CHAPTER 6:

BOLUS INSULIN DOSAGES

H. Peter Chase, MD and Erin Cobry, BS

WHAT IS BOLUS INSULIN?

Bolus insulin dosages refer to the quick bursts of insulin given to cover the carbohydrates in meals or snacks or to lower high blood sugar levels. The main purpose of an insulin bolus given for food is to convert sugar to energy and to help maintain good sugar control (good HbA1c levels). This is in contrast to the basal insulin which also helps with sugar control by keeping sugar and ketone production by the liver turned off. Bolus insulin doses are always given by the pump user/family, in contrast to the basal insulin doses which are programmed into the pump to be delivered automatically. The main two uses of insulin boluses are to cover the carbs in food to be eaten and to do corrections for high blood sugars.

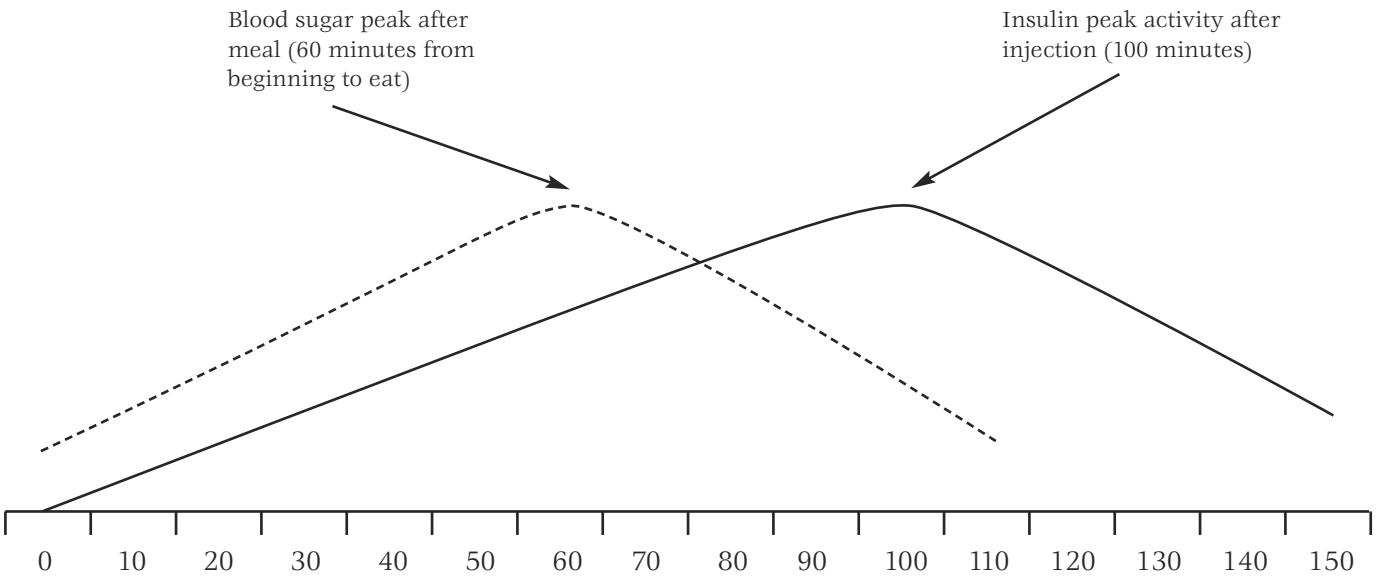
BOLUS INSULIN DOSAGES FOR FOOD

1. When to take

Food boluses are taken before meals or snacks. The bolus dose (or the grams of carbs to be eaten) must be entered into the pump by the user and then activated for it to be given. The grams of carbs (and the current blood sugar) are entered into the "smart" pump which then indicates the units of insulin that should be taken as a bolus. Approximately 50 percent of the total daily pump insulin dose should be

FIGURE 1:

RELATION BETWEEN MEAL SUGAR PEAK AND INSULIN ACTIVITY PEAK



given as boluses before meals and snacks. At least part of the bolus (for the correction and for food that will definitely be eaten) is ideally given 15 to 30 minutes prior to the first bite. Blood sugar levels peak approximately 60 minutes after eating whereas rapid acting insulins (Humalog/NovoLog/Apidra) do not peak until later, after approximately 100 minutes (see Figure 1). After the initial bolus, some people give additional small doses as they decide to eat more. This way, at least some insulin is beginning to work while the carbs are being eaten. Everyone is different and boluses can be chosen to fit individual eating habits.

