Northumbria Research Link

Blood Glucose Monitoring in Diabetes Mellitus

Written by

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This article will:

- Introduce Type 1 and 2 Diabetes Mellitus
- Support your understanding of how the human body regulates blood glucose
- Identify correct blood glucose ranges and those which may give cause for concern
- Give rationale to the importance of blood glucose monitoring as a fundamental procedure for people living with diabetes
- Recognise how to measure blood glucose accurately
- Provide a 'how to' guide on monitoring blood glucose using a glucometer
- Gain insight into self-monitoring of blood glucose and developing technologies
- Use contemporary evidence-based practice to underpin blood glucose monitoring practice

Diabetes Mellitus:

Diabetes Mellitus is a condition that results in elevated blood glucose levels (hyperglycaemia); continued elevation can contribute to progressive micro and macro vascular complications leading to renal, nerve and ocular damage, representing a significant contributor to morbidity and mortality (Bilous, Donnelly & Williams, 2010). 463 million people world-wide are living with diabetes mellitus; the UK population prevalence is 5.6% in adults aged 20-79 years (IDF, 2019). The estimated population prevalence of diagnosed and undiagnosed cases in England is approximately 8.5%; (PHE, 2020). Currently there are over 3.8 million people diagnosed with diabetes in the UK; approximately 1/15 people have diabetes. Over a million people are unaware they have the disease (Diabetes UK, 2019)

Type 1 Diabetes Mellitus (T1DM) and other, rarer sub-types represent approximately 10% of cases. The origin of the condition being autoimmune in nature, arising from the complete destruction of insulin secreting beta cells within the pancreas. Type 2 diabetes Mellitus (T2DM) accounts for the remaining 90% of cases and results from the reduced effective action of insulin. This eventually leads to insufficient levels of insulin production, needed to sustain appropriate blood glucose levels. T2DM is caused by a combination of genetic and ethnic predispositions, but predominantly lifestyle factors such as obesity and lack of physical exercise. Incidence is further correlated with increasing age (Holt, Kumar & Watkins, 2015).

Gestational diabetes mellitus (GDM) manifests with a degree of glucose intolerance with onset or first recognition in pregnancy. Individuals affected by GDM have an increased risk of developing type 2 diabetes after pregnancy (Buchanan *et al,* 2007).

There are several rarer subtypes of diabetes outside T1DM, T2DM and GDM, including but not limited to genetic defects leading to diabetes, idiopathic diabetes (presenting with no underlying autoimmune cause), endocrinopathies, or drug and chemical induced diabetes. For these reasons, and the potentially mixed picture of diagnosis, it is less important to label the type of diabetes than it is to understand the mechanisms and importance of hyper and hypo glycaemia and treat accordingly (American Diabetes Association, 2013).

Rationale:

The measurement of blood glucose provides information on the effectiveness of blood glucose metabolism and guides interventions to achieve optimal glucose control within the body.

