ARTICLE

Blood glucose monitoring devices: current considerations

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SUMMARY

Measuring blood glucose concentrations via capillary (fingerprick) blood glucose monitoring or continuous (interstitial) glucose monitoring is an important aspect of management for many people with diabetes.

Blood glucose monitoring informs patient self-management strategies, which can improve the patient's engagement in their own care and reduce barriers to achieving recommended blood glucose targets. Blood glucose monitoring also informs clinician-guided management plans.

Compared to capillary blood glucose monitoring, continuous glucose monitoring in people using insulin significantly improves glycaemic metrics and is associated with improved patient-reported outcomes.

Even with good glycaemic metrics, patients using continuous glucose monitoring should still have access to capillary blood glucose monitoring for correlation of hypoglycaemic readings when accuracy may be compromised or if there is a malfunction with the continuous blood glucose monitor.

Introduction

Diabetes is a burgeoning condition affecting nearly 1.3 million people in Australia.[1] Type 1 diabetes, characterised by insulin deficiency, requires insulin therapy via multiple daily injections or an insulin pump. Type 2 diabetes, underpinned by insulin resistance, is managed with lifestyle interventions and, for most people, medications. Other forms of diabetes, including gestational diabetes, drug-induced diabetes and type 3c diabetes (exocrine pancreatic insufficiency), may also be encountered regularly in general practice. Achieving glycaemic targets is critical in reducing the risk of diabetes-related complications, which have significant negative impacts on the health and wellbeing of people living with diabetes.

Blood glucose monitoring

Blood glucose monitoring is useful for many people with diabetes. To gain the most benefit from blood glucose monitoring, the information gathered should be used to inform positive lifestyle adaptations and to direct self- and clinician-guided management.

Current Australian guidelines recommend that all patients using insulin and sulfonylureas monitor their blood glucose concentrations.[2,3] Other people do not require routine blood glucose monitoring, other than during pregnancy, although monitoring in the setting of dietary changes, changes to physical activity or drug therapy,[4] or if glycaemic metrics are not at target, may be informative. Blood glucose monitoring may also be beneficial before elective surgery or fitness-to-drive assessments, to establish patterns and ensure measurements are within target.

Common times for people to measure their blood glucose concentrations include before meals, before bed, before exercise, if symptoms of hypoglycaemia arise, and before driving or performing other high-risk activities.[3] Additional monitoring may be appropriate and the frequency is individualised.

A meta-analysis including people with non–insulin-treated type 2 diabetes showed that blood glucose monitoring is associated with a reduction in glycated haemoglobin by 0.3%,[5] particularly if it is started at diagnosis[6] and is frequent (between 8 and 14 times per week).[7] However, another analysis identified that this benefit is limited to the first 6 months of monitoring.[8]

The selection of a blood glucose monitoring device should be based on individual health and lifestyle circumstances, personal preferences, the operator's skill level and any concurrent treatment. Either capillary (fingerprick) blood glucose monitoring or continuous (interstitial) glucose monitoring devices can be used.

Capillary blood glucose monitoring

Capillary (fingerprick) blood glucose monitors (glucometers) determine blood glucose concentrations by measuring an electric current generated by a glucose reaction with reagents on the electrode of the measuring strip. The current generated is proportional to the glucose concentration in the sample.[9]

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Types of capillary blood glucose monitors

There are more than 20 models of capillary blood glucose monitors available in Australia (Table 1). People registered with the National Diabetes Service Scheme are eligible to receive a free monitor to best match their needs, via a diabetes educator or the manufacturer.

Accuracy of capillary blood glucose monitors

The Therapeutic Goods Administration requires capillary blood glucose monitors to meet strict accuracy standards set by the International Organization for Standardization (ISO 15197:2013).[10] Ninety-five percent of blood glucose measurements must be within 15% of a laboratory result for blood glucose concentrations 5.5 mmol/L or more, and 95% of blood glucose measurements must be within 0.83 mmol/L of a laboratory result for blood glucose concentrations less than 5.5 mmol/L. Table 2 identifies a potential range for capillary glucose measurements if using a glucometer with the minimum accuracy required.

