Special Article

Experience with Automation as an Aid in the Management of Diabetes

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SUMMARY

This study reports experience in the management of eighty-six diabetic patients using a semiautomated system. Input to the system is effected through a teletype terminal and includes information pertaining to commonly used parameters in the regulation of the diabetic patient. Output from the program includes recommendations for short, intermediate and long acting insulins as often as four times per day, oral hypoglycemic agents and dietary regulation. During one phase of the study management was carried out by a nurse-clinician using the computer as an automated consultation. The current version of the program shows a good correlation for insulin dosage between computer and physician. Because of the necessity of interpreting input information, the user must have some clinical background in the management of diabetes. DIABETES *22*:480-84, June, 1973.

The prevalence of diabetes premonstrates the emergence of problems related to the management of this disease state at many points in the health care system.[1] These problems may be of a primary nature, related directly to diabetes, or incidental, related to other illnesses. For this reason allied health personnel or specialists in unrelated fields not necessarily familiar with diabetic management may find themselves called upon to make decisions regarding complicated treatment problems in patients with diabetes.

The course of action demanded of the consultant in diabetes in these situations is sometimes quite complex in its derivation but more often is of a routine nature involving the consideration of a discrete number of variables and the prescription of a course of action leading to a limited number of consequences. Ideally, the logic underlying such procedures can be portrayed according to the model of a decision tree leading to the construction of matrices of action and consequence.[2] This type of logic lends itself readily to automation and thus makes possible the handling of some parts of the diabetic consultation by computer. A preliminary report on the use of such a system indicated its feasibility and relative safety.[3] The following report describes further experience with similar systems employed as an automated consultation.

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METHODS

A computer program was devised which could make recommendations regarding diet, insulin, and oral hypoglycemic agents in diabetic patients. Input to the system is by teletype terminal which has direct communication with a computer. Input information is coded using the following clinical data: body weight, ideal body weight, twenty-four hour glycosuria, fasting blood glucose, type of diabetes, time of hypoglycemic reactions, weight change, ketonuria, presence of coronary disease, age, sex, present insulin schedule, sulfonylurea drugs, phenformin dosage, presence of nausea or vomiting, past history of nausea with medication, serum cholesterol and triglycerides, presence of complications, pregnancy and menses, average fasting blood sugar in past, history of unconsciousness with insulin reactions, highest dose of insulin, cooperation with diet, presence of significant insulin antibodies, past experience with long acting insulin and willingness to take multiple doses of insulin or not. Within the program, specific questions may be asked regarding intercurrent disease and timing of peak periods of glycosuria.

The output of the program consists of a printout with diet and insulin recommendations including subdivision of insulin doses and types of insulin. In this study a.m. insulin refers to a dose taken fifteen minutes before breakfast and p.m. refers to a dose fifteen minutes before the evening meal. Recommendations for diagnostic tests other than serum triglycerides, cholesterol, blood and urine sugar and blood urea nitrogen cannot be introduced into this program until such time as programs are devised for other common conditions such as hypertension and heart failure. A number of other recommendations are also added. The program is set up to recommend insulin either as short acting, intermediate acting or long acting. A sample printout is shown in figure 1. Diet instruction is limited to a recommendation for calories, carbohydrate, fat and protein. Further subdivision of diet instruction has not been programmed. Dietary changes can occur due to pregnancy, variable exercise, starvation ketosis, obesity, and inanition.

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                         SAMPLE PRINT-OUT
THIS PATIENT'S DIET SHOULD BE:

     TOTAL CALORIES              1480
     CARBOHYDRATE                 148 GRAMS
     PROTEIN                       74 GRAMS
     FAT                           66 GRAMS

BECAUSE VASCULAR DISEASE IS PRESENT, BLOOD-SUGAR LEVELS SHOULD
BE LEFT RELATIVELY HIGH (2+ GLYCOSURIA) TO PROTECT
THE PATIENT FROM HYPOGLYCEMIA.

