Computerized Knowledge Management in Diabetes Care

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Introduction: Many scientific achievements become part of usual diabetes care only after long delays. The purpose of this article is to identify the impact of automated information interventions on diabetes care and patient outcomes and to enable this knowledge to be incorporated into diabetes care practice.

Methods: We conducted systematic electronic and manual searches and identified reports of randomized clinical trials of computer-assisted interventions in diabetes care. Studies were grouped into 3 categories: computerized prompting of diabetes care, utilization of home glucose records in computer-assisted insulin dose adjustment, and computer-assisted diabetes patient education.

Results: Among 40 eligible studies, glycated hemoglobin and blood glucose levels were significantly improved in 7 and 6 trials, respectively. Significantly improved guideline compliance was reported in 6 of 8 computerized prompting studies. Three of 4 pocket-sized insulin dosage computers reduced hypoglycemic events and insulin doses. Metaanalysis of studies using home glucose records in insulin dose adjustment documented a mean decrease in glycated hemoglobin of .14 mmol/L (95% confidence interval [CI], 0.11–0.16) and a decrease in blood glucose of .33 mmol/L (95% CI, 0.28–0.39). Several computerized educational programs improved diet and metabolic indicators.

Discussion: Computerized knowledge management is becoming a vital component of quality diabetes care. Prompting follow-up procedures, computerized insulin therapy adjustment using home glucose records, remote feedback, and counseling have documented benefits in improving diabetes-related outcomes.

Key Words: Diabetes, chronic disease, computerized, knowledge, metaanalysis

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Delay in the application of many scientifically sound recommendations for diabetes care can be measured in decades. The landmark trial on the benefit of early treatment of diabetic retinopathy was published in 1976.[1] The American Diabetes Association (ADA) started to recommend annual eye examinations 12 years later and the recommendation has been restated annually.[2] From 1996 to 1998, only 40.9% of patients with diabetes received the guideline-recommended annual eye examinations according to the National Committee on Quality Assurance.[3] A study of rural family practices showed that only 15% of patients with type 2 diabetes had at least 1 annual glycated hemoglobin determination.[4] The care provided to only 3% of insulin-requiring and 1% of noninsulin-requiring diabetic patients meets 5 of the 7 annually published prevention standards from the American Diabetes Association.[5]

In the United States, diabetes has been diagnosed in 12.1 million people, results in nearly 82,000 lower extremity amputations annually, is the sixth leading cause of death, and accounts for approximately $132 billion U.S. healthcare expenditures.[6,7] The discrepancy between what is known and what is done in diabetes care urges better knowledge management to improve results through sharing and leveraging information.

The limitations of "unaided human minds" in medical decision-making processes are well known and offer an explanation for practice variation, delay in implementation of research results, process errors, and unfavorable outcomes.[8,9] The goals of this study were to identify automated knowledge management interventions that can 1) accelerate the clinical implementation of diabetes care recommendations; 2) empower patients in self-management of diabetes; and 3) support professional diabetes care over a distance. To achieve these goals, randomized, controlled clinical trials (RCTs) of computer-assisted diabetes care were reviewed and meta-analyses were performed.

METHODS

Eligibility criteria for this review and metaanalysis included: 1) the study design was randomized, controlled trials; 2) participants were patients with diabetes mellitus; 3) computer-assisted intervention was compared with no such intervention in a control group; and 4) effect was measured in the process or outcome of diabetes care. The following exclusion criteria were applied: 1) evaluations of closed-loop insulin delivery systems ("artificial pancreas"); and 2) studies with less than 10 units of randomization. Studies selected for this review are limited to prospective 2-group comparison studies.

Study Selection

Extensive electronic literature searches were performed to identify all eligible randomized, controlled clinical trials. The searches included the following 11 databases: MEDLINE, HealthSTAR, CINAHL, Compendex, Dissertation Abstracts, ABI/Inform, EBM Reviews–Best Evidence and the Cochrane Database of Systematic Reviews, ERIC, INSPEC, and PsycINFO. In addition, manual searches were performed by screening the citations of review articles and bibliographies of potentially eligible RCTs. No restrictions with regard to dates of publications were applied. The publication year of the earliest study retrieved[21] was 1976.

By screening the titles, abstracts, and, if necessary, the full text of all retrieved citations, articles meeting the eligibility criteria and not meeting exclusion criteria were selected. Two reviewers independently judged full texts of potentially eligible reports. If there was a difference in the perceived eligibility of a study, the 2 reviewers discussed the report to arrive at consensus.

Study Evaluation

The quality of eligible trials was evaluated using a quality evaluation form consisting of 20 questions aimed at assessing site, sample, randomization, process of observation, data quality, and statistical analysis.[10,11] Authors were contacted to clarify the methods if the article description was ambiguous. Special attention was given to the key domains of randomization, blinding, and withdrawals.[12] No trials scoring zero points in any of the 3 key domains were included in this study.

