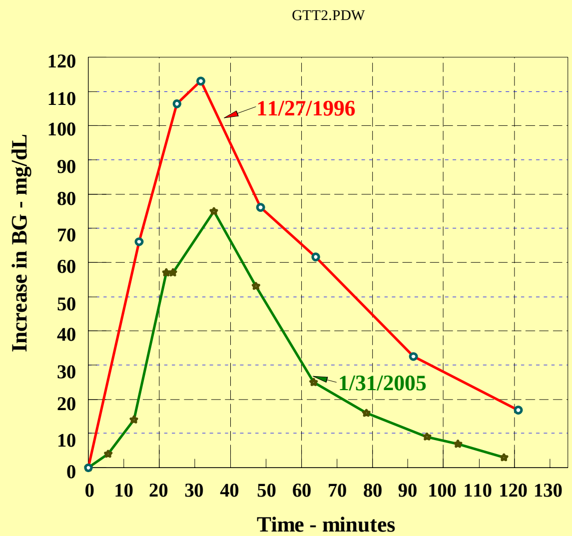
Effects of Aging on BG Control

and

Predictions of A1c



Mini Glucose Tolerance Test with 12 gram Glucose Input

Derek A. Paice — February 2, 2005

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Summary and Conclusions

Firstly, since this is an engineer's approach to the problem of type 2 diabetes, nothing contained herein is to be construed as giving medical advice. Medical advice is properly obtained from your own physician or other qualified medical professional.

I was diagnosed with type 2 diabetes in 1990, and immediately cut out 'sugary' things, but frankly my efforts at BG (blood glucose) control were not a high priority. By 1995 my control was poor and on one occasion my blood was found to have an A1c of 9%. I felt some of the effects of my type 2 diabetes. For example, unusual tiredness after meals, and muscle weakening. I knew I had to do better and took to reading some of the excellent books available about diabetes. It became clear to me that type 2 diabetes is a good example of a closed-loop control system gone wrong. Engineers are familiar with control systems and that was the stimulus that I needed — suddenly I had a personal research project.

Following that initial understanding I continued to read and then set about doing literally hundreds of tests on myself. I published those test results in a booklet titled: ***Diabetes and Diet: A Type 2 Patient's Successful Efforts at Control*.** The booklet is free and available on this site, www.dapaice.com/ This test information enabled me to get excellent control of BG just by eating the right type of foods. In one test, my A1c had dropped to 5.2%. Later, in the year 2000, I developed other medical issues that required me to use prednisone. I had to use a small amount of slow acting insulin to combat the effects of prednisone, but by sticking to my diet I maintained excellent control.

While I was developing and analyzing my test data, I came across a book which for me became THE diabetes technical resource. It explained so much, so simply. That book is referenced as: **Richard K. Bernstein: *Dr Bernstein's Diabetes Solution*, Little, Brown and Company, New York, 1997.**

Over the years I developed friendships with others who, like me, contend with the problem of blood glucose control. One of my Internet colleagues wrote a wonderful supportive book for those who want to understand and control their diabetes. Her book is especially helpful for those concerned with the day-to-day handling of the disease. The reference for that book is: **Gretchen Becker: *The First Year ™ Type 2 Diabetes. An Essential Guide for the Newly Diagnosed*, Marlowe & Company, New York, 2001.**

In early 2005, I tested to determine what effects aging might be having on my body's ability to control blood glucose. The results were very encouraging. Today, my body is better at controlling blood sugar than it was eight years ago. I've prepared this paper, ***Effects of Aging on BG Control,*** to show how I came to that conclusion. Some of the details are rather technical so in this summary I just present the results.

The body of this paper gives my numerical details and useful graphs. I hope you find the graphs informative. I did. The specific results presented apply to me. Your case may be different, so I leave the reader to draw their own conclusions. Here's what I found.

