Self-blood glucose monitoring

What it can and can't tell you

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Self-monitoring of blood glucose levels by patients with type 2 diabetes can help both doctors and patients review glycaemic control and identify ways to improve it. Blood glucose monitoring, however, has several limitations, notably inaccuracy and variability. Ways to measure and minimise these limitations are discussed.

Both the International Diabetes Federation and the National Health and Medical Research Council recommend individualising self-monitoring of blood glucose (self-blood glucose monitoring, or self-BGM) for patients with type 2 diabetes.[1,2] This monitoring can be of considerable help in reviewing glycaemic control and in identifying ways to improve it. This article reviews the strengths and limitations of self-BGM and presents a case illustrating its use in clinical practice. An accompanying patient handout titled 'Blood glucose monitoring: a user's guide' provides advice for people with type 2 diabetes about monitoring their blood glucose levels.

MedicineToday 2015; 16(8): 44-50

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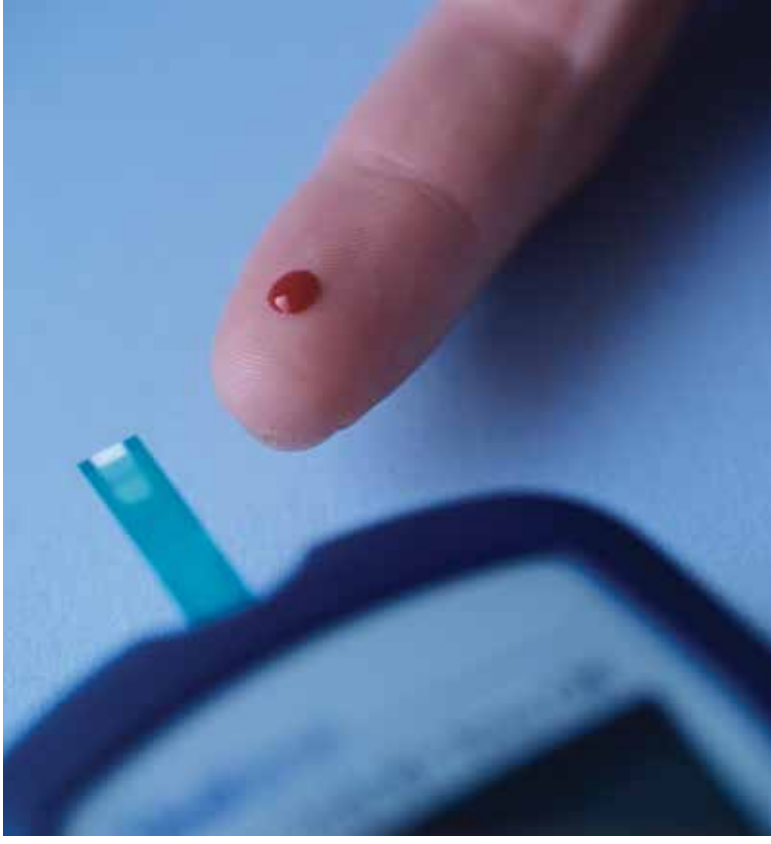

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Self-BGM – accuracy and variability

Blood glucose meters have improved enormously since their introduction in the 1980s. Today they are smaller, faster, cheaper and need less blood in the sample, and results are more reliable. But they are still not perfect. Although these meters are much easier to use, patients can and do still make mistakes. Box 1 summarises system and user factors affecting self-BGM results, with user factors generally being more common.[3] Patients may not care for their meter or strips correctly and may not routinely wash their hands before testing, which can dramatically affect the test results. An example of how much a very small amount of sugar contamination of the blood sample can increase the blood glucose level (BGL) on measurement is provided in Box 2.[4]

Assuming the meter is working correctly and the user is using it correctly, other factors can still affect BGM results, including the timing of measurements.

