

Practical aspects of capillary blood glucose monitoring: A simple guide for primary care

Paul Downie

Correctly educating people with diabetes on how to use their blood glucose monitoring device and encouraging them to perform analyses as accurately as possible is essential in ensuring prompt and correct treatment of hyperglycaemia as well as preventing unnecessary treatment of suspected hypoglycaemia. The reliability of results can be affected by the environment in which the device and strips are stored, operational influences and other clinical factors including medication. This article explores user-dependent factors and some clinical scenarios that are particularly important for people with diabetes and clinicians to understand in helping ensure the accuracy of testing.

I doubt there are many, if any, clinicians reading this journal who won't have come under pressure in the last year or so to reduce the prescribing costs associated with blood glucose monitoring through a reduction in the number of test strips made available to people with diabetes.

In England, reviewing and – where appropriate – revising the local use of self-monitoring of blood glucose (SMBG) in type 2 diabetes to ensure that it is in line with NICE (2008) guidelines is one of the therapeutic targets under consideration by the Quality, Innovation, Productivity and Prevention (QIPP) programme. This large-scale transformational programme is intended to improve quality of care while at the same time making £20 billion of efficiency savings by 2014–15 (see <https://www.evidence.nhs.uk/qipp> [accessed 17.05.13]; similar programmes are in operation in the other UK nations).

Anecdotally, in secondary care I hear many complaints from people with diabetes frustrated that their access to strips is being “rationed” by practices. Sometimes this is appropriate and sometimes it isn't. NICE (2008) outlines which people with type 2 diabetes should have access to self-monitoring. Practical recommendations as to

when they should have access to self-monitoring and how frequently they should test have also been eloquently outlined in this journal (Hall, 2009).

Having access to devices which allow people with diabetes to perform SMBG is an essential tool in their self-management. They are also in common use in hospital wards and within primary care and pharmacies. It is probable that many people with diabetes and clinicians who rely on these meters are sometimes unaware of potential pitfalls in their use. There are numerous circumstances where misleading results may be obtained, which in turn can affect clinical decision-making, resulting in the potential for patient harm. Quite clearly, the ability of a person with diabetes or carer – or, indeed, a healthcare professional – to interpret and manage any given situation correctly fundamentally depends on the accuracy of the result.

The STeP (Structured Testing Program) study reported that SMBG and goal-setting encouraged beneficial behaviours, improving clinical outcomes (Parkin et al, 2011). Others have also found, however, that SMBG can impair quality of life (Simon et al, 2008).

In practical terms, it is mandatory for people with type 2 diabetes who are treated with exogenous

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Article points

1. Correctly educating people with diabetes on how to use their blood glucose monitoring device and encouraging them to perform analyses as accurately as possible is an important aspect of care.
2. People with diabetes should be encouraged to consider that a result might not always be accurate, especially if it seems out of keeping with the clinical picture.
3. Improving glucose meter accuracy can be achieved through observation of testing technique, enquiring about storage of strips, teaching the necessity of proper calibration, and periodic testing of control solutions.

Key words

- Accuracy
- Blood glucose monitoring
- Quality control

Authors

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1. One of the most practically important aspects of blood glucose monitoring is in the accurate detection of hypoglycaemia, which helps ensure the correct and prompt treatment of this potentially dangerous complication.
2. Accurate detection of hypoglycaemia, enabling prompt treatment, is crucial to avoid further harm and is of even more importance when an individual has reduced or absent hypoglycaemic awareness.
3. Driving represents an obvious example where accurate detection of hypoglycaemia is of paramount importance to avoid harm to both people with diabetes and the community at large.

insulin or agents that can lead to hypoglycaemia and all people with type 1 diabetes to have access to SMBG, with the frequency of testing varying according to the precise regimen and many other factors. SMBG is a powerful tool to demonstrate the impact of diet and physical activity; it permits dose adjustment of insulin and it can be used in the detection and correction of hypoglycaemia as well as hyperglycaemia.

