	10/341 (2.9)	3/177 (1.7)	7/164 (4.3)
Experienced an elective rotation with endocrinologist/diabetologist	62/335 (18.5)	35/174 (20.1)	27/161 (16.8)
Baseline knowledge self-assessment, moderate or very knowledgeable[c]			
Knowledge using drugs to manage diabetes[b]	115/339 (33.9)	73/176 (41.5)	42/163 (25.8)
Knowledge adjusting insulin	120/339 (35.4)	70/176 (39.8)	50/163 (30.7)
Knowledge interpreting SMBG[b]	138/339 (40.7)	85/176 (48.3)	53/163 (32.5)
Knowledge setting individualized DM goals	116/339 (34.2)	68/176 (38.6)	48/163 (29.5)
Baseline confidence self-assessment, moderate or very confident[c]			
Confidence in managing individuals with DM	119/338 (35.2)	71/176 (40.3)	48/162 (29.6)

Abbreviations: SMBG indicates self-monitored blood glucose; DM, diabetes mellitus.
[a]Unadjusted.
[b]Significant difference found at the .05 level for intervention versus control, no adjustment for multiple comparisons. Among the 232 (97 intervention, 135 control) residents completing assessment cases, no significant differences by study arm were found.
[c]Score on a five-point scale (1 = not at all knowledgeable/confident, 2 = slightly, 3 = somewhat, 4 = moderately, 5 = very). Less than 3% of residents rated themselves a 5 (very knowledgeable or confident) in any category.

Two hundred thirty-two residents (SimDE = 97 and CG = 135) completed at least one A-case. Table 2 describes each A-case's hypothetical scenario and the results of the study for goal achievement for A1c, LDL, and BP, ignoring appropriate and safe criteria; goal achievement including appropriate and safe criteria; and the composite of these. The proportion of residents bringing each A-case to the composite goal was significantly higher in the intervention group. Statistical significance was maintained using a Bonferroni-corrected $P < .0125$ (.05/4) for composite goal achievement and for composite appropriate and safe goal achievement. SimDE residents who partially completed 18 L-cases had improved A-case outcomes compared with CG residents, but not as good as SimDE residents who completed all cases (data not shown). Median time for completion of an A-case was 25.6 minutes, and there was no consistent pattern observed for amount of time spent on assessment cases and ability to bring A-cases to care goals. Intervention effects were greater for glycemic control and lipid management, with less impact on BP control. Appropriate and safe treatment was observed significantly more often in the intervention group in the four A-cases for starting aspirin in patients with coronary heart disease, making nephrology referrals when warranted for renal disease, using clinical pharmacists in a geriatric polypharmacy situation, and keeping SMBGs > 70 mg/dL. Controls did not perform better than intervention on any of the 41 appropriate and safe criteria assessed. A subgroup analysis of A-case

Table 2

Percentages of Primary Care Residents Meeting Outcome Goals and Criteria for Appropriate and Safe Treatment for Four Distinct Virtual Assessment Cases (A-Cases), From a Randomized Study of How Virtual Case-Based Simulation Improves Diabetes Management, 2010–2011