Data Extraction

Relevant data from each report were extracted into a structured spreadsheet. Source, quality score, study design, sample, setting, duration, control and study interventions, and reported results were noted. If numerous effect variables were reported, a hierarchy was applied to select the 5 most important effects relevant to diabetes care: 1) diabetic complications including organ damage; 2) social functioning; 3) metabolic control; 4) psychologic effect; 5) patient satisfaction; 6) patient participation; 7) utilization of clinical procedures; and 8) cost effects of interventions.

Analysis

Based on the tested intervention, studies were assigned to 1 of the following categories: 1) computerized prompting of diabetes care, 2) utilization of home glucose records in computer-assisted insulin dose adjustment, or 3) computer-assisted diabetes patient education. Studies were summarized in tables corresponding to each category.

Metaanalysis was performed when more than 3 retrieved studies tested the same intervention and measured the same outcome. Both mean and standard deviation data for each outcome were needed. Correspondingly, only 2 outcome variables, glycated hemoglobin and blood glucose, from the utilization of home glucose records in computer-assisted insulin dose adjustment were identified for metaanalysis. The conversion rate of 1 mg/dL = 18 mmols was applied. Although 8 computerized prompting studies measured compliance, they were not metaanalyzed because the specific type of compliance was different (eg, median overall compliance, physical examination compliance, HgbA1c assessment compliance, median overall physician compliance with recommendations, fasting blood glucose compliance, compliance with suggestions, compliance with guidelines, glycosylated HgbA1c order compliance, and blood glucose order compliance). For each study, the difference between the intervention group mean and the control group mean was calculated for glycated hemoglobin and mean blood glucose. The 95% confidence interval for each of the differences was also calculated. Pooled summary mean and corresponding confidence intervals were calculated using random-effects model.[13] When heterogeneity is a possibility, the random-effect model is recommended. The random-effect metaanalysis allows for any heterogeneity in treatment effect beyond that compatible with chance.[14] The results of this analysis were displayed in graphs.

RESULTS

In total, more than 3000 articles were screened. After excluding studies not meeting the 4 eligibility criteria (that is, 1) randomized, controlled trial, 2) patients with diabetes, 3) computer-assisted intervention, and 4) effect measured on process or outcome of care) based on their titles and abstracts, full-text versions of 91 studies were obtained. Ultimately, 48 reports on 44 unique clinical trials were considered eligible. In 40 (90%) of the studies, the computerized function was the intervention, whereas in the remaining 4 (10%) studies, the computer was only a part of a more complex intervention. The mean duration of all trials was 7.0 ± 6.2 months.

Computerized Prompting of Diabetes Care

The primary intervention in this group of 9 studies was aimed at physicians and consisted of clinically relevant and diabetes guideline-based reminders/prompts (Table 1).[15–24] Based on preexisting databases and electronic patient records, automated summaries were generated for over 408 clinicians caring for over 4000 diabetic patients. These studies evaluated the use of computer-generated information for use dur-

TABLE 1. Computerized Prompting of Diabetes Care

					Effects	
Source, year	**Sample/Setting**	**Duration/mos**	**Control**	**Intervention**	**Measures**	**Results Control vs. Intervention**
DICET[15] 1994	274 patients, diabetic clinic and GP groups, Grampian, UK	24	Hospital clinic-based care, with computerized patient reminders	Integrated care approach; patient-specific reminders for general practitioners	Routine diabetic care visits	4.8 vs. 5.3, $P < 0.05$
					Glycated hemoglobin assessments	1.3 vs. 4.5, $P < 0.05$
					Glycated hemoglobin (%)	NS
					BMI	NS
					Creatinine (mmol/L)	NS
Hurwitz et al[16] 1993	181 patients (type 2), 59 physicians, hospital outpatient clinics, Islington, UK	24	Usual outpatient diabetes care by hospital-based outpatient clinics	Prompted community care, requests for blood and urine samples; eye examination reminders; physician alerts	Patients without clinical review (%)	15 vs. 3.4 $P = 0.013$
					Mean no. of clinical reviews/yr	2.2 vs. 3.2, $P < 0.001$
					Glycated hemoglobin (%)	NS
					Mean plasma glucose (mmol/L)	NS
					Deaths per group (%)	NS
Lobach et al.[17–18] 1997	357 patients, 58 primary care physicians, Duke Family Medicine Center, NC	6	Usual outpatient care	Diabetes guideline recommendations printed on the patient encounter form	Median overall compliance (%)	15.6 vs. 32.0, $P = 0.01$
					Physical examination compliance (%)	6.7 vs. 33.3, $P = 0.05$
					HbA1c assessment compliance (%)	NS
					Foot examination compliance (%)	NS
					Ophthalmologic examination compliance (%)	NS
Lobach[19] 1996	45 physicians, Duke Family Medicine Center, NC	3	Automated guideline recommendations only	Biweekly, individualized e-mail to adhere to diabetes guidelines	Median overall physician compliance with recommendations (%)	6.1 vs. 35.3 $P < 0.01$
Mazzuca et al[20] 1990	175 patients, 99 internal medicine residents and faculty, Indiana University, IN	11	3.5-hour seminar on blood sugar regulation	Seminar + individualized computer reminders to consider a recommendation	GHb compliance	NS
					Fasting BG compliance	NS
					SMBG prescriptions	NS
					Referral to dietary clinic (%)	NS
					2nd generation oral hypoglyc. drugs (%)	NS
McDonald[21] 1976	257 patients, 3 nurses, 11 physicians, diabetic clinic, Wishard Memorial Hospital, IN	8	Computer-generated patient summary and encounter form	Surveillance report with suggestions to repeat tests or to respond to medication events	Ordering of tests (% of suggested)	11 vs. 36, $P < 0.0001$
					Change in therapeutics (%)	13 vs. 28, $P < 0.026$