Measurement timing and accuracy

Manufacturers calibrate meters to give readings close to the glucose concentration in fasting venous plasma, rather than the concentration in the sample, which is capillary blood. Venous blood contains less glucose than capillary blood because tissues take up glucose. This difference is small in the fasting state (longer than four or five hours after a meal) but can increase by approximately 1 mmol/L postprandially, when insulin stimulates tissue glucose uptake. This is why the patient should be in the fasting state when the accuracy and variability of their self-BGM results are being assessed by comparing their BGM results with laboratory results (see later).

Measurement timing and variability

BGL values in the same person at the same time of day vary from day to day and vary more after than before meals. Typical

1. FACTORS AFFECTING BGM TEST RESULTS[3]

Inaccuracy

System issues: Assay interference (e.g. haematocrit, temperature, oxygenation, medication)

User issues: Incorrect technique (e.g. encoding, strip storage); incorrect documentation

Variability

System issues: Blood glucose test strips (e.g. size of sample well, content/distribution of test reagents); measurement technique

User issues: Sample contamination (see Box 2)

Abbreviation: BGM = blood glucose monitoring.

2. BGM: EFFECT OF SAMPLE CONTAMINATION[4]

The effects of contamination of the blood sample (0.3 µL) on the results of BGM can be spectacular. For example, one speck (1 µg) of glucose can increase the meter reading by 18.5 mmol/L:

1 µg of glucose = 1 ÷ molecular weight of glucose (µmol)
= 1 ÷ 180
= 0.0056 µmol

0.0056 µmol glucose in 0.3 µL of blood

0.0056 x 10^{-3} mmol glucose in 0.3 x 10^{-6} L of blood
= ([1 ÷ 180] x 10^{-3}) ÷ (0.3 x 10^{-6}) mmol/L
= 18.5 mmol/L

Abbreviation: BGM = blood glucose monitoring.

3. ASSESSING THE VARIABILITY OF BGM RESULTS[4-6]

Variability

Normal distributions of values such as laboratory test results are characterised by:

- centrality – the mean
- variability around centrality – the standard deviation (SD).

In practice, variability in results is usually described in relative terms as the coefficient of variation (CV), which is the ratio of the SD to the measured value, i.e. SD divided by the mean, expressed as a percentage.

CV = SD ÷ mean as a %.

The total variability of the fasting BGLs obtained from repeated BGM in an individual (CV_t) includes the variability of measurement (CV_m) and the day-to-day biological variability (CV_b). The 'real-world' value for CV_m, using the average blood glucose meter, is 13%[3] (as opposed to the American Diabetes Association and the International Standards Organization's lower recommended values), and the CV_b for fasting BGL is 7%.

The total variability (CV_t) of fasting BGL measurements on different days is calculated by the formula $\sqrt{(CV_m^2 + CV_b^2)}$

$CV_t = \sqrt{(13^2 + 7^2)}$
$= 15\%$

Statistically significant changes

Whether a change in a measurement is considered statistically significant is assessed using the 'least significant change' (LSC).

For 80% confidence that the difference between two results is a true difference, the LSC is approximately twice the CV. Therefore, for fasting BGL, 80% of all fasting BGLs in one individual should lie within ± 2 CV_t (i.e. 30%) of their mean value.

Abbreviations: BGL = blood glucose level; BGM = blood glucose monitoring.

coefficients of variation (CV; standard deviation divided by mean value as %) for fasting and postprandial BGL results are at least 15% and 18%, respectively, when both measurement and biological variability are included (Box 3).[4-6] This variation means that 80% of results of tests performed on different days at the same time, by the same user and with the same meter, will lie between 30% and 36% above or below the mean value for fasting and postprandial BGL, respectively (and that 20% will lie outside these limits). These limitations need to be kept in mind when interpreting self-BGM results. Patients often believe that a fasting BGL meter reading of 8.0 means their BGL is 8.0 mmol/L and will be the same the next day, but it should be remembered that the actual BGL results could be considerably lower or higher. For example, if the mean BGL result was 8.0 mmol/L, results of repeated BGL testing might lie between 5.6 and 10.4 mmol/L – i.e. ±30%.