Individualized case goal (and initial clinical info)	Outcomes assessed for goal achievement and meeting appropriate and safe criteria	% Intervention (n = 96)[a]	% Control (n = 135)[a]	*P* value
Hypothetical A—Case #1: A 65-year-old woman with T2DM, coronary heart disease, and kidney disease [GFR < 30 mg/dL] presenting for routine care				
A1c < 8% (initial A1c = 10.8% on no glycemia meds)	A1c goal ignoring appropriate/safe criteria	82.7	50.0	<.001
	Start basal insulin at appropriate dose	83.2	79.1	.46
	Avoid metformin	80.7	71.8	.15
	Avoid thiazolidinedione	84.6	92.0	.22
	A1c goal including above criteria	53.6	30.7	.003
LDL < 70 mg/dL (initial LDL = 85 mg/dL on atorvastatin 40 mg/d and fenofibrate)	LDL goal ignoring appropriate/safe criteria	80.1	31.4	<.001
	Intensify statin therapy	85.2	36.5	<.001
	Discontinue fenofibrate	47.0	5.1	<.001
	Monitor liver enzymes	91.6	69.2	.003
	LDL goal including above criteria	39.4	3.1	<.001
BP < 140/90 mm Hg (initial BP = 145/88 mm Hg on no BP meds)	BP goal ignoring appropriate/safe criteria	99.3	99.2	.92
	Make appropriate BP med choice	90.0	92.3	.64
	Monitor potassium and creatinine	92.7	91.7	.82
	Advised patient to stop NSAID	98.9	95.6	.20
	BP goal including above criteria	84.1	80.5	.53
Other clinical issues	Aspirin was started for CHD	76.1	51.3	.02
	Refer to nephrology	68.3	53.7	.04
	Refer for medical nutrition therapy	97.9	93.3	.16
Composite of above A1c, BP, and LDL goals	Not including appropriate/safe criteria	74.7	20.3	<.001[b]
	Including appropriate/safe criteria	21.2	1.8	.002[b]
Hypothetical A—Case #2: A 37-year-old male patient without known diabetes and on no medications presenting with polydipsia, polyuria, and fatigue. Labs ordered will confirm T1DM diagnosis.				
A1c < 7% (initial A1c = 12.7% on no meds)	A1c goal ignoring appropriate/safe criteria	95.7	77.9	.008
	Order urinalysis to rule out ketonuria	78.9	74.8	.56
	Avoid oral agents (type 1 diagnosis)	85.3	79.6	.3
	Start appropriate multidose insulin dose	63.8	43.8	.01
	Order glucagon kit	40.0	17.4	.002
	A1c goal including above criteria	23.3	7.1	.005
LDL < 100 mg/dL (initial LDL = 108 mg/dL on no meds)	LDL goal ignoring appropriate/safe criteria	98.9	78.7	.009
	Initiate statin therapy	98.9	80.9	.01
	Order liver enzymes	86.0	69.9	.01
	LDL goal including above criteria	86.0	61.0	.006
BP < 140/90 mm Hg (initial confirmed BP = 147/88 mm Hg)	BP goal ignoring appropriate/safe criteria	100	98.5	.51
	Start ACE or ARB	93.1	93.7	.88
	Order potassium and creatinine	92.4	94.9	.47
	BP goal including above criteria	87.2	89.2	.68
Other clinical issues	Order autoantibodies to confirm T1DM	53.0	49.3	.6
Composite of above A1c, BP, and LDL goals	Not including appropriate/safe criteria	95.7	63.2	<.001[b]
	Including appropriate/safe criteria	15.7	4.7	.02

(*Table continues*)

Table 2
(Continued)

Individualized case goal (and initial clinical info)	Outcomes assessed for goal achievement and meeting appropriate and safe criteria	% Intervention (n = 96)[a]	% Control (n = 135)[a]	*P* value
Hypothetical A—Case #3: A 71-year-old male with T2DM and coronary heart disease on multiple medications presents with fasting hypoglycemia, peripheral edema, and symptoms of obstructive sleep apnea.				
A1c < 8% (initial A1c = 8.9% on pioglitazone and glargine)	A1c goal ignoring appropriate/safe criteria	98.9	94.0	.13
	Order sleep study	93.5	89.6	.35
	Discontinue pioglitazone	81.9	83.4	.78
	Avoid SMBG < 70 mg/dL	80.1	62.9	.02
	A1c goal including above criteria	62.4	44.6	.02
LDL < 70 mg/dL (initial LDL = 77 mg/dL on simvastatin 40 mg/d)	LDL goal ignoring appropriate/safe criteria	85.0	38.2	<.001
	Statin therapy intensified	84.8	37.5	<.001
	Liver enzyme tests ordered	92.4	76.4	.03
	LDL goal including above criteria	80.2	28.8	<.001
BP < 140/90 mm Hg (initial BP = 165/99 on HCTZ and metoprolol)	BP goal ignoring appropriate/safe criteria	97.8	81.6	.007
	Prescribe appropriate BP medication	82.2	67.8	.03
	Order potassium and creatinine	96.7	94.4	.44
	BP goal including above criteria	79.9	61.6	.01
Other clinical issues	Start aspirin	80.9	60.2	.006
	Refer to a clinical pharmacist	79.9	19.0	<.001
Composite of above A1c, BP, and LDL goals	Not including appropriate/safe criteria	82.3	33.3	<.001[b]
	Including appropriate/safe criteria	48.0	10.4	<.001[b]
Hypothetical A—Case #4: A 54-year-old woman with T2DM, heart disease, severe obesity [BMI 45], and tobacco use presents with symptoms of depression and painful peripheral neuropathy.				
A1c < 8% (initial A1c = 8.9% on metformin, glargine, pioglitazone, and aspart)	A1c goal ignoring appropriate/safe criteria	100	95.3	.04
	Adjust insulin in safe increments	86.4	79.6	.22
	Discontinue pioglitazone (heart disease)	83.3	80.8	.69
	A1c goal including above criteria	72.8	58.2	.11
LDL < 100 mg/dL (initial LDL = 88 mg/dL, not on a statin)	LDL goal ignoring appropriate/safe criteria	99.3	99.5	.85
	Initiate statin (even though at LDL goal)	80.8	47.0	<.001
	Order liver enzymes	90.9	70.9	.009
	LDL goal including above criteria	76.2	39.1	<.001
BP < 140/90 mm Hg (initial BP = 165/99 mm Hg on no BP meds)	BP goal ignoring appropriate/safe criteria	97.7	87.6	.05
	Start two drugs (Stage 2 HTN diagnosis)	85.2	76.6	.14
	Start thiazide diuretic	88.2	76.0	.04
	Order potassium and creatinine	97.8	96.7	.65
	BP goal including above criteria	72.2	59.3	.07
Other clinical issues	Address neuropathy symptoms	73.8	66.3	.26
	Refer for bariatric surgery consultation	98.9	72.2	.003
	Address depression	95.4	94.0	.67
	Advise to stop smoking	70.1	77.5	.33
Composite of above A1c, BP, and LDL goals	Not including appropriate/safe criteria	96.6	83.5	.02
	Including appropriate/safe criteria	42.1	18.7	.002[b]

