

Self management of insulin-dependent diabetes mellitus

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Diabetes Mellitus is a chronic metabolic disorder which adversely affects the body's ability to manufacture and/or utilise insulin, a hormone required for the transformation of glucose into energy. Diabetes affects ten million people in the US, and its prevalence is increasing by 6% p.a. Long term diabetic complications arise from the greatly accelerated degeneration of blood vessels in many organs, which can lead to

blindness, kidney failure, heart attack, stroke, gangrene and problems of the nervous system. Diabetics are 25 times more prone to blindness than non-diabetics, 17 times more prone to kidney disease, over 5 times more prone to gangrene (often leading to amputation) and twice as prone to heart disease. It is the third leading cause of death by disease, outranked only by cardiovascular disease and cancer. From the time of onset, diabetes reduces life expectancy

by approximately 30%.

There are two clinical types of diabetes: insulin-dependent (previously known as juvenile-onset) diabetes (approximately 20% of the diabetic population), and noninsulin-dependent (previously known as maturity-onset) diabetes. This article concentrates on the home management of insulin-dependent patients. This disease is the third major chronic ailment of children. One half of these victims die from kidney disease

within an average of 25 years following diagnosis.

The cause and prevention of diabetes are still unknown. At present, it can only be treated by a combination of insulin therapy, diet and exercise. There is no cure. Traditional methods of diabetes treatment are being rapidly overtaken by a more scientifically-based approach dedicated to the premise that strict control of blood glucose levels will delay and hopefully prevent the onset of long term

diabetic complications. Statistical evidence to support this proposition does not yet exist, and possibly never will — nevertheless, there is significant clinical evidence to support the modern approach.

The treatment of diabetes lasts a lifetime and is almost exclusively the responsibility of the patient — hence the emphasis on self-management in the home environment. Diabetes is the only disease in which the patient (or his parents) is expected to make independent therapeutic decisions based on clinical observations. It is a prime example of the old adage: knowledge is power. Knowledge of the principles of self-management allows the patient to control his diabetes. It has distressingly often been demonstrated that an understanding of the disease and mastery of the necessary skills are inadequate in a large proportion of diabetics and their families. The first step would be educating the educators!

This article is directed at the general practitioner or paediatrician and aims to assist him in advising patients (or their parents) on the modern principles of self-management of diabetes. Clearly not all patients (or their parents) are educatable or wish to be knowledgeable — but the proportion that want to take control of their diabetes will surely increase. The article is based on an extensive literature survey undertaken to establish the worldwide state-of-art in diabetes care. The article does not claim originality and does not pretend to be definitive on diabetes as such — aspects such as symptoms and diagnosis are neglected. Pointers to the literature are provided in the reference list.

Principles of Treatment

The management of insulin-dependent diabetes mellitus revolves around balancing three *control variables*: Energy availability (food intake), energy expenditure (physical activity) and insulin dosage. All three can be varied in order to achieve satisfactory diabetic control. (The definition of diabetic control is discussed in a later paragraph.)

The effectiveness of insulin within the patient is also a variable, but is only partially controllable. It depends on many factors. Some can be partially prevented: injection site (prevented by daily site rotation), anti-body formation (prevented by using monocomponent in-



sulins), and the use of other medications. Others cannot be controlled or prevented: illness, psychological stress (e.g. excitement) and physiologic condition (e.g. menstrual periods and pregnancy). In the case of anticipated heavy exercise (eg. a tennis match), the usual injection site eg. buttocks, thighs or arms) should be changed eg. to the abdomen where there will be no heavy increase in blood supply which would cause more rapid insulin absorption and possible hypoglycemia.

Once these factors have been prevented or are absent, a balance between the three variables can be achieved and maintained resulting in proper control. This situation defines the *baseline values* for the three variables. This balance can be disturbed for many reasons and always requires a compensating *baseline adjustment*, or a *supplement* to the baseline to regain control².

A baseline adjustment is a modification in a baseline value, and results in a new baseline. It assumes that the other two control variables have been held constant, and that the patient is free from illness and unusual stress. On the other hand, when the other two control variables are not stable, or when the patient is ill or under psychological stress, one-off or temporary supplements are given over and above the baseline. Compensatory supplements react to control disturbances, whereas anticipatory supplements try to prevent them.