A recent open letter to the Department of Health serves to remind healthcare professionals of the particular importance of finger-prick glucose testing for people with type 1 diabetes (a copy is available at <http://bit.ly/Zl6lmP> [accessed 16.05.13]). The letter states that increasing numbers of people with type 1 diabetes have been refused prescriptions for sufficient testing strips, owing to their cost. The letter also reminds healthcare professionals that although testing strips are thought of as expensive, the wider costs to the NHS of the complications of uncontrolled diabetes far outweigh the purchase cost. The letter also says that GPs and pharmacists should ensure that the provision of strips and their use is set in the context of patient education programmes.

Hypoglycaemia and hyperglycaemia

Clearly, one of the most practically important aspects of blood glucose monitoring is in the accurate detection of hypoglycaemia, which helps ensure the correct and prompt treatment of this potentially dangerous complication. Symptoms of hypoglycaemia include tremor, palpitations, sweating, hunger or paraesthesia resulting from activation of the autonomic nervous system, as well as neuroglycopenic symptoms such as confusion, drowsiness and coma (Holt et al, 2010). Accurate detection of hypoglycaemia, enabling prompt treatment, is crucial to avoid further harm and is of even more importance when an individual has reduced or absent hypoglycaemic awareness.

A particular tension has arisen from the pressure to restrict prescribing of strips in light of recently updated Driver and Vehicle Licensing Agency (DVLA) guidance (DVLA, 2012). Driving represents an obvious example where accurate detection of hypoglycaemia is of paramount importance to avoid harm to both people with diabetes and the community at large. Interestingly, only 8 years ago

it was felt that most hand-held devices for glucose determination did not offer sufficient precision, especially in the hypoglycaemic region (Stork et al, 2005). A recent study (Sonmez et al, 2010) assessed five commonly used devices and showed that all failed to detect hypoglycaemia to some extent and recommended that people with diabetes should give more credit to symptoms of hypoglycaemia. This, of course, might not be possible in individuals with hypoglycaemic unawareness. There are studies which highlight the fact that symptom beliefs are not always accurate (Gonder-Frederick et al, 1986). In addition, there are sex differences in plasma glucose thresholds for counter-regulatory hormone release and hypoglycaemic symptom perception (Cox et al, 1996).

The degree of error when self-monitoring obviously becomes more relevant with glucose readings close to or in the hypoglycaemic region. For example, an error of 5% with a glucose level of 4 mmol/L is more significant with more potential for patient harm than with a glucose result of 15 mmol/L. However, it is also crucial to be aware that a falsely low reading in the presence of severe hyperglycaemia or ketoacidosis could result in delayed treatment or inaccurate adjustment of insulin. People with diabetes and healthcare professionals alike need to consider the likely accuracy of glucose readings when making clinical decisions.

There is no universally agreed standard for glucose meter accuracy. Guidelines issued by the International Organization for Standardization (ISO), however, are generally accepted. ISO guideline 15197 suggests that for glucose levels <75 mg/dL (4.16 mmol/L), a meter should read within 15 mg/dL (0.83 mmol/L) of the reference sample, and for levels ≥75 mg/dL, the reading should be within 20%. In addition, a meter should be able to meet these targets in at least 95% of the samples tested (ISO, 2003)

A full discussion of the chemistry behind blood glucose monitors is complex and beyond the scope of this article (and, indeed, my expertise). Simplistically, glucose meters consist of two essential parts: an enzymatic reaction and a detector. The enzyme portion of the glucose meter is generally packaged in a dehydrated state in a disposable strip. Glucose in the user's blood sample rehydrates and reacts with the enzymes to form a product

that can be detected, with the measurement converted to a glucose concentration. The three principal enzymatic reactions utilised by current glucose meters involve glucose oxidase, glucose dehydrogenase and hexokinase (Tonyushkina and Nichols, 2009).

Ensuring accuracy of blood glucose monitoring

With the information laid out above, it is of clear importance, now perhaps more than ever, that both people with diabetes and clinicians can rely on the accuracy of self-monitoring and also ensure that wastage is minimised. The remainder of this article will summarise the user-dependent factors and certain clinical scenarios that are important for people with diabetes and clinicians to understand in helping ensure the accuracy of testing. The reliability of results can be affected by the environment in which the device and strips are stored, operational influences and other clinical factors including medication. These variables should be taken into consideration when interpreting blood glucose results.