The Australian Diabetes Society's recommended glycosylated haemoglobin (HbA_{1c}) targets for different clinical situations have been derived by balancing the benefits and costs of lower or higher levels (Table).[7] Lower values improve glycaemic control and decrease the risk of long-term complications but increase the risk of weight gain and hypoglycaemia (if sulfonylureas and/or insulin are used). Higher values are easier to achieve and have a lesser risk of weight gain and hypoglycaemia but increase the risk of complications and hyperglycaemic and glycosuric symptoms. The RACGP guidelines have a useful algorithm for lowering blood glucose in type 2 diabetes (http://www.racgp.org.au/your-practice/guidelinesdiabetes/8-managing-glycaemia/83-glucose-lowering-agents).[8]

Formulas for converting between HbA_{1c} in % and in mmol/mol and for calculating average BGL from the HbA_{1c} (the estimated average glucose [AG], or eAG) are given in Box 4. Online calculators are available for calculating eAG (e.g. www.diabetes.co.uk/hba1c-to-blood-sugar-level-converter.html).

TABLE. INDIVIDUALISED GLYCAEMIC TARGETS*

Clinical situation	HbA_{1c} target mmol/mol (%)
General target	≤53 (≤7.0)
Pregnancy or planning pregnancy	≤42 (≤6.0)
Short duration diabetes and no CVD:	
• low risk of hypoglycaemia	≤42 (≤6.0)
• at risk of hypoglycaemia†	48–53 (6.5–7.0)
Longer duration diabetes or CVD	≤53 (≤7.0)
High risk of hypoglycaemia	≤64 (≤8.0)
Limited life expectancy	Symptomatic control

Abbreviations: CVD = cardiovascular disease; HbA_1c = glycosylated haemoglobin.
* Derived from the Position Statement of the Australian Diabetes Society[6]
† Sulfonylurea therapy ≤48 mmol/mol (≤6.5%); insulin therapy ≤53 mmol/mol (≤7.0%).

Once an individual's HbA_{1c} target is agreed, the preprandial BGL ('prep' BGL) targets can be set using the following formulas (Box 4):[9]

- for HbA_{1c} in mmol/mol,
  prep BGL mmol/L= $(2HbA_{1c} - 29) \div 11$
- for HbA_{1c} in %,
  prep BGL mmol/L = $2HbA_{1c} - 7$.

Self-BGM schedules for type 2 diabetes

A full schedule of self-BGM includes tests before and after each meal, in the middle of the night (to check for hypoglycaemia) and a quality control (to check the meter). Not surprisingly, few people will do eight blood glucose tests a day. In practice, the best self-BGM schedule is one that:

- is practical and acceptable to the patient
- will provide you with the information you need to assess glycaemic control and to identify what changes in management are needed.

For the patient, the less BGM the better – for the reasons given in Box 5.[10] Many people only test their BGL when they feel they might be hyper- or hypoglycaemic. The Australian Diabetes Society and Diabetes Australia recommend that those on medication that could cause hypoglycaemia (i.e. sulfonylureas or insulin) should always test their BGL before and every two hours when driving (so they know they are 'above 5 to drive').[11] A handout for patients providing advice on how to perform self-BGM is provided.

For the doctor, patient self-BGM to determine the preprandial BGL pattern in the week before being seen is considered sufficient. If three BGL tests a day are too many for the patient to perform then two tests at different times of the day on different days of the week may be enough. If only one BGL test a day is acceptable to the patient then the information could be collected over two weeks. The priority for self-BGM is to test before breakfast first, then before the evening meal and lastly before lunch. Some patients get satisfaction from and/or a feeling of being in control by testing three or more times a day, even though their results will be consistently 4 to 7 mmol/L and require no management change. On the other hand, some

4. HBA_{1c} AND BGL: USEFUL EQUATIONS[9]

HbA_{1c} % versus mmol/mol

When the HbA_{1c} % is 4%, the HbA_{1c} mmol/mol is 20 mmol/mol. For every 1% increase or decrease in the HbA_{1c} % above or below 4%, the HbA_{1c} mmol/mol increases or decreases by 11 mmol/mol.

