CHAPTER 2 LINKING ENERGY FLOW IN THE BODY

The two current methods for predicting glycaemic response due to ingestion of food are discussed, namely carbohydrate counting and the glycaemic index. Furthermore, it is currently incorrectly assumed that 100% of the chemical energy contained in food is available to the human energy system after consumption. In this chapter a better method for quantifying energy from food as well as predicting glycaemic response to ingested carbohydrates is presented.

2.1 Introduction

To construct a simulation model for the glycaemic subsystem of the human energy system the flow of energy into, out of, and in between the various system components has to be quantified. This provides the ability to relate food, exercise, system fuel and storage energy with one universal quantity. In order to define such a quantity the different fuels used by the body have to be examined in detail.

Glucose in the blood circulation system (blood sugar) is one of the primary fuels that drive the human engine [1]. It is made available to the body primarily through ingestion and digestion of carbohydrates (CHO) contained in food, and from converting stored energy reserves into blood sugar [2]. Prediction of blood glucose response due to specific events reveals an astonishing amount of information pertaining to the operation of the entire human energy system.

Accurate control of diabetes is one of the primary beneficiaries of the accurate prediction of blood glucose response. Type 1 diabetics have to know how much insulin to inject and at what time to do so. They can only calculate this if they can accurately predict their glycaemic (blood sugar) response [3].

Prediction of glycaemic response is however not a straightforward operation. It requires knowledge of many variables and some debates in the literature exist pertaining to which methods are better to use than others [4]. What is important though is the fact that ingested food has the most noteworthy effect on blood sugar levels [5].

Furthermore, food consists of three major energy components called macronutrients. These are carbohydrates, fat and protein [6]. Of the three, the carbohydrates have by far the most significant effect on the glycaemic response of the human energy system. Fat and protein on the other hand also induce changes in blood glucose levels, but the effect is considerably smaller [7].

The debate surrounding estimation of glycaemic response due to ingested food is currently subdivided into two major schools of thought. Firstly some researchers contribute the rise and fall of blood glucose concentrations only to the amount of CHO that is ingested [8],[9]. On the other hand other researchers claim that the amount of ingested CHO is of lesser importance. They in turn declare that the "type" or "effectiveness" of the ingested CHO is the deciding factor concerning glycaemic response [10].

Over the past twenty years many experiments and theories were published validating and negating both approaches and some also considered both. In the following sections some of these theories are discussed and a new approach is presented.

2.2 Carbohydrate counting

2.2.1 Background

Carbohydrate counting is a meal planning approach commonly used by clients who have diabetes mellitus [8]. The technique focuses on CHO as the primary nutrient affecting postprandial (after a meal) glycaemic response [9]. The concept of carbohydrate counting has been around since the late 1920s, but it received renewed interest after being named as one of four major meal planning approaches in the Diabetes Control and Complications Trial [11],[12],[13]. In the trial, carbohydrate counting was found to be the most effective in meeting outcome goals and allowed flexibility in food choices.

Recent practice pattern surveys have shown an increasing interest in and use of carbohydrate counting for medical nutrition therapy for both diabetics and healthy people [14],[15]. Gillespie et al performed research into the subject and identified three distinct levels of carbohydrate counting based on increasing levels of complexity [14]. These levels are used to educate people with diabetes and teach them how to "count" their CHO ingestion.

- Level 1, or basic counting, introduces diabetes patients to the concept of carbohydrate counting and focuses on carbohydrate consistency.
- Level 2, or intermediate counting, focuses on the relationships among food, diabetes medications, physical activity, and blood glucose levels. It also introduces the steps needed to manage these variables based on patterns of blood glucose responses.
- Level 3, or advanced counting, is designed to teach clients with Type 1 diabetes who are using multiple daily injections or insulin infusion pumps how to match short-acting insulin to carbohydrates using carbohydrate-to-insulin ratios.