(*Continued*)

TABLE 1.(*Continued*)

					Effects	
Source, year	**Sample/Setting**	**Duration/mos**	**Control**	**Intervention**	**Measures**	**Results Control vs. Intervention**
Moore[22] 1980	220 patients, diabetic clinic, Hermann Hospital, TX	24	No automated suggestions	Patient chart review based automated prompts for examinations, laboratory tests, x-ray etc.	Compliance with suggestions (%)	38 vs. 65, $P < 0.005$
					Mean change in BG (mgm%)	NS
					Mean weight change (%)	NS
					Number of hospitalizations	NS
					Average length of stay	NS
Nilasena et al[23] 1995	164 patients, 35 internal medicine residents, outpatient clinics, VA and Univ Hosp, UT	6	Blank encounter forms without any health status information	Health status and maintenance report; ADA preventive care guidelines	Compliance with guidelines (%)	NS
Overhage et al[24] 1997	2181 patients, 86 internal medicine physicians, Wishard Memorial Hosp, IN	6	No automated suggestions for corollary orders	Automated suggestions for corollary orders for 87 selected tests or treatments	Glyc HbA1c order compliance (%)	7.39 vs. 23.71, $P < 0.0001$
					BG order compliance (%)	4.41 vs. 30.77, $P < 0.0001$
					Overall 24-hour compliance (%)*	29 vs. 50.4, $P < 0.0001$
					Average hospital charges ($)*	NS
					Average length of stay (d)*	NS

*Results include nondiabetic patients

DICET = Diabetes Integrated Care Evaluation Team; BMI = body mass index, SMBG = self-measurement of blood glucose; Glyc = glycosylated; NS = no significant difference; ADA = American Diabetic Association; BG = blood glucose.

ing clinician–patient encounters and resulting process changes were noted. Two studies[15,16] included automated patient self-care reminders in addition to physician reminders and requests for specimens from patients.

Overall compliance with recommended diabetes care procedures was 71% to 227% higher in the prompted group of physicians[17,21,22,24] than in those in the control groups. Compliance with diabetes care guidelines was also significantly better ($P < 0.05$) among the intervention group physicians than in the control group (Table 1) (eg, higher routine diabetes care visit rates per patient during the study period,[15,16] glycated hemoglobin determinations,[15,24] eye and foot examinations,[16] and compliance with suggested test ordering and other diabetes care procedures.[19,21,22,24]) Yet, there were also particular outcomes for which there was not a significant difference between the intervention and the control group: HgbA1c assessment compliance,[17,18] foot examination compliance,[17,18] ophthalmologic examination compliance,[17,18] HgbA1c compliance,[20] fasting blood sugar compliance,[20] self-measurement of blood glucose compliance, and referral to dietary clinic.[20] Four of the studies[1–19,23] provided a general measure of compliance incorporating the following adherence to care measures: foot examination, physical examination, glycemic monitoring, urine protein determination, renal care, cholesterol level, ophthalmologic examination, neurologic care, influenza vaccination, and pneumococcal vaccination. In these studies, the overall adherence score was calculated by dividing the number of items completed in accordance with the guidelines by the total number of items recommended for the patient. Three of the 4 studies[17–19] showed significant improvement ($P < 0.05$) in the overall adherence measure.

Utilization of Home Glucose Records in Computer-Assisted Insulin Dose Adjustment

The second group of 25 studies[25–49] with 1286 adult and 197 children participants used glucose measurements taken at home to support computerized analysis and reporting for insulin dose and therapy adjustment by clinicians (Table 2). Patients collected and transmitted data electronically.[33,35,37,43–45,47,48] Significant improvements in glycated hemoglobin for the intervention group patients were noted as a result of using computerized analysis of home glucose records.[26,36,40,42,44–46] In the 2 studies that assessed patient satisfaction, the intervention group patients were found to be significantly more satisfied with the care they received.[33,41]