1.My ability to control BG as aging took place was not compromised over an 8-year period during which time I adhered to a low glycemic index diet. That diet enabled me to achieve A1c's, a measure of average blood glucose level, in the range of 5.2 to 6%. These numbers are considered to reflect excellent control. During the past four years, I have used a small amount of basal insulin (14 units/day) to counteract increased insulin resistance caused by prednisone, the medication prescribed for other ailments.

2. Fasting blood glucose has a major effect on A1c. Thus, a basal insulin such as Ultralente can be very beneficial at reducing A1c for those with type 2 diabetes.

3. Two small carbohydrate meals raise BG less than one meal with the same total number of carbohydrates.

Here are the specific details from my tests.

Introduction

It is natural for someone with type 2 diabetes to ask how their diabetes might change with time. This paper gives one person's answer to that question. It is a continuation of my earlier work, and I'm happy to report that I still maintain excellent blood glucose. In considering the value of my one-person test results for others (a statistician would say n =1) it is left for the reader to judge the significance of thousands of finger prick tests by one research engineer, compared to fewer per-person tests on multiple patients.

Defining Key Parameters

1. AUC

When quantifying glycemic effects, the term AUC (area under the curve) could mean different things to different people. The following discussion will have much to say about AUC so at the outset it is necessary to remove any possible ambiguity. The definitions stated here will help.

If one plots BG (blood glucose level) against time, a curve results. The area under that curve is defined as the AUC. It includes all values of BG, including the fasting value. In many calculations, including those used to determine glycemic index, we are not concerned with total AUC, but rather the change in AUC. This could occur from some stimulus such as eating food. Where changes are being addressed a delta is included in front of the value. For example, the change in area under the curve is written as △AUC.

2. Average BG

Most home glucose testers store each test result. On command they can provide BG value, time of test, and an average of the BG numbers. Only under very special conditions will the average of the BG numbers reflect the average value of BG.

The average value of a graphed function that varies continuously is a constant value which gives the same AUC as the varying function. Thus if we get a certain value of say AUC1, for a plot of BG versus time over a period of 120 minutes, then the average BG is AUC1/120.

Determination of Aging Effects

It is often assumed that for a type 2 diabetic the ability to control average blood glucose gets more difficult as the person ages. One of the assumptions is that the already strained pancreas simply "wears out." And eventually, most type 2 patients need help from external insulin or medication, or both. With careful attention to diet this may not be true for some people.

As noted earlier, when I was diagnosed with type 2 diabetes in 1990, I did not strive for good control until 1997. During those seven years of poor control, aging effects continued at will. When I did finally decide to get good control, I carried out many tests to determine the effects of different foods on BG levels. Also, a mini GTT (glucose tolerance test) was made to document the inherent ability of the author's body to control blood glucose. This data is particularly useful for determining the effects of aging. The data given here provides documentation of aging effects.

For the mini GTT, 12 grams of almost pure glucose are ingested at time zero. BG is then monitored every 10 to 15 minutes. Gretchen Becker describes a similar method in her book, which addresses the concerns and needs of people when they are first diagnosed with diabetes [3].

For me, time zero in the mini GTT begins first thing in the morning before consuming any food or medications. The eventual output from the mini GTT is the △AUC when BG has fallen to within 10% of the starting value. Typical graphed result from two mini GTTs are shown below in figure 1.