All three levels emphasize portion-control and offer opportunities for using creative teaching methods, such as a variety of carbohydrate resource tools and publications. However, neither one of these levels makes any reference as to the type of carbohydrates that are ingested. Carbohydrate counting is simply done by measuring and restricting the total amount of dietary CHO in a meal.

The type or "building blocks" of the ingested CHO can however have a significant effect on the expected glycaemic response due to consuming the meal. Dietary carbohydrates consist of three major "building blocks" or monosaccharides. These are glucose, fructose and galactose. When these carbohydrates are combined, the secondary "building blocks" or disaccharides are formed. These are sucrose (combination of fructose and glucose) and lactose (combination of galactose and glucose), which are also the most commonly found CHO in normal diets [16].

Some more complex carbohydrates that are also made up of combinations of the monosaccharides are the oligosaccharides. These include the α-galactosides, the fructo- and the maltooligosaccharides. Furthermore, there are also some other types of CHO, like polysaccharides that can be further subdivided into the starchy and non-starchy polysaccharides. Because of the differences in the CHO, each of these has a variable digestibility and therefore has a higher or lower impact on glycaemic response [16],[17].

Whenever these carbohydrates are ingested as food the digestive tract, including both the small and the large intestines, breaks down (or hydrolyses) the CHO into the simplest form namely the monosaccherides (glucose, fructose and galactose). These are then transported to the liver through the portal vein where the monosaccherides are converted to glucose. Some of the glucose is then released into the bloodstream invariably causing the blood sugar levels to rise [18].

Because of the rise in blood sugar levels, diabetic patients have to inject insulin for regulatory control. Through the method of CHO counting the person then estimates the required insulin dose corresponding to the amount of CHO ingested [3],[5]. Some success has been obtained, however some limitations are found concerning this method.

2.2.2 Limitations concerning carbohydrate counting

Using the method of carbohydrate counting has greatly enabled glycaemic control for people diagnosed with Type 1 diabetes mellitus. However, the method has a few limitations.

Certain questions often arise regarding the use and applicability of CHO counting. Questions such as:

- How much CHO is contained in food?
- Does the method work?
- How much carbohydrate can be prescribed to a person?
- How does one balance the diet with fat and protein?
- Which patients are the best candidates for carbohydrate counting? [19]

Gregory and Davis wrote an article that provides possible answers to these questions based on clinical experience at the Vanderbilt University Medical Centre, Diabetes Research and Training Centre, and the Diabetes Control and Complications Trial [19]. Even though they primarily promote carbohydrate counting, they do however acknowledge that the method is not easily comprehensible for any individual. This might be due to the fact that food composition tables are not always available. Furthermore, the values surrounding the amount of CHO in a particular food are generally high and difficult to grasp.

Another problem that is widely acknowledged is that because there are so many different types of CHO, it can hardly be expected that they all produce a similar glycaemic response. Current counting methods simply tally the total CHO content of the entire meal and predict an insulin dosage accordingly.

Extensive research has been done on the subject of glycaemic effect and it will be discussed in more detail in the next section.

2.3 Glycaemic Index

2.3.1 Background

In 1981 at the University of Toronto, Canada, Dr David Jenkins did research to determine the "best" food that diabetics should eat [20]. At that time it was still assumed that all carbohydrates cause the same glycaemic response when ingested. He and his research team however tested many foods and concluded that the glycaemic responses to different carbohydrates varied extensively. This is what led to the development of the glycaemic index of foods (GI) [10],[20].

In essence the GI of a particular foodstuff relates to the glycaemic response or rise and fall of blood sugar level its ingestion induces. Only foods that contain carbohydrates induce a significant rise in blood sugar levels in human beings. Neither pure protein nor pure fat has any substantial impact on blood glucose levels [7].

The glycaemic index of foods is therefore a ranking of foods based upon their short-term effect on blood sugar levels. To make a fair comparison, all foods are compared with a reference food and are tested in equal carbohydrate amounts. The standard against which GI is measured is 50 g of carbohydrate in the form of pure glucose. This "reference" amount is assumed to be the relative value of 100 [10].