To evaluate the impact of computer-assisted support on insulin therapy decisions, 6 computerized dosage adjustment systems were compared with conventional sources of decision support (Table 2).[27–29,32,38,39,40,46] At the time of evaluation, 5 systems were already available as small pocket-sized computers to provide advice on demand.[28,29,38,40,46] The input data for the computer algorithms were blood glucose,[27,28,32,38,40,46] urine glucose,[29] insulin regimen,[27,32,40] food intake,[27,32,38,40,46] physical activities,[38,46] hypoglycemic episodes,[38] and time of day.[46] Computerized insulin dose adjustment resulted in lower dose among the intervention patients.[27,28,38,39] Pocket-sized systems have been used independently by patients and described as safe and easy-to-use. Studies in which patients transmitted blood glucose measurements electronically from home and in exchange received diabetes management advice from a computer or a health professional[25,26,30,31,34,36,41,42,49] used telephone modems,[25,30,34] automated calling systems,[31,42] or a videotext network (the French Minitel system).[26,49] Telematic transmissions were successful (less than 1% failure rate) and resulted in lowering blood glucose,[26] glycated hemoglobin,[26,36,41,42] and diabetic symptoms.[42] Intervention group patients also benefited from the intervention by achieving a greater weight reduction.[25,36,49]

Metaanalysis of 16 studies[25,26,28–34,37–39,41,42,47–49] in which home glucose records were used to perform computer-assisted insulin dose adjustment (Table 2) resulted in significant decrease in glycated hemoglobin (average decrease of −0.14 (95% CI, −0.11–0.16) (Fig. 1). The metaanalysis of 9 studies[25–27,30,38–41,45,46,49] (Table 2) documented a significantly greater decrease in blood glucose among the intervention group participants (mean decrease of −.33 mmol/L; 95% CI, −.28–.38) (Fig. 2).

Computer-Assisted Diabetes Patient Education

Ten studies[50–61] with a total of 626 participants, including 79 children, evaluated the impact of computerized education on monitoring blood sugar levels, managing diet and medication, adjusting lifestyle, and preventing complications (Table 3). The evaluated diabetes education content areas included: diet,[50–54,56,57,59,60,61] blood glucose monitoring and control,[50,51,54–56,61] plans for social activities and eating out,[40,51–53,56] diabetic complications,[50,54,56,61] school performance,[50] exercise,[54,56,57] self-care and treatment,[50,51,54,56] emotional and physical stress,[54] insulin injections,[56] pregnancy,[56] alcohol,[56] travel,[56] foot care,[61] and the mechanisms for hypoglycemic drug action.[52,53,61] Statistically significant outcome improvement, particularly glycated hemoglobin, prelunch blood glucose level, and serum cholesterol, were also documented.[50,52,54,56] Several educational programs went beyond presenting general information, offering specific measures based on patient self-assessments (eg, comprehensive test of diabetes management skills,[51,55,56,61] food habits assessment,[52,53] and review of self-monitored data[54,57]).

DISCUSSION

In this review, we have included the computer-based interventions in diabetes care that have been tested in randomized, controlled trials and were shown to be linked with quality of diabetes related clinical processes or health outcomes. Studies that tested the use of a computer for nonclinical purposes did not make this review.

Computerized prompting to healthcare professionals appears to have an impressive impact on the compliance with recommended diabetes care guidelines and procedures. Receiving appropriate care is the first step toward better outcomes in chronic disease management. Following the suggested guidelines can lead to better self-care by patients as well.

Besides the obvious advantages of automated information technologies to make clinical expertise accessible even in remote areas, improved metabolic control was achieved through intensified control and feedback in many studies. Small, pocket-sized dosage computers allowed for increased mobility and therapy recommendations on demand. Recording and analysis of diabetes control parameters can lead to lowering of glycated hemoglobin levels. Some intervention patients were also able to show weight reduction through more frequent counseling without an increase in visits to a physician.

The results of this study show that distant diabetes control and counseling can reduce both glycated hemoglobin and blood sugar. Insulin-requiring patients were able to reduce the doses of insulin, blood glucose, and stabilize or decrease their glycated hemoglobin levels without increased clinician contact. This evidence is very beneficial for people facing distance and other barriers in receiving just-in-time needed care in controlling their diabetes and avoiding complications.

Shortcomings of available studies represent opportunities for future research regarding the application of computerized knowledge management in diabetes care. The follow-up period in most studies was not long enough to assess the long-term differences made by the computerized intervention in the outcome of this chronic disease. We would like to remind readers to avoid overinterpreting nonsignificant results of studies with small sample sizes of 20 or fewer

TABLE 2. Utilization of Home Glucose Records in Computer-Assisted Insulin Dose Adjustment