               INSULIN RECOMMENDATIONS

                        AM      NOON      PM     MIDNIGHT
UNITS INTERMEDIATE      34       0         9        0

UNITS SHORT ACTING      20       0         0        0

UNITS LONG  ACTING       0       0         0        0
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FIG. 1. This is a sample printout showing dietary recommendations, a warning against hypoglycemia, and an insulin recommendation consisting of three components.

The project was designed in three phases. In the first phase a limited program was developed for a small number of variables as a feasibility study. In the second phase a number of other variables were added allowing for more flexibility. During this phase the patient was managed by a nurse clinician using the computer as a consultative facility. She was instructed to request examination by a physician when new complaints arose or time for an annual physical examination had lapsed. In the third phase the program was expanded to include hospital inpatient situations. In each case the recommendations by the computer were checked by a diabetologist and comparison between the physician and the computer studied. The system was designed using Regular or Semilente, Lente and Ultralente insulins. The distribution of case material is shown in table 1.

RESULTS

The programs were used in ninety-four instances on outpatients and in 104 instances on inpatients. The correlation between the computer and the physician for the various doses of insulins is shown in table 2. In the Phase II and III programs the correlations are all highly significant. Comparisons are valid only between the Phase II and III programs since in the Phase I program only nineteen pieces of clinical data were sampled in contrast to at least thirty-six in the later programs. Furthermore the number of possibilities for alternative decisions increased from fifty-two in Phase I to 160 in Phases II and III thus increasing both the flexibility and variability of the program.

The Phase II program was used in forty-nine outpatient visits in an experimental setting such that a nurse-clinician actually performed the primary care of the patient, using the computer as an automated consultation. The results of her decisions each time were reviewed by two diabetologists, and potentially hazardous computer decisions which were likely to lead to hypoglycemia or ketosis were countermanded in five out of forty-nine instances. This prompted the revision

TABLE 1
Case Material

No. of patients	No. of visits	Patients on insulin	Patients not on insulin
	Outpatients		
61	94	50	11
	Inpatients		
25	104	24	1

TABLE 2
Correlation of insulin recommended by computer vs. physician

Insulin	r	P	
	Phase I		(N = 14)
AM Lente	.949	<.001	
PM Lente	.000	>.05	
AM Regular	.686	<.01	
PM Regular	.000	>.05	
Total	.983	<.001	
	Phase II		(N = 49)
AM Lente	.918	<.001	
PM Lente	.790	<.001	
AM Regular	.955	<.001	
PM Regular	.649	<.001	
Total	.864	<.001	
	Phase III		(N = 99)
AM Lente	.906	<.001	
PM Lente	.831	<.001	
AM Regular	.878	<.001	
PM Regular	.777	<.001	
Total	.928	<.001	

r = Coefficient of correlation
P = Statistical probability using Students "t" test.
N = Number of cases

of the program to the Phase III version. The correlations in Phase II are little different from those in Phase III except that in the latter case potentially hazardous decisions appear to have been eliminated. The Phase III program was used in ninety-nine instances on in- and outpatients by medical students. In table 3 it is noted that the agreement between the physician and the computer was somewhat better for outpatients than inpatients. Correlation between computer and physician was usually better for total dose than for timing and type of insulin. Branching in this program provided an option such that by further questioning an early morning prescription for insulin could be obtained even though at that time the morning blood glucose be not available. Most of the differences noted between physician and computer in the Phase III program were temporal when sequential inpatient visits were included. In these inpatient situations the computer and the physician did not necessarily institute changes on the same day but tended eventually to converge toward the same conclusion.

TABLE 3

Correlation of physician with computer for dose differences

	Phase III			
Insulin	Inpatients (N = 82)		Outpatients (N = 17)	
	r	P	r	P
AM Lente	.892	<.001	.937	<.001
PM Lente	.742	<.001	.982	<.001
AM Regular	.871	<.001	.919	<.001
PM Regular	.750	<.001	.989	<.001
Total	.916	.001	.951	.001

The flow-chart of a patient managed with computer assistance through twelve days of hospitalization including a surgical procedure is shown in figure 2. A minimization of glycosuria was considered to be important because of a chronic urinary tract infection aggravated by an atonic bladder. The computer correctly prescribed an insulin schedule for the day of surgery and upon instruction arranged for insulin three times daily. Total insulin dosage was gradually increased during the illness. In most instances the fasting blood glucose was not known at the time the program was run.