Abbreviations: T2DM indicates type 2 diabetes; GFR, glomerular filtration rate; A1c, glycated hemoglobin; LDL, low-density lipoprotein; BP, blood pressure; NSAID, nonsteroidal anti-inflammatory drug; CHD, coronary heart disease; T1DM, type 1 diabetes; SMBG, self-monitored blood glucose; ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blocker; HCTZ, hydrochlorothiazide; HTN, hypertension; BMI, body mass index.

[a]Numerator raw numbers are not included because the percentages are model based, obtained from generalized mixed models that control for baseline knowledge and account for clustering of residents in the program.

[b]$P < .0125$. Bonferroni correction for four cases to composite goal and four to composite goal appropriately.

outcomes by PGY level (Supplemental Digital Table 1 at http://links.lww.com/ACADMED/A225) demonstrated that all PGYs had a benefit from the intervention, but the largest intervention effects were in PGY1.

Table 3 shows knowledge test results. Nine out of the 10 knowledge questions were answered correctly more often by SimDE residents compared with CG, with statistically significant results for 5 of 10 questions. Significant correlations were observed between knowledge test results and A-case composite goal achievement (all cases, $P < .05$).

Changes in self-assessed knowledge and confidence were significantly greater for SimDE than CG for all items assessed, for all PGY levels, with the majority (9/15) of these comparisons reaching statistical significance at a threshold alpha of .05 (Table 4).

Results of the mixed quantitative and qualitative analysis of satisfaction in the SimDE group have been previously published.[31] Likert responses on satisfaction items were favorably higher than neutral for all areas assessed including general satisfaction (93%) and willingness to recommend it to colleagues (91%). In addition, 77% of residents said they applied the learning to actual patients, 63% said they shortened visit intervals, 78% indicated they were more likely to add or increase drugs if their patients were not at goal, and 92% indicated they were more confident about insulin use in actual patients. Residents commented positively on the help the intervention provided with learning general aspects of diabetes management, insulin management, and achieving individualized goals.

Table 3

Mean Scores and Performance Results on a 10-Question Multiple-Choice Knowledge Test Completed by Primary Care Residents in the Intervention and Control Groups After the SimDE Intervention Period, From a Randomized Study of How Virtual Case-Based Simulation Improves Diabetes Management, 2010–2011[a]