Source, Year	Sample/Setting	Duration mos	Control Care	Intervention Care	Effects: Measures	Effects: Results Control vs. Intervention
Ahring et al[25] 1992	42 patients (type 1), 2 rural endocrine clinics, Newfoundland, Canada	3	SMBG data (in glucometer) brought in every 6 weeks	Weekly SMBG data transmission to the clinic with follow-up telephone counseling	Change weight (kg) Change insulin doses (U/kg) HbA1c (%) Change random blood glucose (mM)	+0.5 vs. −0.2, NS +0.3 vs. +0.75 NS NS NS
Billiard et al[26] 1991	19 patients, (type 1), University of Angers, France	6	SMBG with a conventional glucometer	SMBG transmission, computerized analysis and telematic physician feedback	HbA1c (%) Physician time spent/visit (min) Total daily insulin dose BMI	6.8 vs. 6.7, $P = 0.05$ 15 vs. 19, $P < 0.05$ No changes, NS NS
Cavan et al[27] 1998	20 patients (type 1) diabetic clinic, St. Thomas Hosp, London, UK	4 days	Insulin dosage advice from diabetes specialist nurse	Diabetes advisory system (DIAS) provides advice on insulin dosage	Median insulin dose reduction (%) Mean BG (mmol/L) Symptomatic hypoglycemia/day, Mean % of blood glucose values < 3 mmol/L	$P < 0.05$ NS NS NS
Chiarelli et al[28] 1990	20 patients, Dept of Pediatrics, University of Chieti, Italy	6	Manual methods of insulin dosage adjustment	Computerized insulin dosage adjustment	Hypoglycemic events/wk, 2nd term Changes daily insulin dose (U/kg) HgbA1c (%) Premeal glycemia (mM) SMBG (measurements/ week)	2.3 vs. 1.2, $P < 0.001$ +0.01 vs. −0.12, $P < 0.0001$ NS NS NS
Danne et al[29] 1992	10 pediatric patients, Free University of Berlin, Germany	3	Exact recording of urinary glucose excretion, no extra patient contacts	Computerized insulin dosage recommendation based on urine glucose level	Changes in Glyc HbA1c (%) Changes urine glucose/ week (%) Changes insulin dose/day (IU/kg) Hypoglycemia or serum glucose values < 60 mg/dL per week	−0.15 vs. −0.2[‡] −0.15 vs. −0.7[‡] −0.03 vs. +0.07[‡] NS
Di Biase et al[30] 1997	20 pregnant women (type 1), University "La Sapienza," Rome, Italy	7	Weekly visits in diabetes unit	Weekly data transmission, and analysis by DIANET; telematic feedback by diabetologist, additional clinic visits	End-pregnancy BG (before breakfast and lunch, after dinner) HbA1c (%) Hypoglycemic reactions	Lower in intervention, $P < 0.025$ NS NS
Hayes[31] 1996	61 patients (type 1), Children's Hosp Endocrinology Clinic, Columbus, OH	4	Usual outpatient care	Automated follow-up calls, BG levels submission; customized computerized diabetes management advice	Change in Glyc HbA1c (%) Diabetes management habits (scales)	NS NS
Hejlesen et al[32] 1998	12 patients (type 1), Sonderborg Hospital, Denmark	2	Experienced diabetologist advice on insulin dosage	Diabetes advisory system (DIAS)'s advice on insulin dosage	HbA1c (%) Insulin dosage (U/d)	NS NS

(*Continued*)

TABLE 2. (*Continued*)

Source, Year	Sample/Setting	Duration mos	Control Care	Intervention Care	Effects: Measures	Effects: Results Control vs. Intervention
Marrero et al[33] 1989	57 patients (type 1), Indiana Univ Diabetes Research and Training Center, IN	4	SMBG with glucometers without memory function	SMBG results recorded in a memory glucometer; data analysis with Glucofacts Software	Quality of interaction w/physician	$P < 0.001$
					Understanding of diabetes	$P < 0.002$
					Importance of testing	$P < 0.006$
Marrero et al[34] 1995	106 patients (type 1), James Whitcomb Riley Hospital for Children, IN	12	Regimen adjustments during scheduled visits	2 week SMBG data transfer, reviewed and telephone feedback (CLOC) + 3 monthly clinic visits	Negative perceptions	Less in intervention, $P = 0.001$
					HbA1c (%)	NS
					Diabetes Quality of Life for Youth	NS
					Hospitalization or ER visits (total)	NS
Matsuyama et al[35] 1993	32 patients (type 2), VA Medical Center outpatient clinic, ID	2	Pill counts to assess medication adherence	Medication monitoring using MEMS and pharmacists give therapy recommendations	Drug adjustments recommended	15 vs. 8, $P = 0.028$
					Patient education recommended	2 vs. 7, $P = 0.028$
					Glyc hemoglobin	NS
Mease et al[36] 2000	28 patients (type 2) Eisenhower Army Medical Center. GA	3	Usual care with recommendation for diabetes education classes	Teleconsultation using Aviva 20/20 and Aviva 10/10, by case manager and physician	HbA1c (%)	8.6 vs. 8.2, $P < 0.05$
					Weight (lbs)	223 vs. 206, $P < 0.05$
Morrish et al[37] 1989	18 patients (type 1) metabolic Medicine Unit, Guy's Hospital, London, UK	6	Glucometer without memory function, recording in a diary, monthly visits to the clinic	SMBG data in glucometer, monthly data transfer and analysis w/Ames Diabetes Patient Management software	Absolute change in HbA_1 (%)	NS
					Absolute change in Fructosamine (mmol DMF equivalent/L)	NS
Peters et al[38–39] 1996	42 patients (type 1), Diabetes Center Hellbachtal, Germany	32 days	Personal counseling by physicians and nurses for individual insulin dosage	Insulin dosage recommendations by a computer system	Mean BG, last 14 days (mg/dL)	165.7 vs. 153.1, $P < 0.01$
					SD of BG, last 14 days (mg/dL)	50.4 vs. 46.8, $P < 0.05$
					Insulin consumption (U/kg)	0.64 vs. 0.57, $P < 0.05$
					HbA1c(%)	NS
Peterson et al[40] 1986	16 patients (type 1), Santa Barbara, CA	1.5	Use of standard algorithms for insulin adjustment	Individualized insulin dose recommendations by a computer	Mean weekly BG (mg/dL)	148 vs. 121, $P < 0.01$
					SMBG tests (per week)	51 vs. 58, $P < 0.01$
					HbA1c (%)	NS
					Hypoglycemia <50 mg/dL	Higher in intervention week 2, comparable later on
Piette et al[41] 2001	272 patients, university-affiliated VA outpatient clinics, CA	12	Usual care	Biweekly ATDM health assessment and self-care education calls; follow-up call	HbA1c (%)	(> 8%) 9.2 vs. 8.7, $P = 0.04$; (> 9%) 10.2 vs. 9.1, $P = 0.04$
					Satisfaction with care	3.7 vs. 3.8, $P = 0.05$