2. Determining the I/C ratio
(also see Chapter 8)

Most families attend carb counting classes prior to starting insulin pump therapy. The dietitian is an important member of the pump team and will need to review and reinforce carb counting. Many people already use Insulin/Carb (I/C) ratios for different times of the day while on multiple daily injections. The food records, insulin dosages taken and blood sugar levels two and four hours after meals are used to make changes to the I/C ratios.

Insulin dosages sometimes change after starting the pump. This may be because an intermediate-acting insulin (e.g., morning NPH peaking at lunchtime) is no longer being used. In order to make more accurate changes to the insulin dosages, good record keeping in the period after beginning the pump is essential.

The "rule of 500" is sometimes used to help estimate initial I/C ratios if they are unknown. The total insulin per day (e.g., 50 units) is divided into 500. For example, if 50 units are given in one day, then 500 ÷ 50 = 10. Therefore, one unit of insulin would cover 10g of carbohydrate, so the I/C ratio is 1:10.

3. Checking the I/C ratio

The best way to know if an insulin dose for food is correct is to take blood sugar levels before and two hours and four hours after the meal. The ADA recommends that the peak blood sugar level be less than 180 mg/dl (< 10.0 mmol/L) at any time following a meal. Unless a person is using a continuous glucose monitor (CGM) it is impossible to know the sugar levels at all times after the meal, so the best approximation would be to check at two and four hours post-meal. Many care providers even suggest that the two and four hour values be below 140 mg/dl (< 7.8 mmol/L). This is closer to the values in people who do not have diabetes.

To check the I/C ratio, it is important to start with a blood sugar level in the target range for age (see Chapter 7) and eat a low-fat (less than 20 grams) meal with known carbs. Frozen meals are often used because the carb content is printed on the box and this will improve the accuracy of the bolus. Excess fat in the meal delays stomach emptying and prolongs blood sugar elevations. Blood sugar levels must be monitored at two and four hours post-meal. Extra snacks and exercise should be avoided when doing the checking to prevent any additional changes to the blood sugar level. Most people use different I/C ratios for meals or snacks at different times of the day. Therefore, a meal bolus check may need to be tried at each meal time. At bedtime, reduced I/C ratios are often used to help prevent lows during the night.

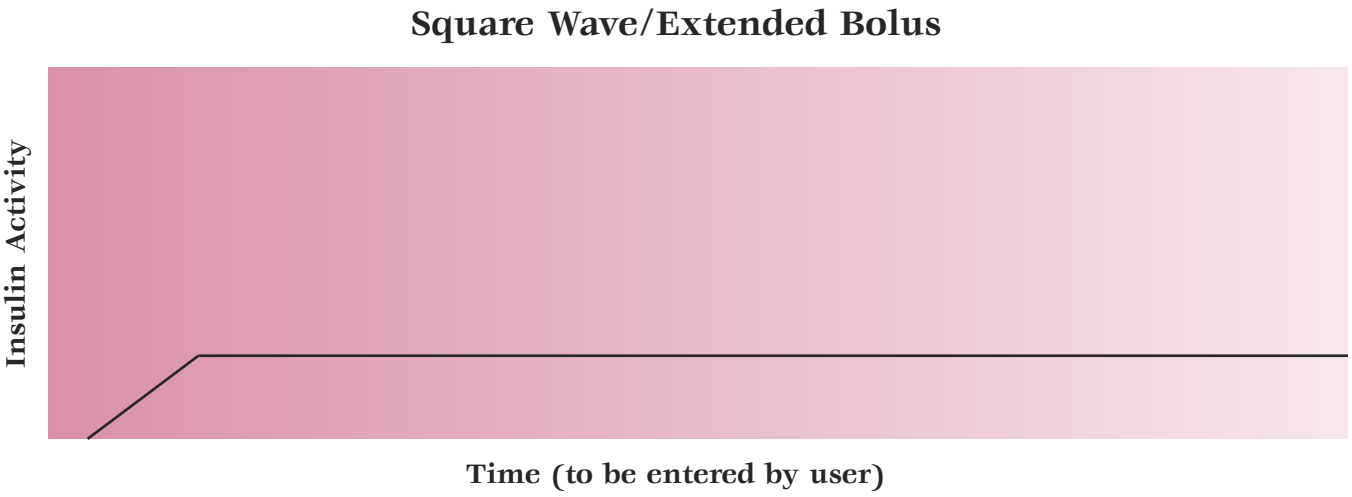
If the blood sugar levels are high at two or four hours post meal, the I/C ratio for that time of day needs to be increased. If a ratio of 1:15 is being used (1 unit/15 grams of carbs), it might be changed to 1:10 (1 unit/10 grams of carbs).