Category	Intervention (n = 92)	Control (n = 128)	*P* value
Total score (items correctly answered out of 10), mean (SD)	5.3 (1.8)	4.1 (1.6)	.005
5 or more correct responses, % of respondents achieving	45.7	15.6	<.001
Individual knowledge question results, % with correct answer			
1. Screen for diabetes using acceptable criteria	74.9	75.5	.93
2. Start basal insulin; set individualized A1c goal	57.8	26.8	.001
3. Check ketones in newly diagnosed symptomatic patients and start insulin	24.8	29.3	.62
4. Reduce basal insulin due to nocturnal hypoglycemia	63.7	70.4	.39
5. Relax A1c target due to hypoglycemia unawareness in a patient with T1DM	56.1	32.7	.004
6. Start insulin in a newly diagnosed symptomatic patient with T2DM	34.7	11.4	.001
7. Use a loop diuretic rather than thiazide diuretic in a patient with renal insufficiency; prescribe statin monotherapy (rather than combination lipid therapy); discontinue metformin due to renal contraindication	42.8	18.6	.007
8. Initiate BP treatment (without confirmatory testing) in patient with BP > 180/100 mm Hg; prescribe a statin in high CV risk patients regardless of LDL level	59.0	44.4	.05
9. Start a statin; screen for depression; start basal insulin	65.2	57.2	.28
10. Manage geriatric issues such as polypharmacy; screen for depression; address hypoglycemia; start a statin	47.3	41.7	.43

Abbreviations: SimDE indicates Simulated Diabetes Education; A1c, glycosylated hemoglobin; T1DM, type 1 diabetes; T2DM, type 2 diabetes; BP, blood pressure; CV, cardiovascular; LDL, low-density lipoprotein.

[a]Predicted means, proportions, and *P* values from general and generalized linear mixed model predicting knowledge score or item from study arm and baseline self-assessed knowledge composite. No adjustment for multiple comparisons. Where percentages are reported, numerator raw numbers are not included because the percentages are model based, obtained from generalized mixed models that control for baseline knowledge and account for clustering of residents in the program.

Discussion

This study demonstrated that virtual case-based SimDE significantly improved the ability of resident physicians to achieve patient care goals appropriately and safely in virtual situations. It also improved objective measures of diabetes care knowledge and resulted in greater self-confidence in important aspects of diabetes management, including use of insulin, interpreting blood sugars, and individualizing treatment goals.[31] SimDE residents said they were more likely to add medications and shorten visit intervals when seeing actual patients not at clinical goals.[31] The learning intervention required about one hour of resident time each month for six months, was delivered as an adjunct to existing residency activities, and was well liked by residents.

Previous randomized trials of similar simulated diabetes education for practicing primary care physicians demonstrated improved quality of care and safety outcomes in real patients.[24,25] Actual patient data were not permitted in this study in order to protect resident confidentiality at residency sites and because of low continuity of care in most ambulatory residency settings, but innovative methods were deployed to evaluate provider performance using virtual A-cases. The validity of this virtual assessment methodology is supported by significant positive correlations between mean objective knowledge score and composite outcomes for all A-cases.

Simulation modeling enables systematic and detailed evaluation of key aspects of clinical practice and safety issues using the A-cases. Examples of clinical practices that significantly improved on virtual assessment included statin use in patients not at LDL goal, aspirin use in patients with coronary heart disease, nephrology referrals in patients with renal disease, starting multidose insulin at appropriate

Table 4

Results by PGY-Level Subgroups of Mean Objective Knowledge Test Scores (Postintervention) and Mean Self-Assessed Knowledge and Confidence in Managing Diabetes (Pre- and Postintervention Periods), From a Randomized Study of How Virtual Case-Based Simulation Improves Diabetes Management, 2010–2011

		Intervention (n = 92)			Control (n = 128)			
Outcome	PGY[a]	Pre	Post	Change[b]	Pre	Post	Change[b]	*P* value
Objective knowledge score[c]	1	—	5.2	—	—	3.8	—	.008
	2	—	5.5	—	—	4.1	—	.009
	3–4	—	5.2	—	—	4.5	—	.14
	All PGY	—	*5.3*	—	—	*4.1*	—	*.005*
Knowledge about all available drugs[c]	1	2.7	3.5	0.8	2.6	3	0.4	.04
	2	3.4	3.6	0.2	3	3	0	.57
	3–4	3.5	3.8	0.3	3.4	3.3	–0.1	.01
	All PGY	3.2	3.6	*0.4*	3	3	*0*	*.01*
Knowledge about how to start and adjust insulin[c]	1	2.8	4	1.2	2.5	3	0.5	.007
	2	3.4	4.1	0.7	3.1	3.4	0.3	.08
	3–4	3.5	4.3	0.8	3.5	3.7	0.2	.04
	All PGY	3.2	4.1	*0.9*	3	3.3	*0.3*	*.002*
Knowledge interpreting patient SMBGs[d]	1	3.1	4.3	1.2	2.7	3.4	0.07	.04
	2	3.4	4.2	0.8	3.1	3.5	0.4	.06
	3–4	3.7	4.2	0.5	3.5	3.8	0.3	.46
	All PGY	3.4	4.2	*0.8*	3.1	3.6	*0.5*	*.02*
Knowledge about setting individualized treatment goals[d]	1	3	4	1	2.5	3.1	0.6	.12
	2	3.2	4	0.8	3.1	3.4	0.3	.04
	3–4	3.5	4.2	0.8	3.6	3.8	0.3	.06
	All PGY	3.2	4.1	*0.9*	3	3.4	*0.4*	*.008*
Confidence in managing diabetes[d]	1	2.7	3.8	1.1	2.5	3.1	0.6	.05
	2	3.4	4.1	0.7	3	3.2	0.2	.02
	3–4	3.6	4.1	0.5	3.5	3.6	0.1	.06
	All PGY	3.2	4	*0.8*	3	3.3	*0.3*	*.005*