The frequency with which some of the key decisions were used by the computer in the Phase III program is shown in figure 3. Of those decisions which were used most frequently, numbers 9, 15 and 16 require some

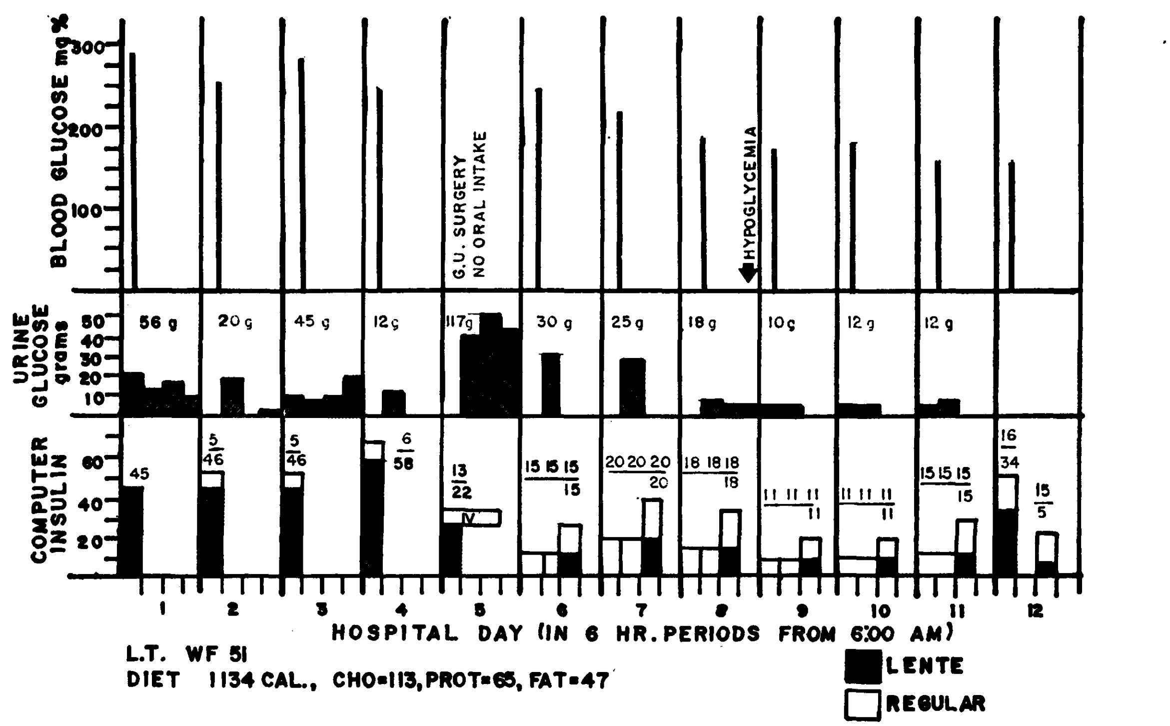

FIG. 2. The flow-chart of a hospitalized fifty-one year old diabetic female is shown. In the insulin line, clear areas represent short acting insulin and crosshatched areas, intermediate acting insulin. A urinary tract infection requiring endoscopy under anesthesia was a complicating feature.