Hence the equations to convert one to the other are:

$$HbA_{1c} \text{ mmol/mol} = 11(HbA_{1c}\ \% - 4) + 20$$

and

$$HbA_{1c}\ \% = (HbA_{1c} \text{ mmol/mol} + 24) \div 11$$

For example, at an HbA_{1c} of 42 mmol/mol, the HbA_{1c} % will be:

$$(42 + 24) \div 11 = 6\%$$

And at an HbA_{1c} of 7%, the HbA_{1c} mmol/mol will be:

$$11(7 - 4) + 20 = 53 \text{ mmol/mol}$$

HbA_{1c} mmol/mol and % and fasting BGL

The strong correlation between HbA_{1c} (an index of the average BGLs over the preceding weeks to months) and BGL means it is possible to derive the average BGL over the period from the HbA_{1c} level.

This estimated average glucose (eAG) can be calculated using the formula eAG = $(1.6 \times HbA_{1c}\ \%) - 2.6$ mmol/L[7]

The simpler formula $2HbA_{1c}\ \% - 6$ may be used.
The corresponding formula for HbA_{1c} in mmol/mol is $(2HbA_{1c} \text{ mmol/mol} - 18) \div 11$

Online calculators are available to determine eAG from HbA_{1c} in % or mmol/mol (e.g. www.diabetes.co.uk/hba1c-to-blood-sugar-level-converter.html). However, many laboratories now report eAG in addition to HbA_{1c}.

Fasting BGL targets can be derived from an individual's target HbA_{1c}. As the fasting BGL is generally 1 mmol/mol lower than the average BGL, the simplified formula for deriving average fasting BGL from HbA_{1c} % becomes $2HbA_{1c}\ \% - 7$. The corresponding formula for HbA_{1c} in mmol/mol is $(2HbA_{1c} - 29) \div 11$

For example, the general HbA_{1c} target of <53 mmol/mol (<7%) would require a preprandial BGL target of 7 mmol/L with an expected range of ±2.1 mmol/L (4.9 to 9.1; ±30%).

Abbreviations: BGL = blood glucose level; BGM = blood glucose monitoring; HbA_{1c} = glycosylated haemoglobin.

patients will 'forget' to complete their self-BGM recording book, or when the BGM results in the meter's memory are reviewed it may be noted that there are results in the meter but not in the book, or vice versa.

If the self-BGM schedule is not satisfactory for the patient and/or the doctor, it should be discussed; it is usually possible to find a schedule that is acceptable to the patient and clinically useful to the health professional.

Assessing self-BGM records

A five-step approach to assessing a patient's self-BGM results is described below and summarised in Boxes 6 and 7. An example of its application is given in the case study in Box 8.

Assess the variability of preprandial BGL results

The least variable BGL values are the fasting values, i.e. those measured before breakfast. If more than 20% of the recorded fasting values lie outside ± 30% of the mean (the percentage expected from the usual variability for fasting BGL, see above), it is difficult to work out what action to take. For example, if seven results over a week range between 3.1 and 12.5 mmol/L (mean 7.5 mmol/L) and the patient is taking a sulfonylurea or insulin then increasing the medication to control the overall excess glycaemia may cause hypoglycaemia. In any event, it is likely that the meter is not working properly and/or the user is not performing the test correctly.

Alternatively, the patient's insulin injection technique may be incorrect (e.g. not injecting into the subcutaneous fat and/or not rotating injection sites or rotating only within limited areas).[12] Referral of patients to a Certified Diabetes Educator may be helpful to identify patients' self-BGM or injection problems and then resolve them.

Assess self-BGM accuracy and variability

The self-BGM and laboratory values of BGL tests performed over a short period of time should be compared (Box 8). These checks should be performed regularly (e.g. each year) and when the patient changes their blood glucose meter.

Assess the relationship between fasting BGL results and a recent HbA_{1c} result

The average fasting BGL should approximate the value calculated from the HbA_{1c} (see above). If the average value differs from the predicted value by more than ±30%, it is likely that either or both of the BGL or HbA_{1c} results are erroneous. Referral of patients to a Certified Diabetes Educator and/or to the testing laboratory may be useful to identify the cause(s) of the error. Alternatively, 'hidden' hyper- or hypoglycaemia may be occurring at times when BGL testing is not performed, which would explain the discrepancy (e.g. after the evening meal; during the night).