(*Continued*)

TABLE 2.(*Continued*)

Source, Year	Sample/Setting	Duration mos	Control Care	Intervention Care	Effects: Measures	Effects: Results Control vs. Intervention
Piette et al[42] 2000	280 patients, 2 general medicine clinics, CA	12	Usual care	Biweekly automated assessment and self-care education calls with followup	Normal Glyc hemoglobin (%) Mean BG (mg/dL) Diabetic symptoms reported (count) Absolute HgbA1c levels (%) Reported selfcare (4 aspects)	8 vs. 17, $P = 0.04$ 221 vs. 180, $P = 0.002$ 5.4 vs. 4, $P < 0.0001$ NS Better in intervention $P < 0.01$
Rivellese et al[43] 1991	21 patients (type 1), diabetic clinics, Italy	1	Data recording in a diary	Computerized recording of 7-day food intake	Time needed for data transfer to dietitian's computer (min)	> 30 vs. ~1‡
Rosenfalck et al.[44] 1993	16 males (type 1), Steno Diabetic Center, Gentofte, Denmark	12	Intensified outpatient care using ordinary logbooks, monthly visits in the clinic	Recording + analysis tool Diva for self-management support, 6 monthly clinic visits	Change in HbA1c (%) Insulin doses BMI Recorded SMBG/6 months	−.3(A), −.4(B) vs. −1.6 $P < 0.05$ NS NS 48 vs. 58
Ryff-de Leche et al[45] 1992	19 patients (type 1 + 2), UniHospital, Basel, Switzerland	3	Monthly insulin dose recommendations based on Camit S2 data mgmt software	Monthly insulin dose recommendations by Cadmo Simulation program	HbA1c (%) Absolute change HgbA1c (%)	6.1 vs. 6.4, $P < 0.001$ ‡
Ryff-de Leche et al[45] 1992	19 patients (type 1), University Hospital Basel, Switzerland	6	Diabetologists' recommendations, based on logbook recordings	Diabetologists' recommendations, electronic log and data analysis with Camit S1	Absolute change HbA1c (%) Percentage (changes) of BG	NS NS
Schrezenmeir et al[46] 1985	12 patients (type 1), Dept. of Endocrinology U of Mainz, Germany	3	2 × 3 insulin injections/day; 6 × 7 scheduled meals	CAMIT recommendations 3–4 injections/day; meal time and size variable	HbA1c after 6-week interval (%) Before meal glucose levels after 6-week interval (mmol/L)	9.1 vs. 8.6, $P < 0.05$ 6.91 vs. 6.22, $P < 0.05$
Shultz et al[47] 1992	20 patients with high HgbA1c, White River Jct. VA Hospital, VT	15	Paper diary	SMBG transmission, report with graphs and statistics to review	Glyc hemoglobin (%)	‡
Tsang et al[48] 2000	19 patients, diabetes clinic, United Christian Hosp., Hong Kong	6	Conventional care and consultations	Electronic diary with a touchscreen to transmit data and receive consultation	HgA1c (%) Ease of use Useful in evaluating eating habits	8.56 vs. 7.84, $P < .05$ 95% 63%
Turnin et al[49] 1992	105 patients (type 1 + 2), Toulouse area, France	6	Conventional care	Remote access to Expert system Diabeto; diet education counseling and e-mail	HbA1 (%) Intake (change) carbohydrates (%) Intake (change) fat (%) Change body weight (kg) Change dietetic knowledge (scale)	+0.2 vs. −0.6‡ 40.7 (± 0) vs. 44.0 (+1.8)‡ 38.5 (−0.3) vs. 36.0 (−2.3)‡ NS −2 vs. +8

CLOC = computer linked outpatient clinic; MEMS = medication event monitoring system; ATDM = automated telephone disease management; BMI = body mass index; CAMIT = computer-assisted meal-related insulin therapy; SD = standard deviation; SMBG = self-measurement of blood glucose; Glyc = glycosylated NS = no significant difference.

‡Between-group *P*-value not available.