Independent international studies have shown variable postmarketing accuracy of capillary blood glucose monitors, with up to 50% not meeting current standards. Newer blood glucose monitors have significantly improved accuracy.[11,12]

Table 1 Capillary blood glucose monitors available in Australia in 2023 by key functionality

Key functionality	Brands of capillary blood glucose monitors	Comments
ketone testing	FreeStyle Optium Neo, FreeStyle Libre 2, LifeSmart TwoPlus, GlucoKey Connect, CareSens N Premier, CareSens Dual	
insulin bolus calculator on meter	FreeStyle InsuLinx, FreeStyle Libre 2	easy (fixed meal-time bolus dose with correction factors) or advanced (carbohydrate counting with correction factors)
	FreeStyle Optium Neo	easy (fixed meal-time bolus dose with correction factors) only
Bluetooth data sync with paired smartphone application	FreeStyle Libre 2	LibreLink app
	OneTouch Verio Flex	One Touch Reveal Mobile app
	Contour Next Link, Contour Next, Contour Next Link 2.4	Contour Diabetes app
	LifeSmart TwoPlus	LifeSmart Sugar Cheq app—requires a separate Bluetooth dongle to connect
	GlucoKey Connect	GlucoKey app
	CareSens N Premier, CareSens Dual	SmartLog app
	Accu-chek Guide Me, Accu-Chek Guide	MySugr app
	Rightest GM700SB	Rightest CARE app
	True Metrix Air	True Manager Air app
insulin dose logging	FreeStyle Optium Neo	on reader
	FreeStyle Libre 2	via LibreLink app or on reader after insulin bolus calculator use
	Contour Next Link, Contour Next, Contour Next Link 2.4	via Contour Diabetes app
	CareSens N, CareSens N POP, CareSens N Voice, CareSens N Premier, CareSens Dual	via SmartLog app
	Accu-chek Guide Me, Accu-Chek Guide	via MySugr app
	Rightest GM700SB	via Rightest CARE app
includes aids for vision-impaired people	FreeStyle Libre 2	text to speech function on LibreLink app
	CareSens N Voice	text to speech and large textured buttons
small size	Contour Next Link 2.4, True Metrix GO	
other available blood glucose monitors	FreeStyle Lite, FreeStyle Freedom Lite, GluNEO, Rightest GM700S, Accu-Chek Instant S	
	Accu-chek Guide Link	pairs with Medtronic insulin pumps

Table 2 Acceptable accuracy of capillary blood glucose monitors

Laboratory blood glucose concentrations	Required blood glucose concentrations for capillary blood glucose monitors [NB1]
5 mmol/L	95% between 4.2 and 5.8 mmol/L
7 mmol/L	95% between 6.0 and 8.0 mmol/L
10 mmol/L	95% between 8.5 and 11.5 mmol/L
20 mmol/L	95% between 17 and 23 mmol/L

NB1: Minimum accuracy for blood glucose monitors is set by the International Organization for Standardization (ISO 15197:2013).[10]

Table 3 Factors influencing the accuracy of blood glucose monitoring

Type of factors	Factors
human	storage finger preparation technique
meter-specific	inherent accuracy maintenance
test strip-specific	inter-strip variance storage and expiry
environmental	altitude humidity temperature
physiological	haematocrit partial pressure of oxygen hypertriglyceridaemia hyperbilirubinaemia
drugs [NB1]	paracetamol [NB2] intravenous vitamin C levodopa mannitol icodextrin

NB1: All listed drugs can cause false elevations or blood glucose monitor error at increasing drug concentrations.
NB2: It is unlikely that paracetamol at therapeutic concentrations would cause significant falsely elevated blood glucose concentrations.

All blood glucose monitors have a lower (0.6–1.2 mmol/L) and upper (27.8–33.3 mmol/L) threshold between which a glucose result is measurable. Measurements outside this range are identified with 'Lo' or 'Hi'.

Several factors can interfere with the accuracy of blood glucose monitoring (see Table 3). Newer blood glucose monitors tend to use a different reagent (glucose dehydrogenase, with or without a cofactor, rather than glucose oxidase). This reduces the susceptibility to interference from haematocrit, the partial pressure of oxygen, and most drugs (aside from icodextrin, a non–glucose-containing peritoneal dialysate).[13]

If the blood glucose concentration is rapidly changing, the blood sample should only be taken from the fingertip; alternative sites to the fingertip are not recommended in this setting.

Calibration of blood glucose monitors is performed by undertaking a standard glucose test using a meter-specific control solution to confirm meter accuracy. There is no requirement to routinely calibrate personal blood glucose monitors, although some manufacturers recommend calibration to be performed with each new packet of testing strips. Calibration is also recommended if the blood glucose monitor gets wet, is dropped or damaged, or if the battery has been changed.