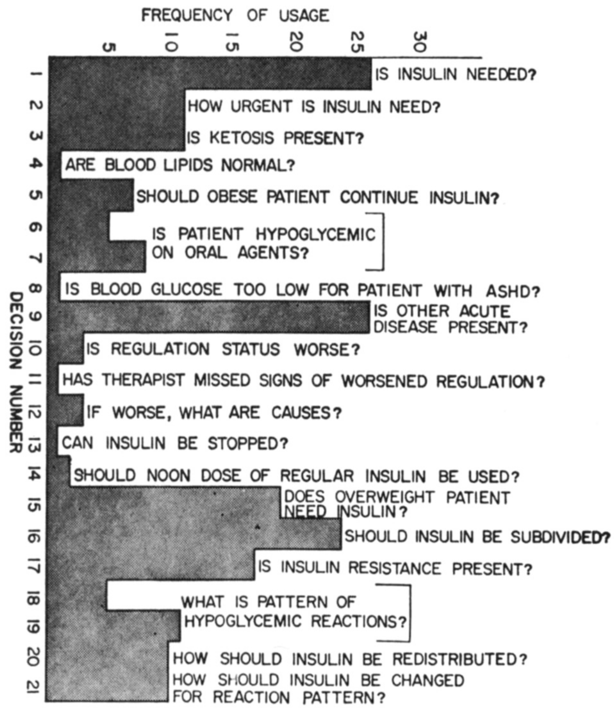

FIG. 3. The frequency with which the program used the indicated decisions is shown. Each decision represents one or more questions asked by the program.

comment. Decision number 9 was based on branching to questions related to the presence of intercurrent disease states which could affect regulation and require anticipatory action on the part of the therapist. The five groups included are acute infectious states, drugs of the thiazide group, chronic inflammatory states, edema and surgery. Decision number 15 pertains to the question whether an obese, adult-onset diabetic needs insulin or not. Decision 16 deals with the advisability of subdividing the time and type of insulin. Both decisions 15 and 16 proved to be particularly problematic, as they are in clinical practice, and contributed most to the variability between computer and physician.

A prescription for Ultralente insulin was appropriately made eleven times in Phase III, and a prescription for a noon dose of Regular insulin was made only three times.

DISCUSSION

The use of a strict decision tree model[2] for the construction of the logic proved to be difficult because of the frequency of decision pathways that were not mutually exclusive. Instead, the model of a hypothetical group of unsorted diabetics is postulated as the "trunk" of the tree. Sorting of this group is carried out by the questions in the program so that the patient is assigned to a "twig" presumably representing an appropriate course of action (figure 4). The criteria for assignment during the sorting could then be established and tested at each point by a series of gates which either did or did not admit the patient. This approach also made it more possible to individualize the treatment and not simply to treat the patient according to some statistical figure. Also the option of reassigning a patient to another category during the process of logic flow is possible.

It has not been possible to obtain a perfect correlation between the computer and the physician but it has been possible to eliminate potentially hazardous decisions. This was accomplished by programming the computer to err on the conservative side. It is doubtful though that such a system could be used by an entirely uninformed operator with no clinical background since most of the problems related to the use of such a system arise from differences in interpretation of some of the input data. Thus some knowledge of clinical medicine is required to correctly code the input information. For example, the decision as to whether insulin should be given twice or three times daily could not be handled by the computer alone and for that reason an option is open in the input information which allows the operator to decide this in some cases.

Such factors as the ability of the patient to cooperate with a recommendation for multiple insulin doses versus the urgency, in a given case, to use a multiple dose schedule would have to be considered. Such abstract decision making is not handled well by computers. Impasses such as this can be handled by setting up exit points from the program which recommend actual con-

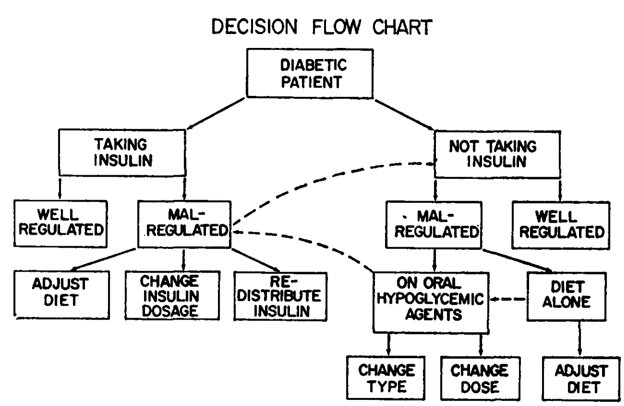

FIG. 4. Model for principal pathways for sorting to arrive at final recommendation.

sultation with a capable physician. In this study a health care professional at the level of a nurse-clinician appeared quite capable of using the computer as an adjunct in the care of diabetic patients. Because of the multiplicity of other diseases occurring in the diabetic population, the automated system described here is of limited use until such time as similar programs have been developed for a number of other intercurrent disease states. Also the amount of input information could be materially reduced if a data base of past history were available on-line in the system. It is doubtful that the use of such a system could directly save time for the physician who is well versed in the management of diabetes, except in a situation where paramedical personnel intervene.