Similarly, if the blood sugar levels are low two or four hours after eating, the I/C ratio for that time of day needs to be decreased. If a ratio of 1:15 is being used (1 unit/15 grams of carbs), it might be changed to 1:20 (1 unit/20 grams of carbs).

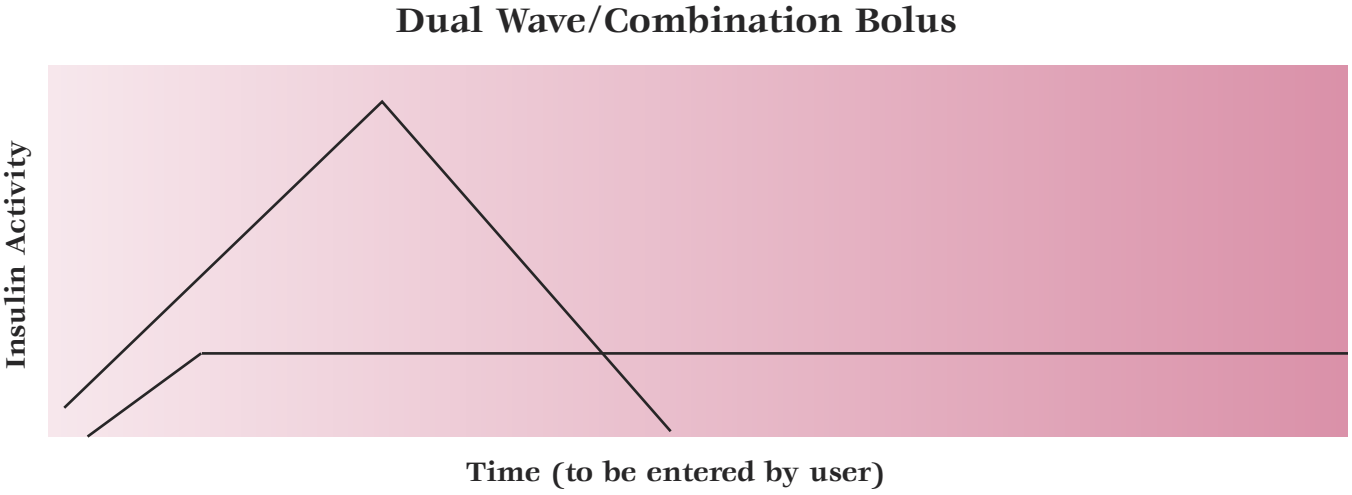
4. Specialized meal boluses

The use of specialized meal boluses is often not taught until the Advanced Pump Training Class. These consist of two types of boluses that may be helpful for certain foods or eating patterns.

A) Square Wave or Extended Bolus
This allows a bolus to be given over a prolonged period, with the duration entered by the person/family. It is particularly helpful for a high fat/high protein meal (e.g., steak, hamburger) without a lot of carbs. Remember that high fat meals delay stomach emptying. This type of bolus is also often used during a period of prolonged snacking (such as with hors d'oeuvres at a party). It is sometimes diagrammed as:



B) Dual Wave or Combination Bolus
This consists of a combination of the square wave/extended bolus given with an immediate (the usual type) bolus. It is ideally given 15 to 30 minutes prior to eating. It is sometimes diagrammed as:



The pump user selects the portion to be given immediately (often 50%) and the portion to be given over an extended time. The timing of the delayed portion (often two hours) must also be entered.

This type of bolus is extremely helpful with high fat/high carb meals that cause the blood sugar levels to remain high for a longer time after eating. The type of food varies for different people, but commonly includes pizza, Chinese food or Italian food. Some pumps even have a built-in food list to select from which then gives the preprogrammed combination bolus that the person/family has found to work best for that food. How does one select the percentage of the bolus to be given immediately versus over time for a particular meal? This must be done by trial and error for each individual.