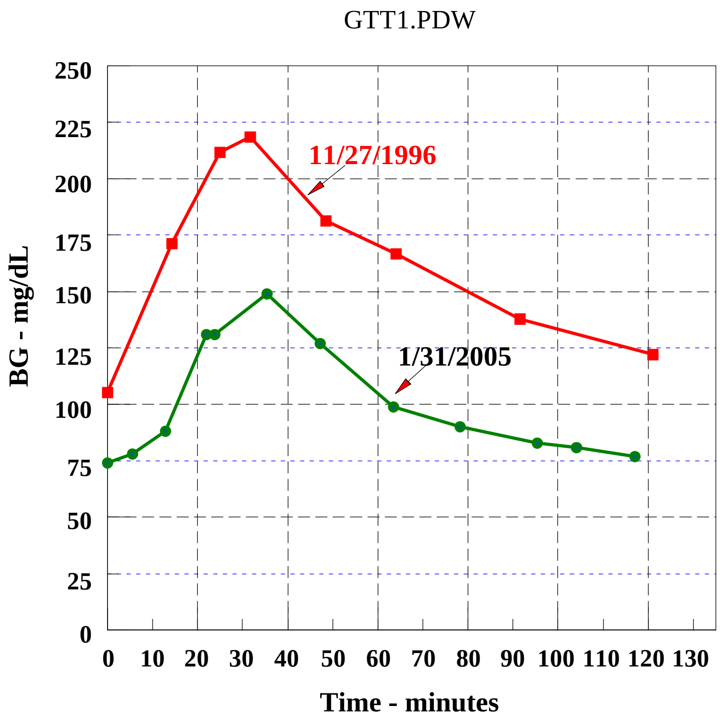

Figure 1. Mini glucose tolerance tests more than 8 years apart.
Stimulus = 12 grams of glucose. (Graph on front cover plots the △BG in this test)

Looking at the dates on the above curves it is seen that despite the passage of time, just over eight years, my ability to control BG has improved, not worsened. Also, my fasting BG is considerably reduced. This is great news for me and also for others who maintain good control. The results of several mini GTT tests made over a period of eight years are summarized in table 1.

It is possible that my recent results have been helped somewhat by the basal insulin that I now take to combat the effects of prednisone, a drug known to raise IR and BG. However, the insulin was discontinued at least 24 hours before the test, and results on 9/9/199 and 2/12/2000 support the view that a small amount of basal insulin may not unduly affect the results of a mini GTT. In the 1/31/2005 test there is evidence that the important phase 1 insulin response, described by Dr Bernstein, is still present — a welcome sign.

Effects of Carbohydrate, and Fasting BG on A1c.

The A1c measurement provides an estimate of a person's average blood glucose level, BG_{avg} over a period of several weeks. Many people with diabetes strive to get their average blood glucose level in the same range as people not having diabetes. This requires getting an A1c in the range of 5 to 6%. To achieve that value, the way in which carbohydrate food and fasting BG combine to determine an average value of BG, will be established using data from numerous experiments performed by the author. Also, a simplified approach is developed in which the △BG versus time relationship following a meal is represented by a triangular response.

Table 1. Results of Mini GTTs for Patient with Type 2 Diabetes. (Determined by △AUC during glucose tolerance test with 12 gram glucose stimulus)		
Date	△AUC mg/dL minutes	Comments
11/27/1996	6,808	
4/15/1997	6,530	Start "Good" control using low carbohydrate diet.
6/15/1997	5,000	
7/30/1997	4,006	
7/5/1999	4,836	
7/29/99	5,183	Start 8 units of Ultralente daily.
9/9/1999	3,919	Discontinued insulin 42 hours before test, then resumed 8 units of Ultralente daily.
2/12/2000	4,460	
10/28/2000	4,832	Start 7 + 7 units of Ultralente daily to combat prednisone medicine.
1/31/2005	3,309	Discontinued insulin 24 hours before test, then resumed 7 + 7 units of Ultralente daily.

Determining A1c from BG_{avg}

Different laboratories may use slightly different formulas for determining A1c. The formula used here is that found in an article in Diabetes Care [4], namely:

$$A1c = \frac{(Mean\ plasma\ glucose + 77.3)}{35.6} \qquad (1)$$

Using the above formula, an A1c of 5.0 is obtained if the mean plasma glucose is 101.