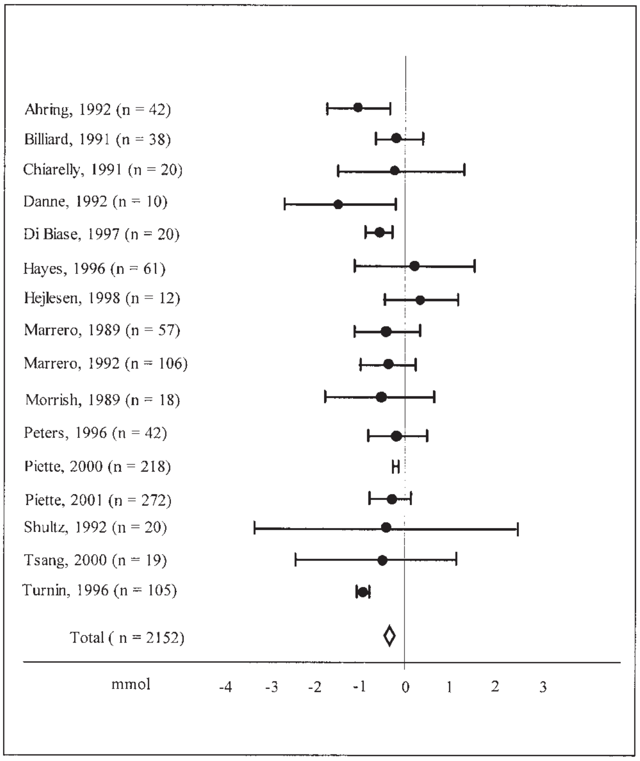

FIGURE 1. Glycated hemoglobin (%) decrease and confidence intervals in studies evaluating utilization of home glucose records in computer-assisted insulin dose adjustment.

patients. While interpreting the results of this study, one should also note the limitation of publication bias.[62,63] Studies that show a superiority effect that is statistically significant will be more likely to 1) be written up by the investigators and submitted for publication and 2) be accepted for publication.

Better knowledge management does not necessarily lead to better clinical outcomes.[64] Some clinical decision support system metaanalyses in other clinical areas (eg, hypertension) have not shown effects on physician knowledge, recording of information, and blood pressure control.[65] It appears that for diabetes, however, knowledge management can lead to improved care. At least 2 other metaanalyses also found that the use of computer-based systems for patients with diabetes could be an effective means of improving metabolic control.[66,67]

Healthcare executives and policymakers would probably like to obtain additional information about costs and more meticulous long-term data on patient acceptance and clinical utilization of the systems, because they are likely to be considering a purchase. Future studies should also include cost calculations of computerized interventions in diabetes care. More research also is needed regarding the effect of computer literacy on access to quality diabetes care by disadvantaged patients.

Researchers in computerized diabetes management face challenging opportunities: integration to provide comprehensive knowledge management support for diabetes care. A comprehensive diabetes management system that combines all successfully tested functions is not available. Yet, there are diabetes clinical management systems that are widely used even though they have not been evaluated in randomized, controlled clinical trials. Systems should be tested in trials that assess their effects on clinical performance and

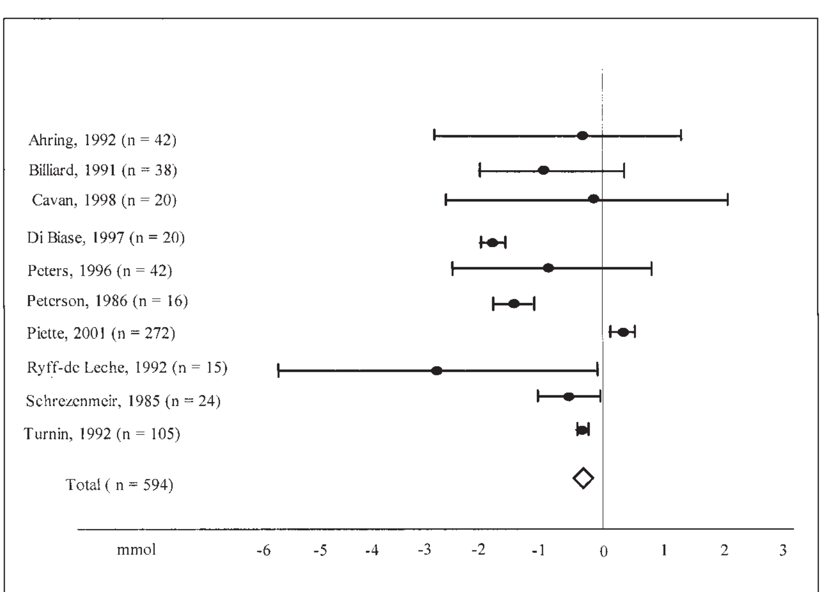

FIGURE 2. Mean blood glucose decrease and confidence intervals in studies evaluating utilization of home glucose records in computer-assisted insulin dose adjustment.