We initially studied a high carb/high fat meal (pizza, regular soda and tiramisu) in 10 pump users (9). We found that all 10 people had better sugar control when they used a 70%/30% (Immediate [I]/Extended [E]) combination bolus.

The best way to determine the I/E ratio is to start with a 50/50 combination (ideally given 15 to 30 minutes before eating) and eat the given food. Check the blood sugar after two hours. If high (e.g., >180 mg/dl or >10 mmol/L) give more as the I-bolus (e.g., 60%) the next time the food is eaten. If low (e.g., <70 mg/dl or <3.9 mmol/L) give less as the I-bolus (e.g., 40%) the next time the food is eaten.

Furthermore, check the blood sugar after four hours (with no food or exercise in between). If high at four hours, give more of the bolus as the E-bolus (e.g., 60%). If low at four hours, give less as the E-bolus (e.g., 40%). If the blood sugars are high at two and four hours the total amount of both the I and E boluses must be increased. If blood sugars are low at both times, the total bolus must be reduced the next time the same food is eaten. In summary, it is a matter of trial and error to find the ratio that works best for each person. However, if the person takes the time to check various foods, the person's post-meal blood sugars can be close to those of a person who does not have diabetes.

CORRECTION BOLUS DOSAGES FOR HIGH BLOOD SUGAR

What is a correction bolus?

Extra (unscheduled) insulin boluses (correction boluses) are important to use if the blood sugar level is high. A correction factor or insulin sensitivity ratio is the amount of insulin needed to decrease the blood sugar level by a certain amount. For example, if the blood sugar level is 200 mg/dl (11.1 mmol/L) and the target blood sugar level is 150 mg/dl (8.3 mmol/L), taking 1 unit of insulin to lower the blood sugar 50 mg/dl (2.8 mmol/L) would be a correction factor of 1:50 (1:2.8mmol/L).

When to use

Multiple correction factors (depending on the time of day) can be programmed into the insulin pump. After the blood sugar level is entered, the correction factor for that time of day tells how much insulin needs to be given to lower a person's blood sugar value back to the target level. Correction boluses should not be given more frequently than every two hours to avoid stacking of insulin which could result in low blood sugar levels. Larger dosages will be necessary if ketones are present, and should be given by syringe or pen because of the possibility of a pump malfunction. The healthcare team should be contacted if moderate or large urine ketones or blood ketones >1.0 mmol/L are present.

Determining the correction insulin bolus

Most people use correction boluses while receiving multiple daily insulin injections. These same correction doses may then be used when starting an insulin pump.

If the correction factor is unknown, a formula can be used to estimate the value. Start by dividing the total units of insulin used in one day into 1700 (or 1500 for a person who is more insulin resistant). Corresponding numbers for mmol/L would be 95 or 85 (the latter for more insulin resistant people). For example, if the person receives a total of 34 units of insulin per day, then $1700 \div 34 = 50$ (for mmol/L, $95 \div 34 = 2.8$). From this formula, one unit of insulin lowers the blood sugar level approximately 50 mg/dl (2.8 mmol/L) and the correction factor would then be 1:50 (1:2.8 mmol/L).

Checking the correction bolus

The best way to determine if the correction factor is correct is to do a blood sugar check two hours after giving the correction bolus (with no food intake or exercise in the two hours). If the sugar level at two hours is above the upper limit for age, the correction factor needs to be increased. For example, if the previous correction factor estimate was 1:50 (1:2.8 mmol/L), consider using a correction dose of one unit of insulin to decrease the sugar level by

40 mg/dl. If the blood sugar is too low two hours later, perhaps try 1:60 rather than 1:50. (In mmol/L the increase in insulin would be from 1 unit/2.8 mmol/L to 1 unit/2.3 mmol/L. The decrease in insulin would be from 1 unit/2.8 mmol/L to 1 unit/3.3 mmol/L.)