Food Response Curve

The author's response to eating 30 grams and 60 grams of whole-wheat bread, a high glycemic index carbohydrate, is given in reference [1]. In this original data, developed several years ago, the curves were plotted from BG measurements calibrated for whole blood. The curves are reproduced here in figure 2, but have been scaled by a factor of 1.12 to represent the plasma measurements given by laboratories.

It is interesting, perhaps surprising, to see the repeatability of two consecutive response curves for 30 grams of bread. One was started at time zero and the second was started after 120 minutes. Measurements of AUC for these two results are amazingly close, within 2%.

Figure 3 shows that △BG resulting from eating a bread meal may be reasonably approximated with a triangular wave pattern. Parameters of those triangles for two different amounts of whole-wheat bread are summarized in table 2. In that table, the △AUC is also determined by integration using commercially available software called PSI-Plot. The approximate △AUC found from the proposed simple triangular response is defined by the area of a triangle, namely, 0.5 × base × height.

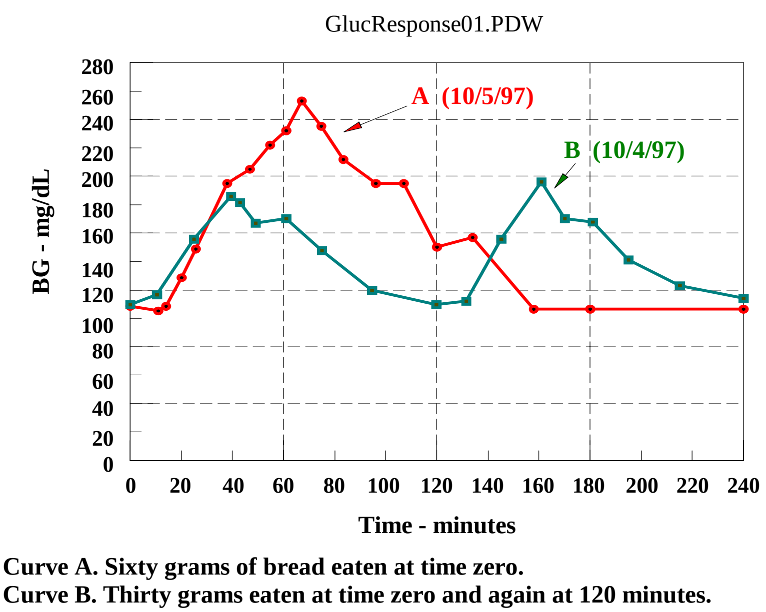

Figure 2. Response to eating different amounts of whole-wheat bread.

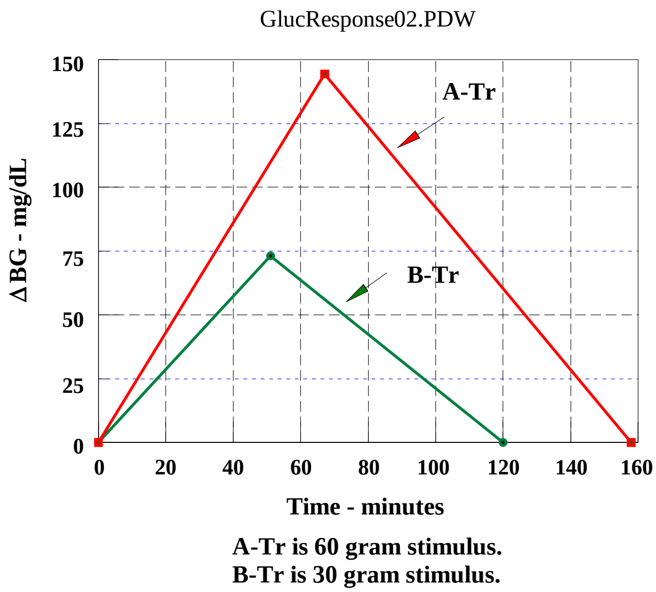

Figure 3. Simplified △BG response to whole-wheat bread stimulus.

