Abstract
While the prevalence of all types of chronic conditions is increasing, diabetes is one of the few long-term conditions that individuals can successfully manage on a day-to-day basis, providing that they have access to appropriate advice and support. Blood glucose monitoring and patient education are essential in diabetes care and management, and if used appropriately, can help to achieve maximum benefit for the patient and diabetes care team. This article considers the link between blood glucose levels and the incidence of diabetes-related complications. It explores the different blood glucose monitoring strategies, particularly self-monitoring of blood glucose in people with type 2 diabetes. The frequency of blood glucose monitoring, and the identification of patterns and trends in blood glucose control are highlighted and applied to practice.

Author
Paula Holt
Lecturer in diabetes care, School of Healthcare, University of Leeds.
Correspondence to: p.holt@leeds.ac.uk

Keywords
Blood glucose levels, blood glucose monitoring, diabetes, glycated haemoglobin, hyperglycaemia, hypoglycaemia, self-monitoring

Aims and intended learning outcomes
This article aims to highlight the role of blood glucose monitoring in the prevention of diabetes-related complications, and to provide information on the different methods and approaches that can be used to monitor diabetes control. After reading this article and completing the time out activities you should be able to:
- Discuss the importance of effective blood glucose monitoring in people with type 1 and type 2 diabetes.
- Identify recommended blood glucose levels in both type 1 and type 2 diabetes.
- Discuss the use of urinalysis, HbA1c (glycated haemoglobin) and self-monitoring of blood glucose in reducing the risk of diabetes-related complications.
- Recognise patterns and trends in patients’ blood glucose levels.

Introduction
The number of people who are being diagnosed with type 1 or type 2 diabetes is increasing rapidly, with current estimates suggesting that 220 million people worldwide have diabetes (Ali et al 2012). If current trends continue, it is predicted that 366 million people worldwide will have diabetes by 2030 (Wild et al 2004). In the UK, three million people are known to have diabetes (Diabetes UK 2013), but there may be around one million people who have the condition, but are yet to receive a formal diagnosis (NHS Choices 2012). The cost of treating diabetes and its complications is estimated to be in excess of £9 billion in the UK, which accounts for approximately 10% of the NHS budget (Diabetes.co.uk 2014).
**Diabetes-related complications**

Type 1 and type 2 diabetes are characterised by hyperglycaemia, which results from defects in insulin secretion, insulin action or both. Several pathogenic mechanisms are associated with the development of diabetes. Autoimmune destruction of the beta cells, leading to absolute insulin deficiency, is characteristic of type 1 diabetes. Abnormalities resulting in resistance to insulin action and subsequent beta cell insufficiency, mainly caused by obesity and a sedentary lifestyle, are the main causes of type 2 diabetes (American Diabetes Association 2006).

Type 1 and type 2 diabetes can result in complications. These can be divided into two main categories: microvascular and macrovascular complications. Microvascular complications include retinopathy, neuropathy and nephropathy and begin with the onset of chronic hyperglycaemia (Gerich 2005). In people with type 1 diabetes, this will usually coincide with a diagnosis of diabetes, but for people with type 2 diabetes, damage to the microvascular system can occur years before the person has been diagnosed with diabetes or has even sought medical help. It is known that people can have type 2 diabetes for up to 12 years before they are formally diagnosed and consequently, 50% of people at the time of being diagnosed with type 2 diabetes already have established microvascular complications (Holt 2009). Macrovascular complications, such as heart disease, stroke and peripheral vascular disease, may also begin well before diabetes is diagnosed, particularly in the presence of other cardiovascular risk factors, such as smoking, obesity and a sedentary lifestyle, and are the leading cause of morbidity and mortality especially in patients with type 2 diabetes. When compared to a person without diabetes, an individual with type 2 diabetes has a twofold to fourfold increased risk of dying from a myocardial infarction or stroke and a tenfold to fifteenfold increased risk of leg amputation (Gerich 2005).