Abbreviations: PGY indicates postgraduate year; SMBG, self-monitored blood glucose.
[a]Sample sizes for PGY subgroups: PGY1, n = 76; PGY2, n = 76; PGY3–4, n = 69.
[b]For change analysis, predicted means and *P* values from general linear mixed models predicting item from study arm, time, and their interaction. *P* value for interaction term. No adjustment for multiple comparisons.
[c]Mean number of questions correct out of 10.
[d]Mean rating on a five-point Likert scale. Higher score indicates higher self-rated knowledge or confidence.

doses, avoiding SMBGs < 70 mg/dL, and providing glucagon kits when indicated. Performance gaps identified through this type of virtual assessment suggest areas in need of improvement and could be used to direct future learning activities as envisioned in the practice-based learning interventions recommended by the ACGME.[35]

Of note is that even though the intervention significantly improved most outcomes, postintervention clinical performance in both groups was far from ideal, raising questions about the adequacy of current residency training methods and the clinical competency of graduates. The low scoring on assessment cases for achieving goals safely and appropriately was likely due in part to the difficulty of achieving the measured composite criteria, requiring 15 to 18 evidence-based guideline-driven criteria to be met per case. Nevertheless, the differences between measures of goal achievement with and without the appropriate and safe criteria were dramatic and suggest that inappropriate and unsafe care may occur frequently in practice. Our data raise concerns that "goal-driven" accountability measures, which do not consider appropriateness of treatment, might lead to higher rates of risky prescribing events.

Previous studies show that many graduates of primary care residency programs are inadequately trained in outpatient diabetes care and often delay appropriate and timely intensification of treatment such as insulin.[7] Most residency programs still emphasize inpatient training, and limited longitudinal continuity-of-care experiences, limits on residency work hours, and reduced funding to support faculty teaching time are other barriers to adequate training in outpatient chronic disease care.[36] Educational activity using simulation models can help address these barriers because of the economy, brevity, standardization of learning content, and personalization of the experience. Moreover, simulation models can quickly incorporate new evidence-based recommendations as knowledge evolves. Finally, this type of learning intervention can be implemented conjointly with a wide range of other strategies designed to improve quality of chronic disease care,[37,38] can be delivered conveniently via Internet, and is scalable to unlimited numbers of residency sites at low marginal costs relative to the work involved in updating and enhancing the educational experience as guidelines change. The virtual cases can be used as an adjunct to other residency training activity, and our findings suggest that the education may work best for those with lower baseline knowledge and experience, suggesting possible benefits of extending this learning strategy to medical students or other health science students.

Although the virtual encounters cannot authentically replicate all of the potential challenges of face-to-face meetings with real patients, many common challenges to patient self-management, such as pharmacologic and behavioral adherence, depression, and variation in behavioral readiness to change, were incorporated into the simulation model. Realism was magnified by allowing each learner to follow a unique trajectory based on actions taken, including the potential to cause harm and for remedial actions based on corrective feedback received between encounters. SimDE residents who partially completed 18 L-cases had improved A-case outcomes compared with the control, but not as good as SimDE residents who completed all cases. More research is needed to determine whether a smaller number of more focused L-cases could result in similar outcomes to those observed by this study, or whether a larger number of cases could result in better outcomes. The benefit of simulation in ensuring that trainees are exposed to a wide variety of virtual patients in addition to their actual patients is an intriguing area for medical education research.