A control *algorithm* is a pre-determined plan which defines which variable has to be changed when and by how much in order to regain diabetic control. Controllability requires observability: All algorithms require the patient to monitor his degree of control by regular glycosuria and ketonuria measurements of blood glucose measurements, and by physiologic observations.

Hypoglycaemia and hyperglycaemia

Under conditions of poor control, two extremes can develop: hypoglycaemia and hyperglycaemia.

● **Hypoglycaemia** results from too little food, too much exercise or too much insulin. Typical warning signs are that the patient's behaviour is excited, nervous, irritable or confused. The tongue feels moist, numb or tingling. He may also feel shaky, sweaty and hungry. Breathing can be normal or rapid and shallow. The most important point is that its onset is sudden. The treatment always consists of providing rapidly-digestible carbohydrates, followed by some more slowly digested food. The patient typically receives a sweet, or regular cold drink, or orange juice or a lump of sugar, followed by a bread exchange. Unconscious patients may have to be treated with an injection of glucagon (an insulin-counteracting hormone also secreted by the pancreas) or

may require intravenous glucose.

● **Hyperglycaemia** is caused by too much food, too little exercise, too little insulin or illness. Behaviour is often drowsy. The tongue feels dry. Breathing is deep and laboured. The skin is flushed and dry. Its onset is gradual. Treatment always consists of proper insulin therapy. If ketoacidosis has set in, hospitalisation may be required.

A complicating factor may be the Somogyi effect (rebound). This consists of hyperglycaemia resulting from hypoglycaemia, caused by an overcompensation by the body. The liver responds to hypoglycaemia by releasing glucose which, combined with the rapidly-digestible carbohydrates taken by the patient may result in hyperglycaemia.

Note: a very common cause of hyperglycaemia is too little insulin during illness. The patient should be carefully instructed on handling common illnesses.

Differential diagnosis between hyperglycaemia and hypoglycaemia consists of a blood glucose test.

What is diabetic control?

The objectives of diabetic control contain a short term component (prevent hypoglycaemia and hyperglycaemia) and a long term component (prevent or delay the onset of long term complications). There are also valid social and psychological objectives (eg. promote emotional well-being, make diabetes unobtrusive to the life style of the patient), as well as nutritional objectives. Most control algorithms are defined in terms of glucose homeostasis. These objectives are quantitative, measurable at home, and can provide a link between short terms and long term components.

The *traditional approach* has modest and achievable control objectives: Absence of diabetic symptoms, absence of ketoacidosis and absence of hypoglycaemia³. It is based almost exclusively on monitoring urinalysis and suffers from the resultant restrictions (see box). A typical quantitative objective is to keep 50% of all tests at less than 2% glycosuria.

The *modern approach* aims for a permanent state of aglycosuria and normo-glycemia and is based on monitoring blood glucose measurements. Blood glucose measurements are essential, since whatever range of values are used as control objectives, this range will lie substantially below the point at which urinalysis is likely to be

helpful. Typical control objectives are shown in Table 1.⁴

In cases where this is not practical for whatever reason, a more achievable aim is fasting normoglycaemia with short postprandial hyperglycaemia. The modern approach links short term to long term control components, since there is clinical evidence that a return to normal or close to normal blood glucose levels does reverse a variety of diabetic abnormalities. Needless to say, many other diabetic long term complications are irreversible, e.g. retinal microangiopathy.⁵

Control algorithms

The control algorithms will be described in terms of the baseline, adjustments and supplements for each of the three variables insulin, food and exercise.

Insulin Baseline: The insulin baseline is established by trial and error. A common approach is to use a split insulin regimen of twice-daily Semitard insulin injections providing 0.7 units/kg bodyweight/24 hours. If necessary, Actrapid insulin may be added. Alternatively one may start off with a split-and-mixed insulin regimen. Experiment until proper control has been established.

Insulin Adjustments²: Insulin adjustments are always based on preprandial blood glucose or glycosuria measurements, and often on postprandial measurements as well.

Adjustments for hypoglycaemia: A single hypoglycaemia episode which cannot be explained by unusual exercise or by delayed or inadequate meals, requires a reduction of approximately 10% in the dosage of the relevant insulin component. The relevant insulin component is that which is primarily responsible for blood glucose control during the period of the day when the unexplained hypoglycaemic episode occurred. This is further explained for a split-and-mixed insulin regimen in Table 2:

Adjustments for hyperglycaemia: An increase of approximately 10% in the dosage of the relevant insulin component is made for hyperglycaemia episodes which cannot be explained by diminished activity or by excessive eating, or by emotional upset or by illness. Adjustments should be made only when hyperglycaemia occurs in a consistent pattern on three successive days.