Some scientists however have decided to use 50 g of carbohydrate in the form of white bread and use this reference as 100 instead [10]. The use of the two standards has caused some confusion but it is possible to convert from one to the other by simply multiplying with a factor of 1.4. (Glucose has a GI value of 140 when white bread is the reference food, or if the reference food is white bread, the GI of the food should be divided by 1.4 to find the GI referenced to pure glucose.) Throughout the rest of this study the glucose reference will be used as the standard.

The measurement procedure for GI is as follows: A healthy person is required to fast for at least 6 to 10 hours prior to performing the test. This fasting ensures that any traces of glucose and effects of previous meals are negligible.

The next step is to ingest the reference food (in this case glucose). For the glucose reference 50 g of pure glucose (usually diluted in water for easier consumption) is used. Over the next two hours, blood samples are taken at 15-minute intervals during the first hour followed by two 30-minute intervals for the remaining hour. Blood sugar levels of the samples are measured in the laboratory and recorded. The result is a graph of blood sugar level plotted against elapsed time.

After a similar fasting period the procedure as described above is repeated. But, instead of ingesting pure glucose, the food for which the GI has to be calculated is eaten. The amount of food that has to be taken has to be the amount that contains exactly 50 g of carbohydrates. (In the case of potatoes, for example, 250 g of potato are required because that portion will yield 50 g of carbohydrates.) Again the blood sugar measurements are taken as described for the reference food.

GI is henceforth defined as the fractional relationship (percentage) between the glycaemic responses of the measured food and the reference food. To relate the responses the area under the curves

(AUC) are calculated for each test and compared by dividing the AUC of the test food by the AUC of the reference food. The calculation of the AUC for one of the tests is graphically presented in Figure 2.1.

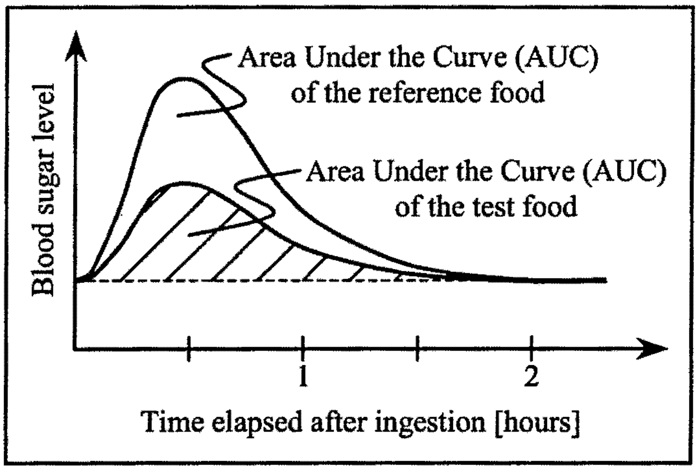

Figure 2.1 – Measurement of AUC of the glucose response due to ingested CHO in order to determine the GI of the test food.

The test is repeated several times and with multiple test subjects to obtain an average value. To find the GI, the AUC of the test food is expressed as a percentage of the AUC of the reference food. Equation (2.1) shows the final calculation of GI where AUC_{Food} is the area under the glucose response curve of the food in question (the test food) and $AUC_{Reference}$ is the area under the glucose response curve of the reference food (in this case pure glucose).

$$GI = \frac{AUC_{Food}}{AUC_{Reference}} \tag{2.1}$$

The GI factors determined for different foods have been found to mostly yield repeatable values per individual and as such are useful indicators when selecting carbohydrate food for glycaemic control by people with blood glucose disorders such as diabetes.

The concept has however received quite a lot of criticism, which will be discussed in the following section [4].

