Bio Factsheet

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Answering Exam Questions: Diabetes

This Factsheet reviews recent exam questions on diabetes – and it is a very common topic!

In 2007 there were an estimated 246 million people suffering from diabetes and many scientists believe that is an epidemic in many developing and newly industrialized nations.

Complications from diabetes, such as coronary artery disease, stroke, renal failure and blindness are resulting in increasing disability, reduced life expectancy and enormous health costs for virtually every society.

There are two types of diabetes:
• Type 1 (insulin dependent) in which the body cannot produce insulin
• Type 2 (non-insulin dependent) in which the body cannot efficiently use the insulin which is produced

Patients suspected of suffering from diabetes are usually given a glucose tolerance test, as follows:
• patient fasts for several hours
• a measured amount of glucose is ingested
• blood glucose levels are monitored at regular intervals over next few hours

Fig.1 Diabetic’s blood glucose levels and blood insulin levels, compared with samples from a healthy person

Two hormones, insulin and glucagon normally regulate blood glucose levels

1. Insulin reduces blood glucose levels by:
Stimulating the conversion of glucose to glycogen
Inhibiting new production of glucose (gluconeogenesis)
Increasing the uptake of glucose into muscle cells
Increasing cellular uptake of glucose for respiration

2. Glucagon: stimulates the conversion of glycogen stored in the liver and muscles to glucose.

In humans, the normal level of blood glucose is about 90mg/100 cm³ of blood, but this can vary. For example, during fasting or after prolonged and heavy physical activity, the blood glucose level may drop to 70 mg/100 cm³. After a meal rich in carbohydrate has been digested, the blood glucose level may rise to 150mg/100 cm³.

Why must blood glucose levels not get too high?
Because it would decrease the water (solute) potential of the blood, cause water to be drawn out of the body cells and would increase the viscosity of blood, putting a strain on the heart

Why must blood glucose levels not get too low?
Because glucose is needed as a respiratory substrate (energy source for cells) and it may lead to unconsciousness or coma.
Typical Exam Question
Two hormones, insulin and glucagon normally regulate blood glucose levels.
The concentrations of blood glucose, insulin and glucagon were measured in a group of patients over a 5 - hour period, during which time a carbohydrate-rich meal was ingested. Fig.2 shows the results.

(a) Describe the sequence of events following the ingestion of the meal (3)
(b) Explain how the graph illustrates the concept of negative feedback (3)

One of the most common type of exam questions simply asks you to interpret a graph or table which compares what happens when a diabetic person and a non-diabetic person drinks a glucose solution. Table 1 below shows the changes in blood glucose concentrations of diabetic and non-diabetic women over a sixty-minute period, after eating a glucose-rich meal.

Table 1 Changes in blood glucose concentrations

<table>
<thead>
<tr>
<th>Time after meal/min</th>
<th>Mean blood glucose concentration/mmol dm$^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diabetic women</td>
</tr>
<tr>
<td>0</td>
<td>11.8</td>
</tr>
<tr>
<td>30</td>
<td>16.4</td>
</tr>
<tr>
<td>60</td>
<td>17.6</td>
</tr>
</tbody>
</table>

As you can see, eating the glucose-rich meal increased the blood glucose concentration of both groups. But the increase is much greater in the diabetic group. After one hour the blood glucose levels of the diabetic women have increased by about 50%.

The blood glucose levels of the non-diabetic women on the other hand have actually fallen below what they were before the meal.
Risk Factors
People are more likely to develop diabetes if they have one or more risk factors:
- Obesity
- Male
- Elderly
- High calorie diet

Fig. 3 shows the percentage of men and women in each age group affected by diabetes mellitus.

![Fig 3](image)

Between the ages of 16 and 34 diabetes is more common in women than in men but thereafter it is more common in men. Prevalence increases with age for both sexes up to 74 years.

Fig 4 shows the relationship between obesity and diabetes found in a study of over 3000 people. Body Mass Index (BMI) is a widely used indicator of obesity.