Postprandial hyperglycaemia, defined as a high blood glucose level two hours after the person has eaten (National Institute for Health and Care Excellence (NICE) 2010), has been shown to be an independent risk factor in the development and progression of macrovascular disease (Lebovitz 2001), however, there is a lack of information about the mechanisms involved in this association. It is thought that postprandial hyperglycaemia has a direct, destructive effect on the blood vessels of the cardiovascular system by increasing vascular permeability and coagulability and decreasing thrombolysis, all of which increase a person’s susceptibility to fatal clot formation. Hyperglycaemia is also responsible for the generation of free radicals, which promote atherogenesis leading to atherosclerosis (Lebovitz 2001). However, the National Health and Nutrition Examination Survey demonstrated that only 37% of people with diabetes achieved glycaemic control, defined as HbA1c <7.0% (53mmol/mol) (Saydah et al 2004).

**Monitoring blood glucose levels**

New and emerging pharmacological therapies, more sophisticated methods of monitoring blood glucose levels and quality patient education can be combined to help reduce the incidence of complications and increase the quality of life for people with diabetes. Reliable information on a person’s glycaemic control is essential in diabetes care and management. Healthcare professionals will use this information to evaluate the effectiveness of treatment and lifestyle regimens, and to identify where adjustments may need to be made to maintain blood glucose levels within recommended parameters. It also helps the person with diabetes to identify incidences of hypoglycaemia and hyperglycaemia, the effects of diet and exercise on blood glucose levels, and the effectiveness of prescribed medications (Goldstein et al 2004).

The two main methods used to monitor blood glucose control in people with diabetes is HbA1c and self-monitoring of blood glucose levels. Before these methods became widely available, urinalysis was considered to be a useful, easy to perform, cheap and non-invasive method of monitoring levels of hyperglycaemia. For an accurate recording, urinalysis relied on a generic and stable renal threshold, which is not possible to achieve making the test unreliable and unpredictable. It is known that there are wide patient-to-patient variations in renal threshold and individual renal thresholds change as a result of different conditions such as time of day, ageing and pregnancy. Urine glucose tests tended to over or underestimate blood glucose levels and importantly, were not able to assess for hypoglycaemia. To this end, urinalysis has now largely been replaced with the more effective and reliable HbA1c testing and self-monitoring of blood glucose levels (Renard 2005).
Glycated haemoglobin
HbA1c is known as the gold standard in blood glucose monitoring and provides information on the person’s long-term glycaemic control. It is also a reliable predictor of future long-term complications associated with diabetes (Renard 2005). In one large observational study, it was reported that a 1% increase in HbA1c values over 31mmol/mol (5%) increases the person’s risk of cardiovascular disease by 20% (Khaw et al 2004). Furthermore, it was found that people with a HbA1c between 31mmol/mol and 37mmol/mol (5.0-5.5%) had a 2.5-fold increased risk of dying from cardiovascular disease when compared with individuals with a HbA1c ≤31mmol/mol (5%) (Khaw et al 2001). In addition, two landmark studies have demonstrated that the incidence and development of all diabetes-related complications are significantly reduced when blood glucose levels are kept within the target range of 4-7mmol/L (Diabetes Control and Complications Trial Research Group 1995, UK Prospective Diabetes Study Group 1998).

To test the HbA1c, a venous blood sample is required and is analysed to determine the amount of glucose attached to the haem element of red blood cells. This is known as glycated haemoglobin and is recorded as mmol/mol (previously as a percentage), with 48mmol/mol (6.5%) or below being the optimum level to achieve (National Collaborating Centre for Chronic Conditions 2008). The blood test relies on a normal erythrocyte lifespan of 120 days and measures the amount of glycated haemoglobin over the preceding two to three months. For this reason, the HbA1c is usually performed quarterly (Renard 2005), and not more frequently than every two months. The result is, therefore, based on an average blood glucose level over the past two to three months and reflects a combination of preprandial and postprandial blood glucose levels. The blood test is not able to record ‘real-time’ levels of glucose or specific incidences of hypoglycaemia or hyperglycaemia, but an advantage to the test is that the results cannot be specifically manipulated by the patient, for example with the patient only monitoring when he or she is confident that his or her blood glucose levels will be within normal limits, and it cannot be reported inaccurately (Murata et al 2009). This provides a useful guide to blood glucose control when the patient’s blood glucose readings do not appear to match the HbA1c result.

In considering the reliability and value of HbA1c measures, Mazze et al (2011) questioned the characteristics of ‘good’ glycaemic control and argued that in trying to achieve optimum blood glucose levels, the rate and severity of glucose variability and risk of hypoglycaemia is increased. Evidence suggests that not only high blood glucose levels, but excessive peaks and troughs in glucose variability also contribute significantly to the development of vascular complications (Zaccardi et al 2009). Since the HbA1c is not able to identify the level, amount and duration of glucose variability, it is limited in its ability to characterise good glycaemic control.