User-dependent factors

Optimal user technique is crucial, and user error will only serve to magnify the analytic errors of the meters themselves. Approximately 91–97% of overall inaccuracies are operator dependent (Dungan et al, 2007; Bergenstal, 2008). Points to consider are presented below.

Hand washing

This is important in order to remove substances from the skin that could falsely elevate glucose readings. The use of warm water also leads to vasodilation, which can help obtain a good size sample. It is important to dry hands thoroughly, otherwise this could falsely lower the result. This and any other factor that leads to a falsely low reading could, for example, result in an inappropriate and unnecessary treatment of “hypoglycaemia”, so-called “pseudohypoglycaemia”.

Volume of sample

Insufficient sample of blood is a major source of error leading to an underestimation of the real glucose value (Yared et al, 2005).

Coding

Calibration is another potential source of error. The way in which strips chemically react vary according to differences in their manufacture. The reactivity of each “lot” of strips is measured so that the best calibration curve can be determined. Each lot’s reagent will have its own specific reactivity and each lot will have a slight variation from true; thus, a calibration factor is required to match the strip lot to the meter. The process by which the best calibration code for a given test strip is communicated to the meter is known as calibration or coding. A number of glucose meters require the operator to insert a calibration code based on the lot of test strip utilised for analysis. It has been estimated that a miscoded meter can produce readings which are inaccurate by up to 4 mmol/L. Another study found deviations of greater than $\pm 30\%$ (-31.6% to $+60.9\%$) when results were obtained with miscalibrated meters (Baum et al, 2006). Some SMBG devices having an automatic calibration or coding feature.

Quality control

Quality control solution should be used regularly to perform quality control checks of the meter and test-strip performance. This also reinforces the accuracy of user technique. The use of appropriate control material can be analysed to provide reassurance that the device is working correctly and assure the operator of the reliability of patient results – this is “internal” quality control. It is also advisable that all sites performing blood glucose analysis also undertake “external” quality control, which can be done by the analysis of samples with an undisclosed value from an external source (Medicines and Healthcare products Regulatory Agency, 2011). However, this is only available in some areas.

Miscellaneous

There are a number of very simple things to consider when choosing a device, such as whether it suits the user and whether he or she can operate it. An individual with diabetes should also have an expectation of results in various situations such that he or she might recognise a spurious result. The monitor should also use mmol/L as units, not mg/dL. In addition, very simple things such as ensuring that the date and time are correct are vital. One study showed that only 40% of patients

Page points

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2. These variables should be taken into consideration when interpreting blood glucose results.
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Page points

1. Incorrect storage of test strips can lead to inaccurate results, and strips have only a finite lifetime even under ideal storage conditions.
2. Correctly educating people with diabetes on how to use their blood glucose monitoring device and encouraging them to perform analyses as accurately as possible is essential in ensuring prompt and correct treatment of hyperglycaemia as well as preventing unnecessary treatment of suspected hypoglycaemia.
3. If there are any doubts regarding meter accuracy, the device should be checked against a meter of known accuracy or by comparing a specimen against a laboratory-derived result.

had their meters programmed with a date and time to within 1 hour of the actual time (Meneghini and Arce, 2005).

Environmental considerations

Strip and device storage

Incorrect storage of test strips can lead to inaccurate results, and strips have only a finite lifetime even under ideal storage conditions. Exposure of the strips to heat and cold can denature the enzymes and exposure to humidity can prematurely rehydrate the proteins and limit their reactivity when utilised for testing. The disposable reagents for glucose meters must therefore be protected from extremes of temperature, humidity and moisture. Test strips should not be stored in closed vehicles for extended periods.