Factors affecting choice of capillary blood glucose monitors

Identifying a capillary blood glucose monitor that meets the individualised needs for each patient reduces barriers to appropriate glucose monitoring, providing opportunities for effective self- or clinician-guided dose adjustments. To determine the most appropriate capillary blood glucose monitor for people with diabetes, consider the following:

- size of the device
- screen font size
- ease of test strip and lancet use
- capability to link to smart phone applications via Bluetooth, with automatic glucose data synchronisation
- insulin bolus calculator function
- ketone monitoring capacity.

Table 1 lists currently available capillary blood glucose monitors in Australia by key functionality.

Continuous glucose monitoring

Continuous (interstitial) glucose monitors determine blood glucose concentrations via a sensor inserted under the skin. The sensor measures electric currents in the interstitial fluid, which are proportional to the blood glucose concentration. The transmitter sends glucose data to a receiver (smartphone application, device or insulin pump), which displays the data.

Types of continuous glucose monitors

There are two types of continuous glucose monitoring:

- **real-time monitoring**—blood glucose data are transmitted to the user's device every 1–5 minutes (Dexcom G6, Medtronic Guardian 3, Medtronic Guardian 4)
- **intermittently scanned (flash) monitoring**—blood glucose data are only stored when the sensor is scanned by a smartphone application or a device (FreeStyle Libre 2). A complete glycaemic picture is available if the FreeStyle Libre sensor is scanned every 8 hours.

Continuous glucose monitors are worn by the person continuously for 7–14 days (see Table 4 for specific duration per device). They do not need to be removed for any usual daily activities (i.e. showering, sports including swimming).

Other important features of continuous glucose monitors include the presence of customisable alerts, sensor and transmitter sizes, sensor wear time, capacity to share data with caregivers, and calibration requirements (Table 4 outlines these features for each device). Medtronic Guardian 3 is the only continuous glucose monitor that requires calibration; capillary blood glucose measurement is required at least every 12 hours.

Easy-to-generate reports providing a standardised ambulatory glucose profile and relevant glycaemic metrics are essential for clinician and patient review.

Benefits and indications for use of continuous glucose monitors

Compared to capillary blood glucose monitoring, real-time continuous glucose monitoring has been shown to consistently improve glycaemic metrics in children,[14] adolescents[15] and adults,[16] including older adults,[17] with type 1 diabetes. In pivotal trials, glycated haemoglobin concentrations typically decreased by 0.4–0.6%, the time in target range (3.9–10 mmol/L) increased by 60–100 minutes/day, and the time below target range decreased by 10–45 minutes/day.[18] Similar results have been found in trials comparing intermittently scanned (flash) monitoring with capillary blood glucose monitoring.[18,19]

Table 4 Properties of standalone continuous glucose monitors available in Australia in 2023

	FreeStyle Libre 2	Dexcom G6	Medtronic Guardian 3	Medtronic Guardian 4
Sensor and transmitter in one device	yes	no	no	no
Sensor warm-up time	1 hour	2 hours	2 hours	2 hours
Calibration	not required	not routinely required [NB1]	required every 12 hours	not routinely required [NB1]
Alerts (specific changes that prompt an alert to the patient)	blood glucose above or below customisable target range	blood glucose above or below customisable target range blood glucose urgently low (less than 3.1 mmol/L) [NB2] blood glucose predicted to be urgently low within 20 minutes blood glucose rising or falling rapidly	blood glucose above or below customisable target range blood glucose predicted to be above or below target range soon (customised timeframe and range) blood glucose urgently low (less than 3.1 mmol/L) [NB2] blood glucose rising or falling rapidly	blood glucose above or below customisable target range blood glucose predicted to be above or below target range soon (customised timeframe and range) blood glucose urgently low (less than 3.1 mmol/L) [NB2] blood glucose rising or falling rapidly
Sensor wear time	14 days	10 days	7 days	7 days
Transmitter life	14 days	90 days	1 year, rechargeable	1 year, rechargeable
Smartphone application	LibreLink	Dexcom Follow	Guardian Connect	Guardian Connect
Interfering substances	intravenous vitamin C (false elevation)	hydroxycarbamide (hydroxyurea) (false elevation)	paracetamol [NB3], hydroxycarbamide (hydroxyurea) (false elevation)	paracetamol [NB3], hydroxycarbamide (hydroxyurea) (false elevation)

NB1: Calibration can be performed if a particular sensor is suspected to be inaccurate.
NB2: The 'urgently low' alert can't be turned off.
NB3: It is unlikely that paracetamol at therapeutic concentrations would cause significant falsely elevated glucose concentrations.