Complete time out activity 2

Self-monitoring of blood glucose
Self-monitoring of blood glucose levels is performed by the patient who, using a small lancet device, obtains a sample of capillary blood which is applied to a reagent strip and inserted into a handheld machine for testing blood glucose. The lateral aspect of the fingers are the most common sites used to obtain capillary blood, but sites such as the forearm can also be used (Renard 2005).

Self-monitoring of blood glucose levels should be performed to complement HbA1c because it is able to provide patients with real-time measurements of their blood glucose levels. It can provide feedback on the effects of diet, exercise and stress on actual blood glucose levels at the point of testing, and can give the person information on the day-to-day patterns and trends in blood glucose levels (Holt 2007), which need to be considered when evaluating the effectiveness of diet, lifestyle and prescribed medications (Benhalima and Mathieu 2012). The identification of patterns and trends can enable more timely and specific therapeutic adjustments to be made rather than adopting a blanket approach to lowering blood glucose levels. In addition, because self-monitoring of blood glucose can record real-time blood glucose levels, it is particularly useful in determining levels of hypoglycaemia and hyperglycaemia, which can help to improve patient safety (Bergenstal et al 2005). This is important for patients who are being treated with insulin, sulfonylureas or glinides, which are known hypoglycaemic agents.

Self-monitoring of blood glucose is also important in motivating patients to make lifestyle and medication adjustments. For those treated with a basal or bolus insulin regimen, preprandial glucose monitoring can
indicate the efficacy of the previously injected basal insulin and at the same time, offers a reference point for the amount of fast-acting insulin to be injected to meet mealtime, carbohydrate requirements (Renard 2005). Postprandial self-monitoring is recommended for people who have a fasting blood glucose level within the normal range, but do not reach recommended HbA1c levels (Bergenal et al 2005).

Complete time out activity 3

Self-monitoring of blood glucose levels is also recommended for those who drive and are taking insulin. Diabetes UK (2012) advises that people with diabetes avoid long and stressful journeys and that a blood glucose test is done immediately before starting the journey and ideally every two hours during the journey. It is important that the time, date and results are recorded in the memory of the blood glucose meter because the information may be needed if the driver were to be involved in an accident. Any abnormalities in blood glucose levels should be treated effectively before the person starts or continues the journey (Driver and Vehicle Licensing Agency 2013).

There has been much debate in recent years regarding the value of self-monitoring of blood glucose levels in people with type 2 diabetes who are not treated with insulin, particularly whether the cost and inconvenience are greater than the benefits. In a meta-analysis of nine randomised controlled trials, Malanda et al (2012) found that 1,261 patients with type 2 diabetes who performed self-monitoring of blood glucose levels showed a small but significant decrease in HbA1c at six months when compared to 1,063 people in the control groups. However, this improvement in HbA1c was not seen in those who continued to self-monitor for one year. Reasons for this may include patient motivation to monitor and actively manage blood glucose levels being high initially, but declining over time. It was also noted that people who had a HbA1c <64mmol/mol (8%) at the start of the trial were less likely to benefit from self-monitoring of blood glucose levels when compared to those people whose HbA1c was >64mmol/mol (8%). This group showed a greater improvement in HbA1c, with the most notable change seen in those who had a baseline HbA1c >86mmol/mol (10%) (Namak et al 2013). It is likely that the person with a higher HbA1c will experience higher pre and postprandial blood glucose levels than the person with a lower HbA1c, and therefore may be more inclined to take an active role in reducing his or her blood glucose levels.

It has been found that self-monitoring of blood glucose levels is associated with strong beliefs that diabetes has negative consequences on health, but this does not seem to encourage people to make changes to their health behaviours (Benhalima and Mathieu 2012). Often, individual frustration occurs when blood glucose readings are not understood by the person or do not match the person’s expectation or, in contrast, cease to be of interest when they are entirely predictable (Benhalima and Mathieu 2012). However, health behaviours can only be modified if the person understands fully the pathological processes governing blood glucose levels and the factors that can affect these. Therefore, there is no point monitoring blood glucose levels unless the results can be acted on effectively.