2.3.2 Limitations concerning GI

The application of GI unfortunately presents a few problems. These include the following:

- GI alone does not provide a practical application platform for its use due to the fact that GI values in themselves cannot easily be quantitatively applied to meal planning. This problem persists because GI values are not related to food portion sizes. It is a property of the food but not the amount of the food.

- Many food manufacturers and producers oppose GI labelling of foods because many consumers perceive high GI values as negative and therefore undesirable. This fact creates a skewed image of certain foodstuffs because GI is not the only determining factor concerning blood sugar response due to the food. In many cases the amount of food consumed has more to do with glycaemic response than it has with the type of CHO that is ingested.

  For example, a massive 1.3 kg of watermelon (containing only 8 g of carbohydrate per 150 g serving) has to be ingested to produce the same glycaemic response as 50 g of glucose powder. Because of its relatively high GI value of 72, it can be perceived by some people that watermelon is "bad" to eat. But, since the CHO content of watermelon is relatively small, a normal sized portion would produce totally acceptable blood sugar levels [10].

- GI values are based on average glycaemic responses measured in a number of different individuals. The problem is that there is often a significant variation in the measurements. Average GI values calculated are regarded by many as unscientific and therefore have little to contribute to general dietary planning and management. The reasons for the variances are not yet described to scientific satisfaction, and may be attributable to a host of metabolic and biochemical factors. However, as of yet the glycaemic response to GI-measured food yields acceptably repeatable results for individual test subjects.

Although generalised, GI values do provide some indication of relative variances to be expected when determining glycaemic response or energy utilisation in the human body. GI values therefore have a valid role to play in nutritional management. In the following sections the specific role that GI can play will be discussed in more detail.

2.3.3 Glycaemic load

The glycaemic index received much criticism in the literature because of the limitations mentioned in section 2.3.2. In response to these negative comments Brand Miller published an article to highlight the advantages of the index in an attempt to counter some of the criticism [4]. In her article she stated that: "It (GI) was never intended to be used in isolation". This comment was in response to a statement that GI should not be used due to the negative connotations linked to certain foodstuffs [4].

The amount of CHO that was associated with those foods were not considered. For example, it might be perceived that cola, with a GI of 64, is "better" for human consumption (will induce a lower glycaemic response) than cranberry juice, with a GI of 75, because of the lower GI. Similarly people might want to eliminate carrots from their diets because of the extremely high GI of 93 [10].

However, common sense should argue that cranberry juice should be "healthier" than cola and that carrots cannot be "unhealthy" as the GI value indicates. The reason for this common misconception is that the amount of CHO that is consumed in normal portions of the food is not taken into account when comparing the foods [21]. Using merely GI will only be applicable if foods were considered that contain equal amounts of CHO.

Therefore, to relate foods with varying amounts of CHO Salmerón et al introduced a novel dietary variable termed "glycaemic load" [22]. The glycaemic load (GL) of a food is simply defined as the product of the glycaemic index (GI) of the food and the carbohydrate content of the portion that is considered (m_{CHO}). This calculation is shown in equation (2.2).

$$GL = GI.m_{CHO} \tag{2.2}$$

In the example above a normal portion of carrots for example contain 5 g of CHO. The glycaemic load of the portion of carrots is then $GL = GI.m_{CHO} = (93\%)(5) = 4.7$. The comparison between the cola (m_{CHO}=51, GL=32.8) and the cranberry juice (m_{CHO}=15, GL=11.3) yields that cranberry juice is indeed the "better" choice if glycaemic response is to be limited.

Since the introduction of the glycaemic load concept many studies have been conducted to establish links between GL and diseases, abnormalities, and health risks [23]. However, the concept has not yet publicly been accepted as the general criterion for ranking the "healthiness" of different foods. This might be due to the difficulty of having to memorise both GI values and CHO content of foods.

In the next section a new approach is presented that is based on a similar argument as the glycaemic load, but the new approach is aimed at easy-of-use as well as accuracy of glycaemic prediction.