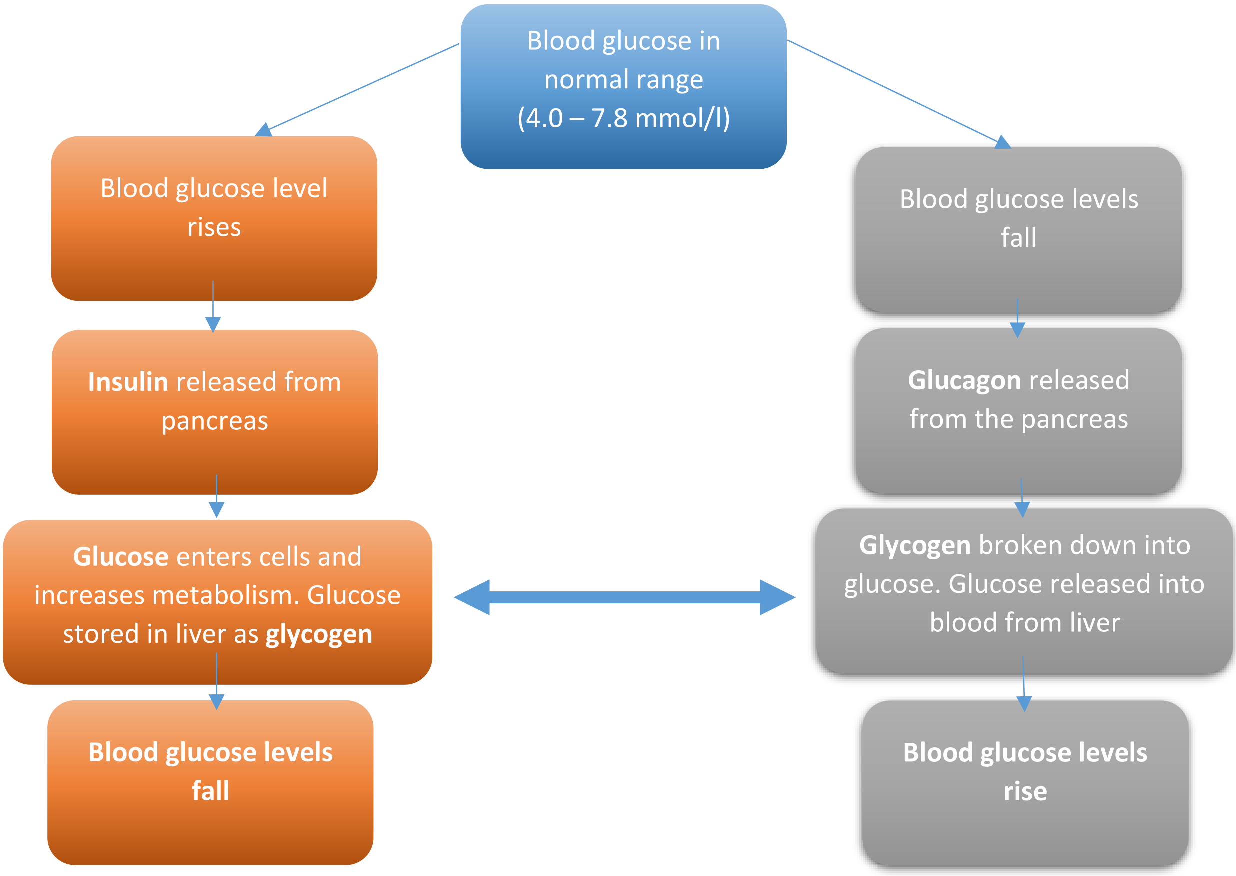
Glucose is a monosaccharide and is an essential fuel for the brain and other body cells formed as an end product of carbohydrate digestion (Maughan, 2008). Glucose is either metabolised to produce energy or is stored in the muscles and liver as glycogen. Changes in glucose level after absorption of carbohydrate is termed the ‘glycaemic response’ (Sanders, 2016; Maughan, 2008). Regulation of normal glucose metabolism is shown in Figure 1.

The measurement of blood glucose is a key self-care activity for people with diabetes and has been shown to positively correlate with improved long –term glycaemic control (Shaji *et al* 2013; Shrivastava, Shrivastava and Ramasamy, 2013) and can function as a cue to action in diabetes self-management (Brackney, 2018).

The measurement of blood glucose is an essential component of care for individuals:

- With T1DM and T2DM
- People with diabetes who have recently commenced or changed dosages of medication to increase insulin levels
- People with diabetes undergoing surgery
- People who are acutely sick
- In an emergency where consciousness level may be affected by low blood glucose (adapted from Delves-Yates, 2018a)

Figure 1: Regulation of normal glucose metabolism



Reference: Adapted from Boore *et al*, (2018)

Learning Point:

Type 1 diabetes results in an absolute absence of insulin therefore blood glucose levels continue to rise because glucose cannot enter cells to be metabolised and produce energy; excess glucose cannot be stored as glycogen. These individuals require insulin injections every day.