5. SELF-BGM: PATIENT BARRIERS[10]

- Patients may not understand why they are monitoring their BGLs
- Some health professionals may not review and/or discuss the results of monitoring
- Self-monitoring of blood glucose may be intrusive and/or embarrassing

Abbreviations: BGL = blood glucose level; BGM = blood glucose monitoring.

6. STEPS IN ASSESSING RESULTS OF SELF-BGM

1. Assess the variability of fasting BGL results from self-BGM
2. Assess self-BGM accuracy and variability (self-BGM versus laboratory results – see Box 7)
3. Compare average preprandial BGL results with the value predicted by the HbA_{1c}
4. Assess whether preprandial BGL results are on target
5. Assess whether HbA_{1c} is on target

Abbreviations: BGL = blood glucose level; BGM = blood glucose monitoring; HbA_{1c} = glycosylated haemoglobin.

7. SELF-BGM: CHECKING ACCURACY AND VARIABILITY[4-6]

- The patient should fast overnight and take their blood glucose monitoring equipment to the specimen collection centre. They should measure the level of their blood glucose immediately (within minutes) before and after venesection
- Accuracy is assessed by comparing the mean of the BGL values the patient has measured with the laboratory BGL value (the mean patient BGL should lie within ±20% of the laboratory value)
- Variability is assessed by measuring the distance of the BGM results from their mean (results should lie within ±30% of their mean value [i.e. $2CV_m$])

Abbreviations: BGL = blood glucose level; BGM = blood glucose monitoring.

Assess whether preprandial BGL values are on target

If a patient's preprandial BGL values are not on target, lifestyle and/or hypoglycaemic medication may need to be reviewed.

If preprandial BGLs are on target, assess whether the HbA_{1c} is also on target

If both preprandial BGLs and the HbA_{1c} are on target, a time should be arranged with the patient for their next review. If the targets are not being met, the patient may be experiencing 'hidden' hyperglycaemia that should be identified and addressed.

8. CASE STUDY

Dylan is 67 years old and has had diabetes for 18 years. He is taking 45 units of basal analogue insulin at night, modified release gliclazide 120 mg in the morning and metformin 1 g before his morning and evening meals. His HbA_{1c} is 62 mmol/mol (7.8%). His record of his self-BGM results over the preceding week is reviewed (Table).

How do you interpret Dylan's results and what action do you suggest?

TABLE. DYLAN'S SELF-BGM RESULTS

Day	BGL (mmol/L)						
	Breakfast		Lunch		Tea		Tests at other times*
	Before	After	Before	After	Before	After	
Mon				7.3			12.1
Tues	5.1				11.8	9.1	
Wed		19.7	6.4				13.4
Thurs	14.2			17.4		21.4	
Fri		9.6	8.7				
Sat	12.3				5.8		8.3
Sun	10.9			9.1			

* Before bed.
Abbreviations: BGL = blood glucose level; BGM = blood glucose monitoring; HbA_{1c} = glycosylated haemoglobin.

Interpretation

There is no pattern to Dylan's self-BGM. There are preprandial and postprandial BGL values but there is no point in checking postprandial BGL until the preprandial BGL is under control. (If the preprandial BGL is high, the postprandial BGL will also be high.) The preprandial BGL values are therefore the only ones you need to be interested in here (particularly the fasting – i.e. pre-breakfast – values). Dylan has only performed four BGL measurements before breakfast, but even this limited number shows excess variability from the mean value of 10.6 mmol/L: the Tuesday and Thursday readings of 5.1 and 14.2 are outside the range of 7.4 to 13.8 (mean fasting BGL ±30%).

Action

- Discuss Dylan's self-BGM schedule and find one that is acceptable to him and will be useful to you.
- Refer Dylan to a Certified Diabetes Educator to review his BGM and insulin injection techniques.
- After Dylan has seen the educator, check the accuracy of his self-BGM (compare his fasting BGL value with the laboratory value).
- Arrange to see Dylan two weeks after this to review his results.