Our analysis is limited by selective participation in the study and incomplete L-case completion. Further evaluation would be warranted to assess efficacy if such education were to be mandatory in residency training. Physicians are generally considered poor at self-assessment, and another limitation of our study is the use of self-assessment to evaluate changes in knowledge and self-confidence in managing diabetes.[39,40] Whereas the SimDE group had greater increases in self-assessed confidence and perceived knowledge, the more reliable outcomes observed for objective knowledge scores and performance on assessment cases are reassuring.

Bias could also be introduced because A-case completion was lower for SimDE participants (55%) than CG (82%). A-case noncompleters identified lack of time as the principal barrier to case completion, and total time commitment in this study was about eight hours for SimDE and about two hours for CG, making it more likely for the CG group to find time for the assessment cases. A sensitivity analysis of A-case completers and noncompleters revealed no statistically significant differences on baseline characteristics, including baseline knowledge, between the two groups, further supporting lack of time rather than other resident characteristics as the main barrier to A-case completion.

This study was limited to resident physicians, but other trainees, such as nurse practitioners, physician assistants, pharmacists, and practicing physicians, may also benefit from virtual case-based simulated education.[41] Such education is customized to each learner's actions within each case, resulting in unique learning trajectories, and such highly personalized and interactive education (e.g., learning by doing) is more powerful and efficient than didactic education based on current adult learning theories.[42–44]

Virtual case-based SimDE enhanced measures of resident performance, improved objective and subjective knowledge scores, and raised self-confidence in managing patients with diabetes. Broader use of such virtual diabetes education using simulation models may be warranted to improve the much-needed diabetes care capabilities of the future health care workforce. In addition, the innovative virtual patient outcome assessment method may prove useful in other settings where actual patient outcomes are difficult or costly to measure.

Acknowledgments: Dr. Sperl-Hillen is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

The authors gratefully acknowledge the assistance and support of Eugenia Canaan, MALS, and Amy Murphy, MHHA, of the HealthPartners Institute for Education and Research (HPIER), for their understanding of graduate medical education, help with implementation, and with their role in getting the educational intervention approved for continuing medical education credit. They also acknowledge Vijayakumar Thirumalai of HPIER and Andrew Rudge, BS, formerly with HPIER, for their diligent programming assistance to help create the educational intervention and prepare data for analysis; George Biltz, MD, of the University of Minnesota for assisting with modeling the physiology in the simulation for a consulting fee; David Kendall, MD, formerly with the American Diabetes Association for his role as independent review officer, which included monitoring the development, implementation, and safety of the intervention delivered to the resident physicians, as well as evaluating the progress of the analysis (he deferred compensation for these activities to the American Diabetes Association); and Mary VanBeusekom of HPIER for her editing skills.

Funding/Support: This study was funded by an R18 translational research grant from the National Institute of Diabetes and Digestive and Kidney Diseases grant number: 5R18DK079861.

Other disclosures: The authors declare the following potential conflicts of interest: JoAnn M. Sperl-Hillen, MD, Patrick J. O'Connor, MD, MPH, MA, William A. Rush, PhD, and Paul Johnson, PhD, are listed inventors on a U.S. patent related to the intervention developed for this study (# 8,388,348 B2) issued March 5, 2013, titled "Disease Treatment Simulation." HPIER has a royalty-bearing license agreement with a third party to commercialize the simulation technology for the purpose of broader dissemination. Dr. Sperl-Hillen serves as a nonpaid member of the board of directors for that licensee.

Ethical approval: The study was reviewed in advance, approved, and monitored by the HealthPartners institutional review board.

Previous presentations: Results have been presented in abstract and poster form at Hot Topics in Simulation Education—A New York City Simulation Symposium Sponsored by the New York Simulation Center for the Health Sciences (NYSIM); October 11, 2013; New York, New York.

Dr. Sperl-Hillen is senior research investigator, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Dr. O'Connor is assistant medical director, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Ms. Ekstrom is senior research project manager, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Dr. Rush is research investigator, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Mr. Asche is manager of statistical services, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Mr. Fernandes is research project manager, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Ms. Appana is manager of Web development research, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Mr. Amundson is research info program analyst IV, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

Dr. Johnson is professor, Curtis L. Carlson Chair in Decision Sciences, Carlson School of Management, University of Minnesota, Minneapolis, Minnesota.

Ms. Curran is director of educational quality IME, HealthPartners Institute for Education and Research, Minneapolis, Minnesota.