In considering the costs and benefits of self-monitoring of blood glucose levels in people with type 2 diabetes, NICE (2010) concluded that self-monitoring does not appear to improve glycaemic control when introduced as a standalone intervention and should only be offered to a person as part of a comprehensive care package including access to patient education. There may be occasions, however, when self-monitoring of blood glucose levels is recommended to provide useful information for the diabetes healthcare professional rather than the patient.

Case studies
In this section, case studies will be presented alongside discussion on self-monitoring of blood glucose. The case studies are as follows:

- Jake is a 23-year-old man who has had type 1 diabetes since he was eight. He is given insulin four times per day. His most recent HbA1c is 66mmol/mol (8.2%). He reports experiencing hypoglycaemic episodes about once per month.
- Sandra is a 36-year-old woman who was diagnosed recently with type 2 diabetes. There is no history of diabetes in her family and she has little knowledge of the condition. She is obese and her body mass index is 38. She is taking metformin.
- Polly is a 62-year-old woman who has had type 2 diabetes for four years. She does not self-monitor her blood glucose levels. She has her HbA1c recorded every six months and each time the reading is a little higher
CPD diabetes care

than the last. With each HbA1c result, her medication regimen has been changed, but with little effect. Her father died of a diabetes-related stroke aged 69, so she is keen to reduce her blood glucose levels. She has recently attended a structured education programme.

**Complete time out activity**

With regard to self-monitoring, it is important to consider patient safety as well as the need to gain the required information on which to make an evidence-based, informed clinical decision. Because Jake has type 1 diabetes that is controlled with insulin, he is at increased risk of hypoglycaemia and hyperglycaemia, which need to be detected early to ensure his and others’ safety. He is also able to titrate insulin doses to meet his requirements; therefore, he would be advised to self-monitor his blood glucose levels several times per day.

Initially, self-monitoring of blood glucose levels may not be recommended to Sandra because she is coming to terms with having type 2 diabetes, and a priority for her will be to lose weight, which will positively affect her blood glucose levels. Introducing self-monitoring of blood glucose levels at this stage could be a waste of money and resources since Sandra does not understand what has caused an abnormal blood glucose result and how to act on this (NICE 2010). It is important that patients know how to test their blood glucose, why they are testing and what the results mean (Polonsky and Fisher 2013). Two to three-monthly recordings of HbA1c would be more beneficial for Sandra as they would provide a better indication of her blood glucose control, which may be used to initiate further lifestyle and treatment strategies.

Polly could benefit from self-monitoring of blood glucose levels. She has attended a structured education programme, so has some knowledge of the mechanism and importance of blood glucose control. Polly is motivated by the death of her father to achieve good glycaemic control. However, this is proving difficult at the moment despite changes in her medications. Polly could be asked to self-monitor blood glucose levels each day for two weeks before her clinic or GP appointment, which would provide the healthcare professional with her pre and postprandial blood glucose levels, including any peaks and troughs. This would enable identification of times of the day when an increased dose or a different type of pharmacological therapy is needed. It would also provide a basis on which to discuss diet and exercise with Polly and consider how these are linked to subsequent blood glucose levels. Polly would be advised to continue to monitor her blood glucose until a satisfactory HbA1c level had been achieved, then she may stop blood glucose monitoring or only be requested to do it a few days preceding her annual review to enable a more individualised treatment plan to be devised.

**Frequency of blood glucose monitoring**

Unlike the prescription of anti-diabetes medication for which algorithms have been developed, self-monitoring of blood glucose is not a standardised intervention that can be applied in an identical manner across all patients and healthcare settings. It needs to be prescribed on an individual basis according to the person’s specific needs, patient agreement and the clinical information required to determine the most appropriate management intervention (Polonsky and Fisher 2013).

**Identifying patterns and trends**

The frequency and timing of blood glucose tests will be determined by the information needed by the healthcare professional to identify timely medication and/or lifestyle adjustments for the individual. However, the regimen also needs to be acceptable to the patient to maximise adherence, particularly if self-monitoring of blood glucose is required over a long period.