2.4 New concept: Equivalent teaspoons sugar (ets)

In order to utilise the glycaemic index in a quantitative manner for food intake planning the concept of equivalent teaspoons of sugar (ets) is presented. The objective is to develop a universally applicable unit of measure for foods with known GI, which will reflect blood glucose response and will also take food portion size into account. This means quite literally that apples can be compared to pears (or cola to cranberry juice such as in section 2.3.3), both qualitatively and quantitatively.

2.4.1 Energy extracted from ingested carbohydrates

Measurements with a bomb calorimeter suggest that energy of approximately 4 kCal/g can be released from CHO when it is oxidised in pure oxygen [24]. Obviously the human energy system does not use the same process for energy conversion as a bomb calorimeter. Intuitively it can be suspected that the body converts less energy from ingested carbohydrates than the optimum process. It is therefore necessary to investigate how much energy the human energy system actually does convert.

Due to the complex and integrated processes of the human body, it is difficult to measure this conversion process. However, it is well known that the energy extracted from ingested CHO is converted into useful blood sugar energy [25]. But, it is also fairly difficult to measure the amount of blood sugar energy in healthy people. With healthy blood sugar regulation insulin enables storing and utilisation of the blood sugar energy during the conversion process [5]. A possible method would be to integrate the blood sugar response curve over time, account for blood volume and time from ingestion to reaching basal blood sugar again, and hence find a fair approximation of this converted energy.

However, as this is too difficult, a simpler way is proposed in this study. Type 1 diabetics have no or negligible insulin secretion. Without insulin, the blood sugar energy released through digestion cannot be stored or utilised during the conversion process [5]. This condition simplifies the measurements. The level to which diabetics' blood sugar levels rise should therefore give a good measure of the amount of blood sugar energy converted from the ingested CHO.

Therefore a Type 1 diabetic's blood sugar levels can be measured after ingesting the same amount of two different types of CHO, on two separate occasions. (One of the foods is used as a reference.) As an example the person can ingest an equal amount of glucose and fructose. If all the possible energy (4 kCal/g) is made available from the digestion process the similar blood glucose responses would be the expected result.

However, a series of empirical measurements, shown schematically in Figure 2.2, illustrates a trend that is different from this expected result. Blood sugar response to glucose and thus the conversion of glucose into blood sugar energy is approximately four times more efficient than fructose. The subsequent question is: How can the energy available after conversion for any other type of carbohydrate be calculated?

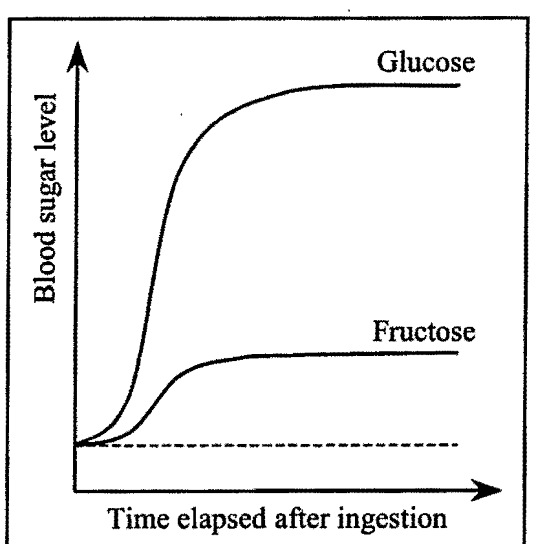

Figure 2.2 – Schematic representation of measurements of blood sugar response when a Type 1 diabetic eats equal amounts of CHO contained in glucose and fructose.

The Glycaemic Index (GI) of glucose, which is the reference food, is 100. This is approximately four times greater than that of fructose, which is only 23 [10]. Therefore, GI actually gives an idea of the energy conversion potential of the carbohydrates under investigation.