Reference 6 contains a sophisticated algorithm for insulin adjustments in controlling

Table 1

Control	% of time blood glucose levels are outside 50 to 150 mg/dl*	Essentially no blood glucose levels (mg/dl)
Good	80	>200
Acceptable	70	>250

* 18 mg/dl = 1 mmol/l.

pregnant diabetics.

Comments: Only adjust one insulin component at a time. Prevent inadvertently increasing insulin dosage in response to rebound hyperglycaemia following hypoglycaemia (Somogyi reaction). When an insulin component is intended to be primarily responsible for blood glucose control for more than one time

to an insulin injection, ie. to determine the required incremental or decremental quantity.

Calibration requires a series of blood glucose measurements during the action profile of the insulin and is a trial-and-error procedure. The insulin response is non-linear, ie. the higher the blood glucose level, the more insulin is required to lower it by a



interval during the day, hyperglycaemia must be evident during all such intervals for the dosage to be increased. If this is not the case, it may be necessary to alter the insulin distribution.

Insulin Supplements: Insulin supplements consist of anticipatory decrements in the relevant baseline insulin component or of anticipatory or compensatory supplemental injections of regular insulin. The main problem is to calibrate the blood glucose response of the patient

given amount. As a result, one has to measure at various blood glucose levels how much insulin is required to decrease the blood glucose to normal.

Typical examples of insulin supplements include¹³:

- An anticipatory decrement in the relevant baseline insulin component to prevent hypoglycaemia resulting from unusual exercise.
- An anticipatory or compensatory injection of regular insulin prior to or after the consumption of an unusually

Table 2

Insulin Component	Maximum effect	Monitoring Time
Morning regular insulin	Between breakfast and lunch	Before lunch
Morning intermediate-acting insulin	Between lunch and supper	Before supper
Evening regular insulin	Between supper and bedtime	Before bedtime
Evening intermediate-acting insulin	Overnight	Before breakfast

large meal (e.g. at a dinner party) where there is not expected to be a compensatory increase in activity.

● An anticipatory increase in the relevant insulin component to prevent hypoglycaemia caused by unusual psychological stress.

Diet Baseline: Determination of the diet baseline is described in the table. It is important to have a balanced nutritionally-sound diet which remains consistent from day to day.

Diet Adjustments: Diet adjustments will not normally be required if the baseline has been designed for well-smoothed glucose peaks. This is not to say that diet adjustments cannot be used.

Reference 6 contain a sophisticated algorithm using diet adjustments to further smooth out glucose peaks and which is based on blood glucose and ketonuria measurements. Such algorithms normally require strict adherence to portion size by means of weighing all food exchanges.

Diet adjustments not related to improving day-to-day control are required for normal growth in children, and seasonal climatic changes.

Diet Supplements: Food supplements can be used to prevent hypoglycaemia caused by for example unusual exercise. Food supplements should be calibrated in a similar manner as described under insulin supplement; ie. the patient should determine his blood glucose response to specific foods. Typical examples of food supplements include:

- In the case of vomiting during illness, use calibrated regular cold drinks to provide energy intake.
- Prevent hypoglycaemia by taking a calibrated amount of sweets, or regular cold drink, or orange juice or a lump of sugar.
- Counteract hyperglycaemia by reducing the next snack or meal.

A sophisticated algorithm for preventing hypoglycaemia which is not based on calibrated food supplements in as follows⁶: At the onset of a hypoglycaemic episode, the blood glucose level should be measured. If this is below 70 mg/dl, then drink 240 ml of milk. Recheck the blood glucose level after 15 minutes. If the blood glucose remained lower than 70 mg/dl, then take another 240 ml of milk and recheck the blood glucose after another 15 minutes. If the result is still less than 70 mg/dl, then take another 240 ml of milk and eat one slice of bread.

Exercise Baseline: The exercise baseline depends on typical activity patterns during the day, and may thus be different for work days, weekends and holidays. It also depends on participation in sport and home exercises. Clearly, this exercise baseline should be reflected in the kilojoules provided in the diet baseline. Two or more diets may be required, for example one for work days and one for weekends.

Exercise Adjustments: The timing of daily exercise can be adapted to smooth out glucose peaks.