References

1 Hoerger TJ, Segel JE, Gregg EW, Saaddine JB. Is glycemic control improving in U.S. adults? Diabetes Care. 2008;31:81–86.
2 Berger JE, Ahmann AJ, Balfour DC, et al. Treating to target: Implementing an effective diabetes care paradigm for managed care. Am J Manag Care. 2010;16(suppl treating):S4-35.
3 Spann SJ, Nutting PA, Galliher JM, et al. Management of type 2 diabetes in the primary care setting: A practice-based research network study. Ann Fam Med. 2006;4:23–31.
4 Phillips LS, Branch WT, Cook CB, et al. Clinical inertia. Ann Intern Med. 2001;135:825–834.
5 Peyrot M, Rubin RR, Lauritzen T, et al. Resistance to insulin therapy among patients and providers: Results of the cross-national Diabetes Attitudes, Wishes, and Needs (DAWN) study. Diabetes Care. 2005;28:2673–2679.
6 Schmittdiel JA, Uratsu CS, Karter AJ, et al. Why don't diabetes patients achieve recommended risk factor targets? Poor adherence versus lack of treatment intensification. J Gen Intern Med. 2008;23:588–594.
7 Ziemer DC, Miller CD, Rhee MK, et al. Clinical inertia contributes to poor diabetes control in a primary care setting. Diabetes Educ. 2005;31:564–571.
8 Karamanoukian RL, Ku JK, DeLaRosa J, Karamanoukian HL, Evans GR. The effects of restricted work hours on clinical training. Am Surg. 2006;72:19–21.
9 Mathis BR, Diers T, Hornung R, Ho M, Rouan GW. Implementing duty-hour restrictions without diminishing patient care or education: Can it be done? Acad Med. 2006;81:68–75.
10 Landrigan CP, Barger LK, Cade BE, Ayas NT, Czeisler CA. Interns' compliance with Accreditation Council for Graduate Medical Education work-hour limits. JAMA. 2006;296:1063–1070.
11 Weinberger SE, Smith LG, Collier VU. Redesigning training for internal medicine. Ann Intern Med. 2006;144:927–932.
12 Coleman EA. Extending simulation learning experiences to patients with chronic health conditions. JAMA. 2014;311:243–244.
13 Association of American Medical Colleges. Medical Simulation in Medical Education: Results of an AAMC Survey. https://members.aamc.org/eweb/upload/Medical%20Simulation%20in%20Medical%20Education%20Results%20of%20an%20AAMC%20Survey.pdf. Accessed May 6, 2014.
14 Latorella K, Pliske R, Hutton R, Chrenka J. Cognitive Task Analysis of Business Jet Pilots' Weather Flying Behaviors: Preliminary Results. Hampton, Va: NASA; 2001. NASA/TM-2001-211034.
15 Leitch RA, Moses GR, Magee H. Simulation and the future of military medicine. Mil Med. 2002;167:350–354.
16 Resusci-Anne. http://www.laerdal.com/us/doc/367/History. Accessed May 6, 2014.
17 Pacsi AL. Human simulators in nursing education. J N Y State Nurses Assoc. Fall 2009. 2008;39:8–11.
18 Michelson JD. Simulation in orthopaedic education: An overview of theory and practice. J Bone Joint Surg Am. 2006;88:1405–1411.
19 Le CQ, Lightner DJ, VanderLei L, Segura JW, Gettman MT. The current role of medical simulation in American urological residency training programs: An assessment by program directors. J Urol. 2007;177:288–291.
20 Wayne DB, Butter J, Siddall VJ, et al. Simulation-based training of internal medicine residents in advanced cardiac life support protocols: A randomized trial. Teach Learn Med. 2005;17:210–216.
21 Barsuk JH, McGaghie WC, Cohen ER, O'Leary KJ, Wayne DB. Simulation-based mastery learning reduces complications during central venous catheter insertion in a medical intensive care unit. Crit Care Med. 2009;37:2697–2701.
22 Chen PT, Huang YC, Cheng HW, et al. New simulation-based airway management training program for junior physicians: Advanced Airway Life Support. Med Teach. 2009;31:e338–e344.
23 Gaba DM. The future vision of simulation in health care. Qual Saf Health Care. 2004;13(suppl 1):i2–i10.
24 O'Connor PJ, Sperl-Hillen JM, Johnson PE, et al. Simulated physician learning intervention to improve safety and quality of diabetes care: A randomized trial. Diabetes Care. 2009;32:585–590.