Consider the triangular wave shown in red in figure 3. There are three numbers describing the points for this triangle, namely, 0, 144.5 , 0. The average of these numbers is simply 144.5/3 namely, 48.17. In contrast the average BG determined from AUC/time is, 0.5 × 158 × 144.5 /158 namely, 72.25.

It is seen that the arithmetic average of a set of BG numbers may not define average BG. However, it is noted that the average value of a triangular response is simply one half of the peak. Thus, if the peak BG and time to return to normal BG can be measured, the △AUC can be reasonably estimated.

The actual glucose response △AUC is compared with the triangle approximation in the two right side columns in table 2. The following observations are made:

1. The △AUC varies approximately as the weight of bread (carbohydrate) eaten.
2. The △AUC calculated from the simplified response triangle compares well with the values obtained by actual curve integration.
3. The triangular response shape can be used to give a good approximation to △AUC.

Parameters required to estimate △AUC from the triangle response are:

1. Fasting BG
2. Peak BG
3. The time for BG to return to within 10% of the initial fasting BG.

Ideally, the parameter defined in 3 above would be the time to return to fasting BG. However, using a 10% factor causes tolerable error. It prevents possibly significant errors caused by meter test strip variations and slow acting changes in body BG level. The latter could, for example, be caused by the 'dawn effect' or normal body movements during testing.

Table 2. Triangle parameters obtained from tests with whole-wheat bread food input.					
Amount of bread eaten	Peak change △BG- mg/dL	Time to reach peak BG Minutes	Total time to return to fasting BG Minutes	△AUC from triangle. mg/dL minutes	△AUC from actual curve integration mg/dL minutes
30 grams average of two tests	81	40	120	4,860	3,971
60 grams	144	67	158	11,376	10,539

A1c Calculations

Assume you eat three meals/day for which the △AUC (in mg/dL.minutes) is determined as described above. If the three meals are different the △AUCs will likely be different. Defining these as △AUC1, △AUC2, and △AUC3, then, in the course of 24 hours the average blood glucose level is given by:

$$BG_{avg} = FBG + (\triangle AUC1 + \triangle AUC2 + \triangle AUC3)/(24 \times 60)$$

As an example, consider the author to have an FBG of 100. If he eats three meals producing △AUC values comparable to 60 grams of whole-wheat bread, then:

$$BG_{avg} = 100 + (3 \times 11{,}376)/(24 \times 60) \text{ i.e., } 123.7$$

From equation 1, his A1c will then be 5.65%

The importance of carbohydrates, fasting BG level, and A1c.

In the above example calculation, the total AUC is the fasting value of 100 mg/dL plus the meal-caused increment of 23.7 mg/dL. The latter being caused by a total daily input of 180 grams of whole-wheat bread, which includes 108 grams of carbohydrate.

Assume that protein has little effect on BG , as determined by the author, and that △AUC varies as the total weight of carbohydrate consumed, then A1c can be plotted as a function of fasting BG and carbohydrate eaten, using equation (1). The results are shown in figure 4. The importance of fasting blood glucose and carbohydrate input is evident.

Although these discussions have focused on a patient with type 2 diabetes, most of the calculations are universally applicable.

If you enjoy calculus you can apply partial differentiation to equation (1) and determine the total differential. This highlights the importance of fasting BG on A1c. If calculus is not your strong point you can put typical numbers into the equation and get the same conclusion, fasting BG is very important.

A basal insulin, such as Ultralente can be very helpful in controlling fasting BG, but it’s only part of the story. If I keep basal insulin constant, but I'm not careful with meals, fasting BG will increase. This is possibly due to the beta cells becoming less effective in a high glucose environment. I deduce from this that in the long term, fasting BG and meal effects are intertwined.