Exercise Supplements: A calibrated set of exercises could be carried out to compensate for hyperglycaemic episodes. Once again the patient should calibrate himself by determining his blood glucose response to exercise. (Note that strenuous exercise should be avoided when the blood glucose level is above 300 mg/dl, due to an inability to perform muscular work.)

Self-Management for Diabetic Control

Previous paragraphs outlined the general principles of treatment, and described various control algorithms.

It should be obvious that many of the adjustments and supplements described above can be substituted for one another, allowing the patient considerable flexibility. He might, for example, prefer to run for 5 minutes rather than take a supplementary insulin injection of 10 units. The important point is that the patient should understand the various algorithms, faithfully monitor his state of control, and calibrate himself to supplements in the different control variables.

It should also be very obvious that the use of these control algorithms is much more meaningful if monitoring is done using blood glucose measurements — the use of urinalysis methods is incompatible with strict control. Another advantage of using blood glucose measurements is that the patient can calibrate his own early warning signals of an impending hypoglycaemic episode. By correlating his own clinical observations with blood glucose measurements under controlled conditions of hypoglycaemia, he will learn to detect the onset of hypoglycaemia much earlier and thus be able to take more effective supplements. Blood glucose measurements also appear to deter the patient from a typical psychological reaction to

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• Further details on insulin, diet - and the monitoring thereof - will be featured in the next (February 1981) issue of *SA Family Practice*.



diabetes — a denial of his illness.

Psychological aspects

'Living with the fear of long term diabetic complications superimposed on daily demands of observing a rigorous medical regimen is a severe stress for the patient and his entire family. Many diabetics are subject to powerful, unpredictable mood and behaviour changes that are a function of metabolic imbalance. In addition, chronic, non-metabolic stresses associated with the disease include the need for diet management, rigid meal schedules, urine or blood glucose testing, various daily therapeutic decisions, daily insulin injections and alterations in life style. These stresses frequently result in significant emotional disequilibrium and occasionally in clinical psychiatric disorder. Impaired self-esteem is common. Denial, anxiety, hostility, and depression also occur and may impair interpersonal relationships at various levels. Despite continuing gains in understanding this disease, our present state of knowledge remains insufficient to prevent diabetes, to cure diabetes, or to provide diabetic patients with optimally-effective treatment. While the search for a means of prevention and a cure continues, we need to focus energies on easing the emotional burdens and improving the quality of life for diabetics and their families.⁸

A major danger in the use of the modern approach to managing diabetic children is that although good diabetic control may be achieved, it is accomplished at the expense of the development of the child's

personality. The young diabetic may become obsessive-compulsive in his attitudes, or he may simply rebel against his parents and follow no treatment plan whatsoever. To what extent children should be subjected to strict control is an exceedingly difficult issue for which no general answers exist.

The future:

The modern approach to diabetes treatment described in this article will probably be replaced by continuous subcutaneous insulin infusion for some patients within the next 5-10 years. Non-diabetics have two insulin delivery rates: A slow basal rate, which is augmented by prandial secretion to dispose of absorbed nutrients. Due to insulin's short circulatory half-life, it is very difficult to mimic the basal rates of insulin delivery even using multiple insulin injections. This problem can be solved by continuous subcutaneous, or intravenous, or intraperitoneal insulin infusion⁹. In closed-loop systems insulin is provided in response to continuous real-time measurements of blood glucose level¹⁰, whereas in open-loop systems insulin is delivered in a pre-programmed manner, independent of the blood glucose level. (Insulin would be delivered at a basal rate, with the patient manually initiating a higher delivery rate, operating for a preset time interval, prior to meals.)

Since the design of miniature long-life, real-time blood glucose sensors is beyond current state-of-art, closed-loop systems are impractical for ambulatory patients.

Considerable experimentation is under way using open-loop systems based on existing electromechanical technology. Experiments have shown that intravenous delivery is optimal (notwithstanding frequent catheter obstruction), followed by intraperitoneal and subcutaneous delivery methods. Due to inadequate information on equipment reliability and physiologic response, these devices have not been used outside of the research arena¹¹. Clinical studies have shown⁹ that open-loop insulin delivery systems do not provide significantly better diabetic control compared to methods described in this article.

The long term objective is to develop an insulin delivery system that is implantable into the intraperitoneal cavity, with the insulin reservoir regularly refilled by percutaneous injection.

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