Greater engagement with data provided by continuous glucose monitoring correlates with improved glycaemic metrics.[20-22] Real-world studies show that this benefit is sustained for at least 12 months in people with type 2 diabetes and 24 months in people with type 1 diabetes.[23]

Continuous glucose monitoring for adults with type 2 diabetes (both those using and not using insulin)[24,25] also achieves improved glycated haemoglobin concentrations without impacting the rate of hypoglycaemia.

Continuous glucose monitoring helps people identify immediate glucose excursions related to life events such as eating, exercise, alcohol consumption and insulin administration, allowing for the self-modification of lifestyle and diabetes management behaviours. Using continuous glucose monitoring with self-evaluation improves glycaemic metrics.[22] Diabetes-specific patient-reported outcomes (fear of hypoglycaemia, diabetes distress)[26] and treatment satisfaction[27] also improve with continuous glucose monitoring.

Guidelines recommend continuous glucose monitors are offered to all patients with type 1 or type 2 diabetes using multiple daily injections or insulin pump therapy who are capable (or whose caregiver is capable) of using the device.[4]

In 2017, the Australian Government fully funded continuous glucose monitoring products for people younger than 21 years of age with type 1 diabetes. This led to an increase in continuous glucose monitoring use from approximately 5% to 79% among this cohort.[28] This scheme expanded in 2020 to include people with concessional status, people who are pregnant or planning pregnancy, and people identified as Aboriginal and Torres Strait Islander. In July 2022, the subsidy was further expanded to partially fund ($32.50 monthly copayment) access for people with type 1 diabetes who do not meet other criteria.[29] FreeStyle Libre 2 sensors can be purchased for $102 each and are the most affordable continuous glucose monitoring option for people not eligible for subsidised access. People with type 2 diabetes are not eligible for subsidised access.

Accuracy of continuous glucose monitors

The mean absolute relative difference (MARD) is used to compare the difference between continuous glucose monitoring and capillary blood glucose monitoring measurements.[30] Devices with a MARD less than 10% are considered safe to guide insulin dosing without confirmatory capillary blood glucose monitoring.[31]

Given a short lag (5–20 minutes) between capillary and interstitial fluid glucose concentrations, the accuracy of continuous glucose monitoring is more limited in the setting of rapidly changing glucose concentrations, rapid fluid shifts (i.e. dialysis) and significant hypoglycaemia. Medtronic Guardian 3, Medtronic Guardian 4 and Dexcom 6 are not recommended for people taking hydroxycarbamide (hydroxyurea), which can cause falsely elevated glucose readings.[32] People using continuous glucose monitoring should always have access to capillary blood glucose monitoring for correlation of hypoglycaemia; this is useful when symptoms are not aligned with continuous blood glucose monitor measurements, when accuracy may be compromised or if there is a malfunction of the continuous blood glucose monitor.

Pairing continuous glucose monitors with insulin pumps

Automated insulin delivery systems consist of a continuous glucose monitor with a Bluetooth-connected insulin pump. A software algorithm adjusts insulin delivery in response to real-time continuous glucose monitoring data.

Low-glucose-suspend systems predict hypoglycaemia, alert the patient with an alarm, and reduce or stop basal insulin delivery to prevent hypoglycaemia. In Australia, the available low-glucose-suspend systems include:

- Medtronic Guardian 3 pairing with Medtronic 640G
- Dexcom G6 pairing with Tandem t:slim X2 Basal IQ.

Hybrid closed-loop systems provide adaptive basal insulin delivery with or without automated microbolus doses to minimise hypoglycaemia and hyperglycaemia. In Australia, the available hybrid closed-loop systems include:

- Dexcom G6 pairing with the Tandem t:slim X2 Control IQ or Ypsomed CamAPS FX
- Medtronic Guardian 3 pairing with various Medtronic 670G, 770G or 780G and Medtronic Guardian 4 pairing with Medtronic 780G.

FreeStyle Libre 2 does not pair with any insulin pump.

Both generation 1 low-glucose-suspend[33] and generation 2 hybrid closed-loop systems improve glycated haemoglobin concentrations, the time in target range and the time below target range in children, adolescents[34] and adults.[35-37]

Conclusion

Identifying and using the most appropriate blood glucose monitoring device can minimise barriers to blood glucose monitoring. This provides an opportunity for self-guided behaviour and treatment modulation and informs clinician-guided

recommendations to optimise diabetes outcomes. Continuous glucose monitoring should be considered for all people with type 1 diabetes (subsidised) and people with type 2 diabetes using multiple daily injections (non-subsidised). Continuous glucose monitoring technology can improve diabetes-related patient-reported outcomes in addition to glycaemic outcomes. <

Conflicts of interest: none declared

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