However, according to researchers the definition of GI states that GI is the "rate of absorption" for a CHO into the bloodstream [10]. If this definition is correct (thereby not defining energy) measurements shown schematically in Figure 2.3 would be expected. However, true empirical measurements (Figure 2.2) contradict Figure 2.3. Therefore, a new definition of GI is proposed, namely that GI provides the "energy conversion potential" of carbohydrates.

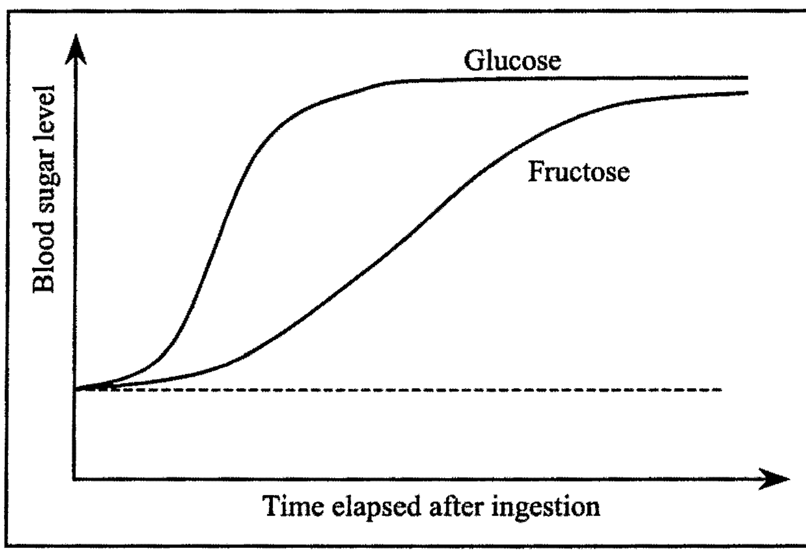

Figure 2.3 – Schematic representation of expected blood glucose response if the correct definition of GI is "rate of digestion": Type 1 diabetic ingesting the same mass of CHO through glucose and fructose.

GI expressed as a percentage (%) can now be used to find the converted CHO energy potential (E_{CHO}, measured in kCal) for a mass (m_{CHO}, measured in g) that is available to the body. Since there are approximately 4 kCal of energy in 1 g of pure glucose, E_{CHO} can be approximated with Equation (2.3a) [26].

$$E_{CHO} = 4\frac{GI}{100}m_{CHO} = \frac{GI.m_{CHO}}{25} \tag{2.3a}$$

If Equation (2.3a) is divided by m_{CHO} throughout, Equation (2.3b) is found.

$$\frac{E_{CHO}}{m_{CHO}} = \frac{GI}{25} \tag{2.3b}$$

Equation (2.3b) can now be used to calculate approximate values for typical energy contents available to the body from ingested carbohydrates. In Table 2.1 a few examples of typical GI values and their corresponding energy contents (E_{CHO}) per mass (m_{CHO}) values are shown.

Food	**GI (%)**	$\frac{E_{CHO}}{m_{CHO}}$ **(kCal/g)**
Glucose	100	4
Fructose	23	1
Apple	38	1.5
Table sugar	65	2.6
White bread	75	3
Whole-wheat bread	65	2.6

Table 2.1 – Typical values for E_{CHO}/m_{CHO} in accordance to corresponding GI values.

From the list it is clear that what dieticians have been preaching for years is true after all. While on a weigh losing diet it is better for weight losers to eat less refined carbohydrates e.g. whole wheat bread than it is to eat more refined carbohydrates like white bread. This way effectively less energy is absorbed from the same amount ingested carbohydrates.

It is however important to note that the final amount of energy that a specific person will be able to convert also has to account for that specific person's digestion and absorption ability. It is therefore not only a property of the food, but also a property of the person that is important. However, the worth of Equation (2.3b) is that for the same person it is now possible to compare different foods and know which has more available energy and which has less.