Case continued

Dylan's fasting BGL results immediately before and after the venesection were 8.8 and 11.8 mmol/L and the laboratory value was 8.9 mmol/L. His average preprandial BGL values before breakfast, lunch and tea were 8.2, 9.4 and 10.1 mmol/L respectively.

How do you interpret Dylan's BGL results and what action do you suggest?

Interpretation

On checking the accuracy of Dylan's self-BGM, the average of his measurements is 10.3 mmol/L, which is well within ±20% of the laboratory value of 8.9 mmol/L (i.e. 7.1 to 10.7). The two individual BGL values lie within ±30% of their average of 10.3 mmol/L (7.2 to 13.4).

From Dylan's preprandial BGL profile, his average preprandial BGL of 9.2 mmol/L is close to the value predicted by the HbA_{1c} of 62 mmol/mol (7.8%), i.e. 8.6 mmol/L (from [$2HbA_{1c}$ mmol/mol – 29] ÷ 11 or $2HbA_{1c}$% – 7). The HbA_{1c} of 62 mmol/mol (7.8%) is above the Australian Diabetes Society general recommendation of <53 mmol/mol (<7%).

Action

Dylan should increase his basal insulin (e.g. by 10%, from 45 to 50 units). You should arrange to recheck Dylan's blood glucose profile in two to three weeks' time.

SUMMARY

Patients' self-monitoring of their BGLs can help in reviewing glycaemic control and identifying ways to improve it. However, although blood glucose meters have improved greatly since their introduction in the 1980s, they are still associated with system and user problems that can affect the accuracy and variability of their results. For example, BGM performed on different days at the same time of day by the same user and using the same meter can produce considerably varying results, with 80% of BGLs lying within ±30% for fasting values and ±36% for postprandial values.

A suitable self-BGM schedule is one that is acceptable to and practical for the patient and is clinically useful to the doctor (usually preprandial blood glucose values in the week preceding a consultation). A stepped approach to assessing patients' self-BGM records can be useful, and should include checking the variability and accuracy of the results and whether preprandial BGLs and HbA_{1c} are on target. MT

References

A list of references is included in the website version (www.medicinetoday.com.au) and the iPad app version of this article.

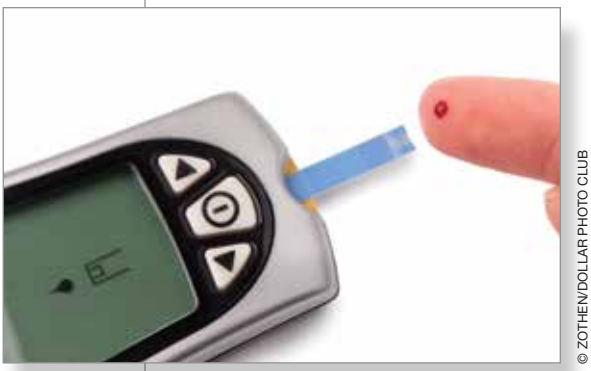
COMPETING INTERESTS: Dr Phillips has received research and travel grants, acted on advisory boards and been involved with clinical trials and seminars sponsored by a range of pharmaceutical companies. He does not think these associations have influenced the content of this article.

Blood glucose monitoring: a user's guide

This handout provides advice on self-monitoring of blood glucose for people with diabetes.

Prepared by Dr Pat Phillips, Consultant Endocrinologist at the Queen Elizabeth Specialist Centre, Adelaide, SA.

The blood glucose monitoring (BGM) system used for self-monitoring of blood glucose levels (self-BGM) comprises a blood glucose meter, a lancet device, blood glucose testing strips and quality control fluid.



How the meter works

The blood glucose meter measures the amount of glucose in the blood you have put on the testing strip. A chemical reaction occurs between the glucose and a chemical in the strip, generating a signal that the meter converts into the reading displayed on the screen (Figure below). The meter is set up so that it gives a blood glucose value that is the same as a laboratory would determine from a blood sample taken from one of your veins.