This study was not designed to prove the superiority of one system of diabetic management over another but has demonstrated the feasibility of closely imitating by automation the system of management currently used in this clinic.[4] An extension of this approach to other related disease states and other diagnostic tests would be desirable.

ACKNOWLEDGMENT

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ABSTRACTS

Anonymous: GLOMERULAR DISEASE IN DIABETES (editorial). Lancet *II*:1403-404, December 30, 1972.

Light microscopic studies of the kidney of diabetics have shown poor correlation between renal histologic changes and symptoms. The most widely known diabetic renal disorder, the nephrotic syndrome, is not necessarily associated with the glomerular nodule described by Kimmelstiel and Wilson. The lesion found most frequently by biopsy of the diabetic kidney using the electron microscope is a diffuse lesion which has two components: one is a thickening of the glomerular-capillary basement membrane, and the other is an increase in the interstitial tissue lying between the capillaries, the mesangium. If the classic Kimmelstiel-Wilson nodule is found, it is invariably accompanied by the diffuse lesion, but the nodule itself is probably of little functional significance. Study of kidneys of diabetic patients who died before the availability of insulin has disclosed that lesions identifiable by light microscopy were infrequent. This has led to the speculation that insulin administration may play a role in the pathogenesis of glomerulopathy. The hypothesis is supported by the facts that diabetic glomeruli contain material which will bind insulin and also contain immunologically detectable insulin. However, the kidneys of diabetics who have never received insulin also have these properties. Another hypothesis is that the glomerular lesion may be initiated by a complexing of circulating insulin and insulin antibodies. No hypothesis seems completely acceptable and there is no treatment that appears capable of preventing the progression of renal diabetic lesions. For prognostic purposes, heavy proteinuria usually is an ominous sign. Recent clinical studies support the feasibility that diabetic renal failure does not contraindicate renal transplantation. T.G.S.

Bagdade, John D.; Nielson, Kathleen L.; and Bulger, Roger J. (Dept. of Med., Univ. of Washington, Sch. of Med. and VA Hosp., Seattle, Wash.): REVERSIBLE ABNORMALITIES IN PHAGOCYTIC FUNCTION IN POORLY CONTROLLED DIABETIC PATIENTS. Amer. J. Med. Sci. *263*:451-56, June 1972.

Verbatim summary. Phagocytic function was compared in nondiabetic control and eleven poorly controlled diabetic subjects before and after treatment. Prior to therapy, the rates at which the type-25 pneumonococcus employed as the test organism was killed by whole blood were significantly reduced ($p < .01$) in the diabetic group. This delay in bacterial killing appeared to result from a marked reduction in phagocytosis, the degree of impairment correlating closely ($p < .001$) with fasting glucose levels. Both of these abnormalities were reversed by diabetic treatment.

Baker, H. W. G.; Best, J. B.; Burger, H. G.; and Cameron, D. P. (Med. Res. Center and Monash Univ. Dept. of Med., Prince Henry's Hosp., Melbourne, Victoria, Australia): PLASMA HUMAN GROWTH HORMONE LEVELS IN RESPONSE TO MEALS: A REAPPRAISAL. Aust. J. Exp. Biol. Med. Sci. *50*:715-24, December 1972.

Verbatim summary. To study the influence of the usual Australian feeding pattern on plasma growth hormone concentrations, six healthy adults were given a three day dietary regime. Meals of constant composition were eaten at the same time each day except that breakfast was omitted on one