![Fig 4](image)

Typical Exam Question
(a) Describe the relationship shown in Fig 4. (2)
(b) Estimate the increase in risk of diabetes caused by a BMI of 37 kg/m² relative to a BMI of 23 kg/m². (2)
(c) Does the increasing uncertainty of the data at high BMIs cast doubt on the relationship between BMI and incidence of diabetes? Explain your answer (3)

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Treating diabetes
Treatment of insulin-dependent diabetes is by injection of insulin. There are two types of insulin available, basal insulin and bolus insulin. Basal insulin is injected once a day and is absorbed slowly into the body. Bolus insulin is usually injected at each mealtime. However, as Fig. 5 shows, there are benefits of injecting both at the same time

![Fig 5](image)

Key points:
Bolus insulin is only present for 5 hours but the basal insulin remains in the blood for 24 hours. It starts to lower blood glucose immediately after the injection and will prevent very high levels of blood glucose e.g. after a meal

The concentration of bolus insulin increases and decreases faster than that of basal insulin so it will only work for a short time

The concentration of bolus insulin peaks at 2 hours, whilst the concentration of basal insulin peaks at 6 hours and remains at this high level for about 6 hours. In other words, the basal insulin will work between meals or during the night when blood glucose concentrations are lower.

However, diabetics should not inject bolus insulin more than 15 minutes before they eat because it will act very rapidly – before the meal has even been digested – and this could lead to very low levels of blood glucose.

Typical Exam Question
A diabetic athlete has been advised to estimate the number of grams of carbohydrate that is present in his meals. This enables him to calculate how much insulin he needs to take to lower his blood glucose concentration.

Each unit of insulin that he injects lowers his blood glucose level by 1.5 mmol dm⁻³.

He needs to inject 1.5 units of insulin for every 10 g of carbohydrate that he eats.

The athlete eats the following breakfast.

<table>
<thead>
<tr>
<th>Food</th>
<th>Estimated carbohydrate/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green tea</td>
<td>0</td>
</tr>
<tr>
<td>125 cm³ orange juice</td>
<td>12</td>
</tr>
<tr>
<td>Two slices of brown toast</td>
<td>43</td>
</tr>
<tr>
<td>374 g baked beans</td>
<td>65</td>
</tr>
</tbody>
</table>

Calculate the number of units of insulin that he should inject to control the rise in blood glucose level as a result of eating this meal.
Producing insulin

Insulin used to be produced from pigs. However, there were several disadvantages to this:

- could provoke an allergic response
- pig insulin is not structurally identical to human insulin
- there were shortages of pigs
- ethical objections to the use of animals
- risk of spreading disease from pigs to humans
- difficult to produce insulin in large quantities
- some people had religious objections to being injected with insulin from other animals

Genetically engineered (transgenic) microorganisms can now be used to produce human insulin.

Treating diabetes with gene therapy

Instead of injecting insulin, patients suffering from insulin dependent diabetes can be given transplants of cells from the islets of Langerhans of healthy matching donors. The cells are injected into the hepatic portal vein and then become lodged in the liver, where they function in the same way as in a normal pancreas. There are both advantages and disadvantages to this approach:

Advantages
- There is no need to measure blood sugar
- Achieves a more stable homeostasis with reduced highs and lows in blood glucose
- It avoids pain, fear and inconvenience of injections
- It mimics normal pancreatic behaviour

Disadvantages
- There is the problem of the cells being rejected by the body.
- Cells may lodge elsewhere
- The cells may take a long time to act

Practice Question

1. An insulin dependent man ingested a glucose solution and his blood glucose levels were measured at regular intervals. The results are shown in the graph.

   ![Concentration of blood glucose](graph)

(a) The man’s blood contained no insulin but the concentration of glucose decreased after 1 hour. Suggest why (2).

   The man used dietary control to try to stabilize his blood glucose concentration within narrow limits. He ate three meals a day: breakfast, a midday meal and an evening meal. He injected insulin once before breakfast and once before the evening meal. The injection he used before breakfast was a mixture of slow-acting insulin and fast-acting insulin.

(b) Explain the advantage of injecting both types of insulin before breakfast (2)

Typical Exam Question

Outline how genetic engineering can be used to produce human insulin (8)

Markscheme

identify the gene for insulin production;
extract the gene using a restriction enzyme e.g. reverse transcriptase;
cut plasmid;
use the same restriction enzyme to obtain complementary ends;
insert the gene into the plasmid to create recombinant DNA;
plasmid is taken up by bacteria;
identify those bacteria that have taken up the plasmid;
culture these bacteria using optimal nutrient levels in a fermenter;
the bacteria produce insulin;
which is extracted and purified.

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Answers

1. (a) ([graph])

   (b) (2)

   slow acting insulin reduces blood glucose over the course of the day, means he doesn't have to inject at lunch.

   (2) (2)

   fast acting insulin reduces blood glucose from breakfast.