TABLE 3. Computer-Assisted Diabetes Patient Education

Source, Year	Sample/Setting	Duration mos	Control Care	Intervention Care	Effects: Measures	Effects: Results Control vs. Intervention
Bloomfield et al[50] 1990	48 patients; Royal Hosp. for Sick Children, Edinburgh, UK	24	Routine clinic care (mean: 5 visits per year)	Computer-based "diabetic club" educational program, 10 sessions	Mean HbA1 change (%)	+1.1 5 vs. +0.05, $P < 0.01$
					Hypoglycemic events (change)	+0.1 vs. +0.4, $P < 0.05$
					School days absent	+3.2 vs. −1.65, $P < 0.01$
					Hospital admissions (days)	NS
					Percentage correct answers on diabetic problems	−0.5 vs, +6.0, $P < 0.01$
Brown et al[51] 1997	59 children, Stanford U Medical Center and Kaiser Permanente, CA	6	Entertainment video game	Educational video game "Packy & Marlon," with role playing	Diabetes self-care rating scale	4.66 vs. 5.16, $P = 0.003$
					GlycHgb (%)	NS
					Knowledge improvement (%)	NS
					Perceived self-efficacy (score)	NS
					Number of urgent care visits/3 months	NS
Glasgow et al[52–53] 1997	206 patients (type 1 + 2), 2 office-based internists providing primary care, OR	12	Usual care with assessment by computer of dietary mgmt, no feedback	Touch screen computer-aided assessment with immediate feedback; problem-solving counseling; phone followup	Serum cholesterol	226 vs. 208, $P = 0.002$
					Food habits score (% change)	−1.3 vs. −8.8%, $P = 0.007$
					Patient satisfaction with office visit	$P < 0.02$
					HbA1c (%)	NS
					BMI	NS
Horan et al[54] 1990	20 adolescents (type 1), at North Carolina State University, NC	4.5	Printed educational material about diabetes management	Diabetes in Self Control (DISC) system: clinical data management, diabetes education, problem solving and goal setting	Prelunch BG	$P < 0.02$
					Predinner BG	$P < 0.025$
					Glyc hemoglobin (HbA1c, HbA1)	NS
					Diabetes knowledge	NS
Kim and Philips[55] 1991	24 patients with poor diabetes management, U of Iowa, IA	1hr/pat	Computer based drill program with simple feedback	Computer based drill program plus elaborate feedback	Number of posttest questions answered correctly (20 maximum)	15.25 vs. 17.17, $P = 0.005$
Lo et al[56] 1996	36 patients (type 1 + 2), Southern Cross Univ, Australia	3	Conventional diabetes education program (16 lessons, 4 sessions each) Diabetes knowledge scores	Computer-aided learning (CAL), 16 lessons, 3 to 6 sessions	GHb	$P = 0.038$
					Diabetes knowledge scores	$P < 0.002$
Sheldon[57] 1996	13 patients (type 1), outpatient clinic, Jackson Memorial Hosp, Miami, FL	3	Pencil-paper log, daily food intake and activities, no feedback	Daily food intake and exercise recorded by CADET III with feedback and summary information	Mean no. of days entered in log	19.50 vs. 52.14, $P = 0.0056$
					Glyc hemoglobin (mg/dL)	NS
					BMI	NS
					Plasma lipids (HDL, LDL, Trig, Cholesterol	NS
Smith et al[58] 2000	30 rural women (type II), Montana State Univ College of Nursing, MT	10	Printed information and education materials	Computerized education and support using electronic communication technology	Change in HbA1c (%)	NS
					Personal resource questionnaire	NS
					Quality of Life Index	NS
					Psychosocial Adaptation to Illness Scale	NS
Wheeler et al[59–60] 1985	16 patients, diet clinic, Indiana	1	1 to 2 nutritional education sessions (30 min each) with dietitian	Computer-assisted instruction (CAI) and videos, nutritional education, meal planning and dietitian support	Change in body weight (lb)	−2.1 vs. −5‡
					Diet minus prescribed diet (change %)	6.4 vs. −39.4‡
					Food exchange skills (score)	+0.8 vs. +5.7‡
					24-h recall fat content (change) (%)	39.6 (−3.1) vs. 36.3 (−7.8)
					Change food portioning skills (score)	+0.4 vs. +0.1
Wise et al[61] 1986	174 patients (type 1+2), Dept of Endocrinology Charing Cross Hosp, UK	4–6	Only HbA1c controls	Interactive computer-based knowledge assessment and instruction	Type 1: HbA1c (%)	−0.1 vs. −0.7‡
					Type 2 (non-insulin): HbA1c (%)	− 0.2 vs. − 0.8‡

DISC = diabetes in self-control; BMI = body mass index; Glyc = glycosylated; Trig = triglycerides.
‡ Between-group *P*-value not available.

patient outcome.[68] Distance technologies so far have mainly been tested as complements to conventional clinician–patient encounters. To explore the full potential benefit of these technologies and their effect on the quality of health care and patient satisfaction, further research should also examine the effect of replacing conventional visits by telematic contacts. Further research and future applications should take advantage of the promulgation of Internet, handheld, and other technologies, and explore their potential for improving diabetes care. All future assessments of technology in diabetes care should also measure satisfaction with care with the added component.

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