Target blood sugar

The target blood sugar is the desired level which will be used as the aim for the correction bolus. If a person is using the correction factor of one unit for every 50 mg/dl (1:50) that the sugar is above 150 mg/dl, then 150 mg/dl is the **target blood sugar**. If the blood sugar level was 300 mg/dl, three units of insulin would be given as a bolus to bring the blood sugar level down to 150 mg/dl. This was determined by subtracting 150 (the target level) from 300 to get 150, and then dividing that result by 50 (the correction factor) to arive at three units of insulin. For people using mmol/L, it would be 1 unit per 2.8 mmol/L and 8.3 mmol/L would be the **target blood sugar**. Then, if the blood sugar level was 16.7 mmol/L, 3 units of insulin would be given. This is one unit for every 2.8 mmol/L above 8.3 mmol/L. Most teens will correct to 100 mg/dl (5.5 mmol/L) during the daytime hours (e.g., 7 a.m. - 7 p.m.) and to 150 mg/dl (8.3 mmol/L) during the evening or nighttime. Some people use only one target blood sugar level (e.g., 120 mg/dl or 6.7 mmol/L) for the entire day, while others will use one target during the day and a different target during the night. It is helpful for the less aggressive target blood sugar to begin two to three hours before bedtime to lessen the chance that the person will have a blood sugar that has dropped right before bedtime or into the night.

Total bolus dosage

Although we have discussed food boluses and correction boluses separately, it is common to be doing both types of boluses at the same time (e.g., before a meal when the blood sugar level is above the target). The smart pumps will do the combined calculation, including subtraction of any remaining "insulin on board" from a previous bolus (from a correction bolus for the OmniPod or from a combination of food and correction boluses for the Paradigm, Deltec Cozmo or Animas pumps). The table below gives an example of the total amount of insulin to give for both food (carbs) and correction boluses. The total insulin required is the sum of the insulin for the correction factor and the insulin for the carb content. The total units of insulin shown in the table would change for a given blood sugar level or meal carb content.

TABLE 1:

EXAMPLE OF TOTAL INSULIN BOLUS DOSAGE

Blood Sugar		Correction Factor*	Carb Content **		Total
(mg/dl)	(mmol/L)	(Units of Insulin)	(Grams of Carbs)	(Units of Insulin)	(Units of Insulin)
≤ 150	≤ 8.3	0	15	1	1
200	11.1	1	30	2	3
250	13.9	2	45	3	5
300	16.7	3	60	4	7
350	19.4	4	75	5	9

* Assuming a correction factor of 1 unit of rapid-acting insulin per 50 mg/dl (2.8 mmol/L) above 150 mg/dl (8.3 mmol/L)
** Assuming an insulin to carb ratio of 1:15 (1 unit of insulin per 15 grams of carbohydrate).

"SMART" PUMPS

Smart pumps are programmed to calculate a bolus based on both the correction factor (if a blood sugar is entered) and the carb content of a meal (if the grams of carbs are entered). These calculations are based on four factors:

1. The **Correction Factor (or the Insulin Sensitivity Ratio)** which is the mg/dl or mmol/L of blood sugar that one unit of insulin will lower
2. The **Target Blood Sugar Level** for that time of day
3. An estimated **Duration of Insulin Action**, which is based on how long an insulin bolus is estimated to be effective (usually three to four hours)
4. The anticipated **Carbohydrate Content** of a meal or snack

The first three factors are entered into the pump by the person doing the pump training. The family, physician and nurse often choose these values for the pump trainer. The values often change over time and must be re-entered as changes are recommended.

For food boluses, the smart pumps can be programmed with I/C ratios for different times of the day. When the grams of carbs for the food are entered into the pump, the units of insulin will then be calculated by the smart pump and displayed on the screen. This is particularly helpful for people not adept at math or who have challenging I/C ratios (e.g., 1:12.5).

After the insulin pump has recommended an insulin dose, the user then has the option to accept or not accept the suggested dose. The insulin dose can also be edited by the user to lower the dose (e.g., if the pump user is about to exercise) or to increase the dose (e.g., if expecting a less active day, a high fat meal, or if an infection is present).

The smart pumps will suggest a reduced dose when blood sugars are under the target blood sugar level and food is to be eaten. For example, if the blood sugar is below 70 mg/dl (3.9 mmol/L) and a snack of around 15 grams of carbs is to be eaten, the pump may not suggest a food bolus. These adjustments are based on the blood sugar level, the sensitivity factor, and the target blood sugar level.

If a blood sugar during the day is high (>300 mg/dl [>16.7 mmol/L]), extra insulin is added to the bolus based on the programmed correction factor. If moderate or large urine ketones or a blood ketone level >1.0 mmol/L is present, the correction insulin dose is often doubled, though this extra insulin must be manually adjusted by the person/family as pumps do not have a feature to consider ketone levels. It is also recommended to contact the diabetes care team if urine ketones are moderate or large or the blood ketone level is >1.0 mmol/L.