A detailed and quantitative verification of the extension of Equation (2.3) is given in Chapter 3. It is accomplished by using measurements of healthy people performed by other researchers. However, there are also various other qualitative "verifications" of the hypothesis. Noakes for example found that fructose, with a GI of 23, does not provide enough energy to prevent hypoglycaemia in athletes during endurance events, especially when fructose is used in the same CHO quantities as glucose [27]. The cause of his finding is thus obvious. There is up to four times less useful energy available from fructose than previously assumed.

2.4.2 Derivation of the ets formula

Equation (2.3) provides insight into a possible application of the GI concept but the values do not provide a means of relating food in a practical manner. For this purpose the following derivation is presented.

Since only the carbohydrates in a meal have a significant effect on blood sugar levels, the assumption is made that the other two macronutrients, fat and protein, are not directly converted into blood sugar during digestion [7],[25]. This assumption hold true to a certain extent since fat and protein digestion occurs significantly slower that that of CHO.

Furthermore, since different carbohydrates require different amounts of energy to digest, a "conversion potential" is to be considered. With this all the losses during digestion, including energy needed for digestion, incomplete digestion, etc. are accounted for. In the previous section it was shown that GI provides a good approximation of this conversion potential.

GI is a property of the food that is considered and is not dependent on the specific person that digests the CHO. The conversion potential for CHO can be measured as discussed in Section 2.3.1. Many factors influence GI including mixed meal effects such as the contents of dietary fibre, fat and protein in the meal [10].

To derive the ets concept the amount of available blood sugar energy contained in a meal is considered. According to the above assumption, only CHO in a meal can provide blood sugar energy. The energy is then equal to the total amount of energy of the CHO contained in the meal and therefore also a function of the amount of CHO contained in the meal (m_{CHO}).

As mentioned earlier, when measured in a laboratory with processes such as bomb calorimeters, carbohydrates are found to release a certain maximum amount of energy per mass [11]. This absolute amount of available energy is denoted as k_{CHO}. The total amount of available blood sugar energy from any meal (E_{CHO}) is then the total energy ($m_{CHO}\ k_{CHO}$) multiplied with the conversion potential (GI_{CHO}). This product is shown in equation (2.4).

$$E_{CHO} = GI_{CHO} m_{CHO} k_{CHO} \tag{2.4}$$

The next step is to relate the amount of energy from CHO in a meal to equivalent teaspoons sugar (ets). One ets (one teaspoonful of cane sugar) contains 5 g of carbohydrates. In other words the total amount of available energy from one ets is $5k_{CHO}$ kCal. Since the GI of sugar is 65, it follows from equation (2.4) that the energy that can be extracted from one teaspoon of cane sugar is [10]

$$E_{teaspoon\ \ sugar} = GI_{sugar} m_{teaspoon\ \ sugar} k_{CHO} = (65)(5)k_{CHO} = 325k_{CHO}. \tag{2.5}$$

Equivalent teaspoons sugar, or ets, is now defined as the fractional amount of blood sugar energy that can be extracted from any foodstuff, in relation to one teaspoonful of cane sugar, expressed in ets. The equation for calculating the ets of any meal is

$$ets = \frac{E_{CHO}}{E_{teaspoon\ \ sugar}} = \frac{GI_{CHO} m_{CHO} k_{CHO}}{325k_{CHO}} = \frac{GI_{CHO} m_{CHO}}{325}. \tag{2.6}$$

Equation (2.6) can now be used to calculate the ets value for any food with a known GI value according to the portion size.

2.4.3 Discussion

The reasoning behind the formulation of ets as a measure of carbohydrate intake is simple. People interested in glycaemic response prediction require a measure with which to relate any food, regardless of digestibility and portion size. By comparing foods with respect to the blood sugar energy they have available per portion provides a practical easy-to-use measure across any scope of foods.