Type 2 diabetes causes cells to be less responsive to insulin and/or reduces insulin production by the pancreas; therefore, glucose entry into the cell is reduced resulting in increased blood glucose levels. Individuals may take medications to increase insulin production, to make cells more receptive to insulin or ultimately, may require injectable insulin

Target blood glucose ranges

Normal target ranges:

- Fasting plasma glucose level of 5-7 mmol/litre **and**

- Plasma glucose level of 4-7 mmol/litre before meals at other times of day (NICE, 2015a)

Hyperglycaemia:

- Random plasma glucose of more than 11 mmol/litre (NICE, 2015b)

Hyperglycaemia describes any blood glucose concentration that is higher than recognised target ranges (Patton and Thibodeau, 2015). Prolonged hyperglycaemia can result in damage to many organs of the body leading to renal failure, blindness or gangrene resulting in amputation (Boore, Cook and Shepherd, 2018).

Acute hyperglycaemia occurs when the body cannot utilise glucose due to insufficient or complete lack of insulin production. This causes the body to generate glucose via glycogenolysis (glycogen breakdown), lipolysis (fat breakdown) and gluconeogenesis (glucose derived from substrates such as lactate, glycerol and glucogenic amino acids). Blood glucose rises further, the person is effectively 'starving in a sea of plenty' (Dean *et al*, 2004). Fatty acid metabolites know as ketone bodies, accumulate from this process, resulting in Ketoacidosis. Ketones are observed in the blood and urine (Marieb and Hoehn, 2015; Patton and Thibodeau 2015). Symptoms of hyperglycaemia are summarised in table 1.

Causes:

- Inadequate doses of insulin
- Infection
- Stress
- Surgery
- Medications (steroids, benzodiazepines)
- Various in nutritional intake
- Individuals receiving enteral / parenteral feeding
- Critical illness

(Marieb and Hoehn, 2015)

Table 1: Symptoms

Gastrointestinal	Nausea Vomiting Abdominal pain Hunger
Adrenergic	'Fight or flight response'
Respiratory	Tachypnoea
Renal	Glycosuria (excess glucose in urine) Polyuria (and dehydration) Polydipsia
Electrolyte imbalance	Excess ketones (from fat metabolism)

	Hypokalaemia Hyponatraemia
Liver and adipose tissue	Acetone breath
Cardiovascular	Cardiac irregularities
Central Nervous System	CNS depression – drowsiness Coma

(Adapted from Marieb and Kohen, 2015; Holt, Kumar and Watkins, 2015)

Learning Point: Diabetic Ketoacidosis (DKA)

- DKA results from severe hyperglycaemia and is a potentially life-threatening medical emergency
- DKA requires high intensity nursing within high dependency / critical care units
- In DKA urine will test positive for ketones and plasma ketones will be elevated
- DKA requires urgent hospital treatment with insulin, fluid and usually potassium replacement
- DKA leads to electrolyte imbalance due to excessive acidosis therefore close monitoring of electrolytes is required
- DKA may be the presenting feature of newly diagnosed T1DM

(Holt, Kumar and Watkins, 2015)

Learning Point: Hyperosmolar Hyperglycaemic Syndrome (HHS)

- HSS presents as extreme levels of hyperglycaemia without significant acidosis or ketones in people with T2DM (>40 mmol/l)
- Ketones may not be present as people with T2DM may still produce low levels of insulin
- May develop over weeks due to illness or dehydration
- Management is similar to that of DKA although less likely to require potassium replacement but may need sub cut heparin to prevent thrombotic complications
- Carries a higher mortality rate than DKA

Hypoglycaemia:

- Random plasma glucose of less than 4 mmol/litre

Hypoglycaemia occurs when blood glucose levels fall resulting in inadequate energy available to the brain leading to abnormal behaviour - sometimes mistaken for drunkenness (Patton and Thibodeau, 2015). If prolonged the individual may lose consciousness and if not treated may die (Boore, Cook and Shepherd, 2018)

STOP

and think:

4 is the floor

The symptoms of hypoglycaemia are outlined in table 2.