25 Sperl-Hillen JM, O'Connor PJ, Rush WA, et al. Simulated physician learning program improves glucose control in adults with diabetes. Diabetes Care. 2010;33:1727–1733.
26 Society of Teachers of Family Medicine Web site. 2012. http://www.stfm.org. Accessed May 6, 2014.
27 O'Connor PJ, Sperl-Hillen JM, Johnson PE, Rush WA. Identification, classification, and frequency of medical errors in outpatient diabetes care. In: Henriksen K, Battles J, Lewin D, Marks E, eds. Advances in Patient Safety: From Research to Implementation. Vol 1. Rockville, Md: Agency for Healthcare Research and Quality; 2005:369–380.
28 Holmboe ES. Oral antihyperglycemic therapy for type 2 diabetes: Clinical applications. JAMA. 2002;287:373–376.
29 Institute for Clinical Systems Improvement (ICSI). Diagnosis and Management of Type 2 Diabetes Mellitus in Adults. 14th ed. Revised 2012. http://www.icsi.org/guidelines_and_more/gl_os_prot/other_health_care_conditions/diabetes_mellitus__type_2/diabetes_mellitus__type_2__management_of___6.html. Accessed May 6, 2014.
30 ADA. Standards of medical care in diabetes—2011. Diabetes Care. 2011;34(suppl 1):S97.
31 Sperl-Hillen JM, O'Connor P, Ekstrom H, et al. Using simulation technology to teach diabetes care management skills to resident physicians. J Diabetes Sci Technol. 2013;7:1243–1254.
32 SiMCare Accelerated Learning Simulations. http://simcarehealth.com. Accessed May 6, 2014.
33 Dutta P, Biltz GR, Johnson PE, et al. SimCare: A model for studying physician decision making activity. In: Henriksen K, Battle J, Marks E, Lewin D, eds. Advances in Patient Safety: From Research to Implementation. Rockville, Md: Agency for Healthcare Research and Quality; 2005:179–192.
34 American Medical Association–Medical Student Section (AMA-MSS) Regions. http://www.ama-assn.org/ama/pub/about-ama/our-people/member-groups-sections/medical-student-section/our-leaders/regions.page. Accessed May 6, 2014.
35 Issenberg SB, Chung HS, Devine LA. Patient safety training simulations based on competency criteria of the Accreditation Council for Graduate Medical Education. Mt Sinai J Med. 2011;78:842–853.
36 Fitzgibbons JP, Bordley DR, Berkowitz LR, Miller BW, Henderson MC. Redesigning residency education in internal medicine: A position paper from the Association of Program Directors in Internal Medicine. Ann Intern Med. 2006;144:920–926.
37 Wagner EH. Chronic disease management: What will it take to improve care for chronic illness? Eff Clin Pract. 1998;1:2–4.
38 Sperl-Hillen JM, O'Connor PJ. Factors driving diabetes care improvement in a large medical group: Ten years of progress. Am J Manag Care. 2005;11(5 suppl):S177–S185.
39 Davis DA, Mazmanian PE, Fordis M, Van Harrison R, Thorpe KE, Perrier L. Accuracy of physician self-assessment compared with observed measures of competence: A systematic review. JAMA. 2006;296:1094–1102.
40 Eva KW, Regehr G. "I'll never play professional football" and other fallacies of self-assessment. J Contin Educ Health Prof. 2008;28:14–19.
41 Williamson JC, Glauser TA, Nevins PH, et al. Current practice patterns and identified educational needs of health care providers in managing patients with type 2 diabetes. Clin Diabetes. 2013;31:3–9.
42 Davis D, Bordage G, Moores LK, et al. The science of continuing medical education: Terms, tools, and gaps: Effectiveness of continuing medical education: American College of Chest Physicians evidence-based educational guidelines. Chest. 2009;135(3 suppl):8S–16S.
43 Zimmerman B. Chapter 39: Development and adaption of expertise: The role of self-regulatory processes and beliefs. In: Ericsson K, Charness N, Feltovich PJ, Hoffman RR, eds. Cambridge Handbook of Expertise and Expert Performance. Cambridge, Mass: Cambridge University Press; 2006.
44 Wigton RS. Applications of judgment analysis and cognitive feedback to medicine. In: Brehmer B, Joyce CRB, eds. Human Judgment: The SJT View. Amsterdam, North-Holland: Elsevier Science Publishers; 1988:227–245.