When trying to achieve optimum blood glucose control, it is important that patients and healthcare professionals do not focus on one or two abnormal blood glucose readings, but consider blood glucose levels measured at regular intervals over three or four consecutive days. This will enable patterns and trends in blood glucose levels to emerge, such as a consistently high reading two hours after lunch. Self-monitoring of blood glucose levels would need to be recorded preprandially, first thing in the morning before the person has eaten, because this gives an indication of the individual’s basal level of insulin. Further monitoring two hours after each main meal is also required. The two-hour postprandial period is required to enable the majority of carbohydrates to be absorbed into the bloodstream and to have created an initial rise in blood glucose levels. This rise should have largely subsided two hours after eating, thus reducing blood glucose levels to within normal limits (Foster 2004). It may also be necessary...
to monitor between 2am and 3am, especially if night-time hypoglycaemia is suspected (Rodbard et al 2007).

**Case study** In the previous case studies section, it was suggested that Polly should record her blood glucose levels before attending clinic. She has done this and Table 1 provides an extract from her blood glucose monitoring record.

**Complete time out activity**

From Polly’s blood glucose monitoring record (Table 1), it can be seen that her preprandial blood glucose levels taken first thing in the morning are generally within normal limits. While her postprandial blood glucose levels two hours after breakfast are relatively stable throughout the week, they are higher than recommended and the same applies with blood glucose levels recorded two hours after lunch. Based on these results it is important to ascertain what Polly is eating for her breakfast and lunch to determine whether the high blood glucose levels are linked to excess dietary carbohydrate intake. If dietary modification will not improve the high blood glucose levels, then it will be necessary to commence Polly on further anti-diabetes medications, which will

<table>
<thead>
<tr>
<th>Day</th>
<th>Blood glucose level before breakfast (mmol/L)</th>
<th>Blood glucose level two hours after breakfast (mmol/L)</th>
<th>Blood glucose level two hours after lunch (mmol/L)</th>
<th>Blood glucose level two hours after evening meal (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>9.0</td>
<td>13.5</td>
<td>6.5</td>
</tr>
<tr>
<td>2</td>
<td>6.8</td>
<td>8.9</td>
<td>15.4</td>
<td>7.0</td>
</tr>
<tr>
<td>3</td>
<td>8.2</td>
<td>8.5</td>
<td>14.5</td>
<td>22.1</td>
</tr>
<tr>
<td>4</td>
<td>8.0</td>
<td>9.6</td>
<td>10.5</td>
<td>19.7</td>
</tr>
<tr>
<td>5</td>
<td>7.1</td>
<td>7.9</td>
<td>12.9</td>
<td>5.6</td>
</tr>
<tr>
<td>6</td>
<td>6.3</td>
<td>8.2</td>
<td>14.7</td>
<td>21.1</td>
</tr>
<tr>
<td>7</td>
<td>6.9</td>
<td>9.5</td>
<td>18.2</td>
<td>8.3</td>
</tr>
</tbody>
</table>

**TABLE 1**

**References**


specifically target postprandial blood glucose levels. When reducing postprandial blood glucose levels, caution needs to be exercised because this could have a knock on, unwanted effect of reducing the preprandial blood glucose levels as well, which may increase Polly’s risk of hypoglycaemia.

Polly’s postprandial blood glucose levels two hours after the evening meal are erratic with no set pattern. This could be related to diet and exercise, but the high peaks and troughs in blood glucose levels need to be addressed and treated because they have been proven to predispose individuals to diabetes-related microvascular and macrovascular complications (Benhalima and Mathieu 2012).

Only recording HbA1c every two to three months would not identify the main times of the day when Polly is experiencing difficulties in controlling her blood glucose levels, which increase her risk of stroke and/or myocardial infarction. In addition, monitoring blood glucose levels once per day or per week only provides the patient and healthcare team with an indication of what the blood glucose level is at that moment in time. It does not provide enough data on which to make clinical decisions and, therefore, the benefit of this strategy should be questioned.

Conclusion
There is a link between blood glucose levels and the incidence of diabetes-related complications, therefore blood glucose monitoring is essential in diabetes management. Self-monitoring of blood glucose levels in people with type 2 diabetes who are not treated with insulin is a controversial issue in health care, and it appears that researchers are finding it difficult to present a convincing argument to support self-monitoring in improving glycaemic control in people with type 2 diabetes. With regards to the frequency of blood glucose monitoring for people with diabetes, this should be prescribed on an individual basis. It is only by monitoring capillary blood glucose levels on a regular, but potentially, time-limited basis that patterns and trends in blood glucose control can be identified, and appropriate treatment and support given.

Now that you have completed the article, you might like to write a practice profile. Guidelines to help you are on page 62.