GlucResponseA1c.PDW

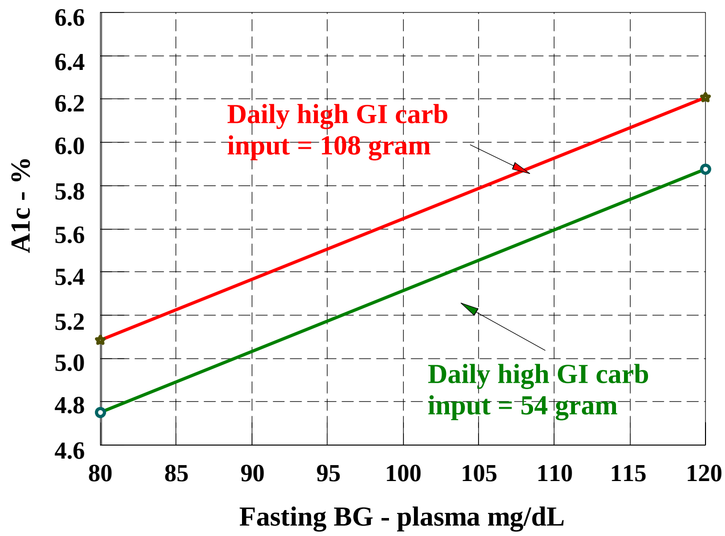

Figure 4. Showing the effects of carbohydrate and fasting BG.

Conclusions for the author — a 75-year old male with type 2 diabetes diagnosed in 1990.

1.The ability of the patient to control BG as aging took place was not compromised over an 8-year period. During this time, adherence to a low glycemic index diet resulted in A1c being in the range of 5.2 to 6%. In the past 4 years, a small amount of basal insulin was used to counteract increased insulin resistance caused by prednisone, a medication taken for other ailments.

2. A good estimate of △AUC can be obtained knowing only fasting blood glucose, peak blood glucose, and the time to return to within fasting blood glucose after eating.

3. Average BG level is found from △AUC and fasting BG measurements.

4. A1c is found from the calculated average BG level.

5. The amount of carbohydrate eaten has a major effect on A1c, thus a high protein, low carbohydrate diet is beneficial.

6. Two small carbohydrate meals raise BG less than one meal with the same total number of carbohydrates.

7. Fasting blood glucose has a major effect on A1c. Thus a basal insulin, such as Ultralente, can be very beneficial at reducing A1c for those with type 2 diabetes.

References:

[1] Richard K. Bernstein: *Dr Bernstein's Diabetes Solution*, Little, Brown and Company, New York, 1997.

[2] Derek A. Paice: *Diabetes and Diet: A Type 2 Patients Successful Efforts at Control.* Available at: www.dapaice.com/

[3] Gretchen Becker: *The First Year Type 2 Diabetes. An Essential Guide for the Newly Diagnosed*, Marlowe & Company, New York, 2001.

[4] Curt L Rohling, et. al., *Defining the Relationship Between Plasma Glucose and HbA1c*, Diabetes Care 25:2, p275-278, Feb. 2002.

About the author.

Born in London England, the author was undergoing advanced flying training in the RAF when he was grounded by polio. His girlfriend, Joan, was the 'angel' who stayed by his side. She inspired him to recover and after two years of convalescence they were married.

He retrained as an electrical engineer and in 1964 with their three children they emigrated to the United States. They all became citizens and he had a successful career in electrical engineering research.

After being diagnosed with type 2 diabetes in 1990, the author applied his engineering skills to achieve good BG control. He is now retired and writes both nonfiction and fiction works.

Derek A. Paice — 2004

Books by, Derek Paice, include those below and others shown on the Home page at www.dapaice.com/

Power Electronic Converter Harmonics: Multipulse Methods for Clean Power, New York: John Wiley & Sons, Inc., 1996 – ref: ISBN 0-7803-1137-X.

Birds, Fools, And Angels. An action/romance novel with substantial autobiographical content. Reference ISBN 1-4140-3175-0.