The point of departure is explained with the following example: If a certain food with a GI value of 50 is consumed, twice the mass of carbohydrate contained in that food will be required in order to effect the same blood glucose response as the reference food (pure glucose with a GI of 100). This same reasoning can be applied to any other food with known GI in order to calculate the mass of carbohydrate required for the equivalent glycaemic response compared to the reference. (Equivalent glycaemic response means an equivalent area under the glycaemic response curve, and not necessarily exactly the identical curve shape.)

A further advantage is that, because pure glucose in its powder form is a foreign reference concept to most people, cane sugar (GI = 65) is used instead. The same logic applies to the reason behind expressing quantities in teaspoonfuls (5 g per teaspoonful). This unit has the benefit that it both contains pure carbohydrate and is an easy concept to grasp. It is far easier for most people to visualise 3 equivalent teaspoonfuls of sugar as an indication of energy intake in a portion of All Bran Flakes, rather than memorizing 24 g of All Bran Flakes with a GI of 41.

Another advantage of the ets concept is that the ets values for typical foods and serving sizes are usually less than 10 e.g. a tomato contains 0.5 ets, one can of soda, 7 ets and an apple has 2.5 ets. Most people find numbers less than 10 easier to grasp (and visualise) than larger numbers e.g. 58 g of CHO. These easy-to-grasp numbers can also be used to approximate the ets value of a mixed meal with relatively high CHO content. The ets values of the individual constituents can simply be added together to arrive at the total ets value for the mixed meal.

Furthermore, according to the assumptions above, equivalent ets values of different foods will result in equivalent blood sugar responses. Using the GI of any food together with its portion size, the equivalent teaspoonfuls of sugar of a mixed meal can therefore be calculated (see equation (2.6)).

It is important to note that glycaemic responses from different ets-calculated food values are repeatable in one individual person. However, significant variances occur between different individuals. This indicates the necessity of characterising each individual in order to establish individualised energy uptake and utilisation parameters before effective quantitative nutritional management can be attempted. These differences will be discussed in more detail in the next chapter.

The ets concept now provides a new method for determining insulin dosages for diabetics. Because foods with higher ets values will provide higher glycaemic responses, more insulin has to be injected for acceptable control. The specific amount of insulin will be discussed later, together with the discussion on differences in individuals.

2.5 Conclusion

A considerable amount of confusion exists regarding the dietary value of food, especially that of carbohydrates (CHO) [4]. In this chapter it was pointed out that the commonly accepted amount of energy that is available from ingested CHO is inaccurate since the human energy system cannot utilise 100% of the available energy contained in food.

It was then shown that the Glycaemic Index (GI) of foods might provide a sufficient approximation of the amount of blood sugar energy available from ingested CHO. Subsequently, it was argued that the universal definition of GI, which is "rate of digestion", is inaccurate. It should rather be defined as "energy conversion potential".

Most importantly, the concept of equivalent teaspoons sugar (ets) was derived. The concept is a novel unit for quantifying blood sugar energy available to the human energy system from ingested CHO.

The following advantages concerning the ets concept are already evident:

- Firstly, less ets in a meal always leads to less blood converted sugar, and therefore less insulin, making food and meal choices straightforward.
- Secondly, ets values for typical everyday foods and serving sizes are usually less than 10 e.g. tomato = 0.5 ets, can of soda = 7 ets, apple = 2.5 ets. Numbers less than 10 are usually easy to grasp.
- Thirdly, in a mixed meal of high CHO content the ets values of the individual constituents can simply be added to arrive at the total ets value for the full meal.
- Fourthly, it is easy to visualise a teaspoon full of sugar, which makes it a practical reference.
- Fifthly, as will be shown later in this study, for Type 1 diabetics the numerical ets value of an ingested meal corresponds remarkable well with the numerical amount of insulin dosage required.

In the following chapters the ets concept will be verified, more energy links with ets in the human energy system will be established and the concept will be used for development of the simulation model. A detailed comparison will also be drawn between the three methods mentioned for insulin dosage calculation (CHO counting, GI and the ets concept).

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