Meters need to be adjusted (calibrated) for different batches of strips – some do this automatically and others require you to re-set the meter with a calibration strip.

Blood sample → **Blood glucose testing strip** → **Chemical reaction** → **Signal** → **Blood glucose meter** → **Result displayed**

Figure. The stages of blood glucose level measurement.

Obtaining the best results

The chemical reaction between the glucose and the chemicals in the strip can be affected by storage, temperature, some medications and interfering substances on your finger. This can affect the blood glucose reading given by the meter.

To obtain accurate results, make sure your meter, strips and blood glucose monitoring technique are all in good shape. The Box on the next page provides some tips for testing.

You can check that the results of your self-BGM are accurate in three different ways:

- **Test/re-test**
  Measure your blood glucose level and then re-measure it with a different blood sample and a new strip. The two values should lie within 30% of each other.

- **Quality control**
  Use the quality control fluid on the strip in place of your blood. This fluid is known to have a certain blood glucose value and you can compare this with the meter reading.
- **Self-BGM versus laboratory result**
  Your doctor can arrange for you to have a laboratory blood glucose test (this is best performed before breakfast, when your blood glucose will be at its lowest level and it is most important that it is measured accurately). If you measure your blood glucose level using your meter immediately (i.e. within minutes) before and again after the blood sample is taken for the laboratory test, you and your doctor can compare your two values with the laboratory value, as well as with each other.

Self-BGM schedules

A full schedule for self-BGM includes tests performed before and two hours after each meal and during the night as well a quality control check. Fortunately this full schedule is rarely needed. You are doing the tests to help you and your diabetes professionals modify your lifestyle and medication; you are not doing them just to fill out the spaces in your BGM record.

- **BGM for you**
  You may want to measure your blood glucose level if you feel 'funny' (a possible indicator of a low blood glucose level) or unwell (a possible indicator of a high blood glucose level). If you take insulin or sulfonylurea tablets, you should always test your blood glucose before you drive and every two hours while driving because these medications may cause you to have low levels (hypoglycaemia). Diabetes Australia recommends 'You need to be above 5 to drive' – i.e. your BGL is over 5 mmol/L.
- **BGM for your professionals**
  The healthcare professionals looking after you like to see a record of your BGM results over the last week or so, particularly the blood glucose levels before meals. They can then advise you on changes to your medication and/or lifestyle. If you think you may be testing too often or not enough, talk to your diabetes professionals and work out a schedule that will provide them with all the information they need.

Getting help

Your doctor and/or Diabetes Nurse Educator can advise you on getting the most out of your self-BGM. The National Diabetes Services Scheme (NDSS) is free and gives you access to subsidised blood glucose testing strips without a doctor's prescription. To join, visit the NDSS website (www.ndss.com.au). MT

10 TIPS FOR TESTING – SELF-BLOOD GLUCOSE MONITORING

1. Look after your glucose meter. Clean it often and don't leave it in bright light, including sunlight, or in the car.
2. If needed, calibrate the meter each time a new pack of blood glucose testing strips is started. Check the meter's accuracy regularly.
3. Note the expiry dates on the strips and quality control fluid, and discard them after that date.
4. Protect the strips from heat, bright light and high humidity. Keep them in the bottle or foil packets until you use them. Don't leave them in the sun or the car.
5. Always wash your hands with soap and warm water before you do a test. This makes it easier to get a blood sample and removes any substances that might affect the blood glucose reading.
6. Use a fresh lancet each time – for hygiene and to reduce pain and tissue damage. Dispose of used lancets in a sharps container.
7. Use the recommended amount of blood on the strip. Drip the blood on to the strip – don't smear it.
8. Record the meter readings so you and your diabetes professionals can clearly see the pattern in your blood glucose levels over time.
9. Check your blood glucose levels more often when you are unwell, when you get an unexpected reading and, if you are taking insulin or a sulfonylurea, every time you drive.
10. Join the National Diabetes Services Scheme to buy subsidised strips.

COPY FOR YOUR PATIENTS

MedicineToday 2015; 16(8): 44-50

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