Clinical circumstances that may affect accuracy

Haematocrit

Serum or plasma has a glucose concentration approximately 11–12% higher than whole blood with a normal haematocrit (Tonyushkina and Nichols, 2009). This is a result of glucose equilibrating into the aqueous portion of a blood sample. As such, haematocrit will affect the water content of a specimen, which in turn affects the accuracy of results from a glucose meter. Individuals with chronic respiratory disease or smokers with a higher haematocrit are therefore at risk of pseudohypoglycaemia. Conversely, conditions where the haematocrit is low – for instance, in pregnancy – will result in a greater percentage of water in the sample and lead to falsely high readings. Conditions such as hypertriglyceridaemia and paraproteinaemia can also lead to a pseudohypoglycaemia through a reduction in the quantity of water in the sample. Finally, haematocrits of hospitalised and acutely ill patients in shock or with dehydration could differ from the assumed normal haematocrits of samples utilised by manufacturers.

Peripheral vascular disease

It should be noted that there are also examples of pseudohypoglycaemia where a falsely low reading has been obtained from people with peripheral vascular disease (Tanvetyanon et al, 2002).

Continuous ambulatory peritoneal dialysis

Another clinical scenario to be aware of that can affect glucose results is where patients are receiving continuous ambulatory peritoneal dialysis (CAPD). Glucose meters that use glucose dehydrogenase pyrroloquinoline quinone (GDH-PQQ) cannot distinguish maltose from glucose. During peritoneal dialysis, the infusion (which usually contains icodextrin) is converted in the body to maltose. Thus, in meters which use the GDH-PQQ method, this can lead to falsely high readings in individuals treated with CAPD. This has led to errors of insulin overdosing, including some with fatal consequences (US Food and Drug Administration, 2009).

A list of monitors that use GDH-PQQ technology can be found at the US Food and Drug Administration website (<http://1.usa.gov/BwRRI> [accessed 17.05.13]).

Conclusion

A thorough understanding of potential sources of error and ways of minimising these are crucial for people with diabetes and healthcare professionals alike (see *Table 1* for a guide to some common problems with meters and recommendation to avoid or remedy these). Correctly educating people with diabetes on how to use their blood glucose monitoring device and encouraging them to perform analyses as accurately as possible is essential in ensuring prompt and correct treatment of hyperglycaemia as well as preventing unnecessary treatment of suspected hypoglycaemia. People with diabetes should be encouraged to consider that SMBG might not always be accurate, especially if a result seems out of keeping with the clinical picture.

Furthermore, in addition to the issues stated above, arguably of even greater importance is the need for people with diabetes to perform appropriate blood glucose monitoring; fundamentally, this means testing at appropriate times and making appropriate changes dependent on the results.

Improving glucose meter accuracy can be achieved through observation of testing technique, enquiring about storage of strips, teaching the necessity of proper calibration, and periodic testing of control solutions. If there are any doubts regarding meter accuracy, the device should be

Table 1. Author's guide to some common problems with meters, and recommendations to avoid or remedy these.

Problem	Result	Recommendation
Test strip not fully inserted into meter	False low	Ensure test strip correctly inserted
User's sample site (for example, the fingertip) is contaminated with sugar	False high	Always clean test site before sampling
User's test site is moist	False low	Always dry test site thoroughly
Not enough blood applied to strip	False low	Repeat test with a new sample
Batteries low on power	Error codes	Replace batteries
Test strips or control solutions stored at temperature extremes	False high or low	Store kit and components according to instructions
Individual is dehydrated	False high	Consider sending venous sample to lab depending on clinical circumstances
Squeezing fingertip too hard because blood is not flowing	False low	Repeat test with a new sample from a new stick
Anaemia or decreased heamatocrit	False high	Consider sending venous sample to lab depending on clinical circumstances
Polycythaemia	False low	Consider sending venous sample to lab depending on clinical circumstances
Increased altitude or hypoxia	Falsely elevated reading, when using glucose oxidase meter (no effect with glucose dehydrogenase)	Be aware of this potential issue
Diabetic ketoacidosis	Result can be falsely low (due to dehydration)	Be aware of this potential issue

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checked against a meter of known accuracy or by comparing a specimen against a laboratory-derived result. ■

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