BOLUS INSULIN FOR SICK DAYS, SURGERY AND KETOSIS

In all three of these situations, it is usually best to contact the diabetes care provider. The information below may be useful for emergencies or until the provider can be reached.

1. Sick days

Illnesses result in variable blood sugar levels, making more frequent blood sugar checking imperative. Some illnesses cause elevated hormone levels, which raise blood sugar levels. Other illnesses, such as vomiting from food poisoning, may cause low blood sugar levels. If blood sugar levels are high, correction insulin boluses should be administered every two hours until the blood sugar level is down. Ketones must also be checked (as discussed in Chapter 11). If the urine ketones are moderate or large, or the blood ketone level is above 1.0 mmol/L, we usually recommend doubling the insulin correction dose. This is always given by syringe in case there is an insertion or pump problem. The injections are repeated every two hours until the ketones are cleared. Extra carbs (e.g., juice) may be necessary to keep the blood sugar levels up while the ketones are being cleared. It

is usually best to do a set change in case the cannula has become dislodged or kinked.

The management of low sugar levels is discussed in Chapter 10. An advantage of the pump is that the basal insulin can be decreased or discontinued. Even though the total insulin dose working will be less, it must be remembered that the last drop of insulin given will still not peak for 100 minutes.

If blood sugar levels become dangerously low (e.g., < 60 mg/dl or < 3.3 mmol/L) and juice, sugar tablets or other carbs cannot be kept down, it may be necessary to administer a low dose of glucagon (see Chapter 10). This is given in a dose of one unit per year of age up to 15 units (the dose for an adult). This dose can be repeated every 20 minutes until the blood sugar is back up to a normal level.

2. Surgery
If the basal rates are set correctly, the insulin should cover the person adequately when not eating. Extra blood sugar monitoring is essential. If stress, infections or other factors raise the blood sugar levels, extra correction boluses as discussed above or temporary basal rate increases can be used. If sugar levels become low, an IV is usually in place and dextrose (sugar) can be given through the IV. When the person is able to eat and keep food down, bolus therapy for carbs can be resumed. As discussed in Understanding Diabetes (3), it is essential to take supplies along to the hospital (including blood sugar and ketone checking supplies and set changes).

3. Ketosis
This is discussed above under "Sick Days" and more thoroughly in Chapter 11. It is essential to check for urine or blood ketones with any illness and anytime the blood sugar value is above 300 mg/dl (16.7 mmol/L). Extra insulin must be given by syringe every two hours until the ketones have cleared. It is usually wise to do a set change. Hospitalizations for DKA (diabetic ketoacidosis) can be avoided 95% of the time if these simple instructions are followed.

MISSED INSULIN BOLUSES

This is discussed in depth in Chapter 2 and Chapter 14. Missed insulin boluses are often a problem in teenagers, resulting in worsening glycemic control (HbA1c levels) while on pump therapy. (7)

SUMMARY

The pump allows for many options for bolus insulin administration. The purpose of all the options is to make life easier and safer for the pump user/family. The pump user/family must learn how to benefit to the fullest from the available options.

DEFINITIONS

ADA: American Diabetes Association.

Correction bolus: An amount of insulin taken to correct a high blood sugar. This varies by the person and by the time of day, as explained in the text.

Dual Wave or Combination bolus: A combination of the square wave/extended bolus and of an immediate (the usual type) bolus.

Food bolus: An amount of insulin taken to cover the carbs to be eaten in a meal or snack. This varies by the person and by the time of day, as explained in the text.

Insulin on board: The amount of insulin in the body from previous boluses which is still acting. This is usually automatically subtracted by the smart pump when the next bolus dose is calculated.

Insulin sensitivity ratio (correction factor): The mg/dl or mmol/L of blood sugar that one unit of insulin will lower. This is also referred to as the correction factor or the correction insulin bolus. The method of determining this factor is described in the text.

Square Wave or Extended bolus: An amount of insulin to be administered by the pump over an extended period of time (entered by the person/family).

Target blood sugar: The desired blood sugar level as determined by the Team for that period of the day. The smart pump calculates the units of insulin needed to reach this level (using the pre-programmed correction factor and subtracting the units of insulin on board still acting).

REFERENCES

9. Chase, HP, et al, Diabetic Med 19;317, 2001.