Causes:

- Inadvertent insulin or sulphonylurea overdose (sulphonylureas work by increasing endogenous insulin production in the person with type 2 diabetes) or in response to a recent change in dose
- Missed or inadequate meal
- Unexpected exercise
- Error in timing of dosage

Table 2: Symptoms

Central nervous system	• Headache • Confusion • Concentration difficulties • Changes is personality
Cardiovascular	• Palpitations
Gastrointestinal	• Hunger • Nausea • Belching
Adrenergic	• Sweating • Anxiety

(Holt, Kumar & Watkins, 2015)

Hypoglycaemia treatment (NICE, 2018):

Mild – moderate hypoglycaemia:

- 10-20g glucose given by mouth either in liquid form (such as *GlucoGel*®) or as granulated sugar / sugar lumps / 4-5 Jelly Babies
- Repeat after 10-15 minutes
- After initial treatment a snack providing sustained carbohydrate release will minimise rebound hypoglycaemia
    - Alternatively:
        - 10g of glucose is obtained from 2 teaspoons of sugar / 3 sugar lumps and also from non-diet drinks i.e.: 100ml *Coca-Cola*®. Note that the carbohydrate content of some glucose drinks is currently subject to change – check the label

Severe hypoglycaemia (causing unconsciousness):

- Glucagon can be given by injection, which increases plasma glucose by mobilising glycogen stored in the liver.
- Give carbohydrate as soon as possible to restore liver glycogen stores
- Glucagon may be prescribed for use in an emergency.
- Alternatively, 20% glucose intravenous infusion can be given via a large gauge needle. 10% glucose may also be used. 50% glucose is not recommended due to potential extravasation injury.
- Blood glucose should be monitored closely, especially if there has been an overdose with long acting insulin or is due to an oral antidiabetic drug as hypoglycaemic effects may persist for many hours.

It is important to note that people with T1DM may become increasingly unaware that they are experiencing a hypoglycaemic episode, as the number of episodes they experience increases. This is termed 'hypo unawareness'. People with T1DM should be assessed for their awareness of hypoglycaemia at each annual review with their doctor (NICE, 2015a).

15 Healthcare Essentials for People Living with Diabetes

Diabetes UK (2020a) highlight the importance of the 15 essential healthcare checks for people living with diabetes. Ensuring people living with diabetes receive theses checks in community practice and at specialist diabetes centres, reduces the risk of serious diabetic complications such as diabetic retinopathy, neuropathy and foot complications. The 15 healthcare essentials include:

1. HbA1c testing
2. Blood pressure measurement
3. Cholesterol testing
4. Retinal screening
5. Foot and leg check

6. Renal function testing
7. Advice on diet
8. Emotional and psychological support
9. Diabetes education course such as DAFNE (type 1) or DESMOND (type 2)
10. Care from diabetes specialists if required
11. Free flu vaccination
12. High quality diabetes care if requiring hospital admission
13. Support with sexual dysfunction
14. Smoking cessation advice
15. Specialist care for conception planning

Self-monitoring of blood glucose (SMBG) – finger-prick testing:

Within the community setting routine self-monitoring of blood glucose levels is advised for all people with T1DM, ideally at least 4 times per day; before each meal and before bed (NICE, 2015a). People with T2DM can also self-monitor blood glucose if they require insulin, have evidence of hypoglycaemia, or if pregnant or planning pregnancy (NICE, 2015c). Frequency of blood glucose testing does vary between individuals and each person will have their own routine with regards to timing of testing. Further adjustments to testing frequency may be required following changes in medications / dosing or intercurrent illness which may give rise to problematic glycaemic control.

Consideration should be given when people who routinely monitor their own blood glucose are admitted to hospital. There is conflicting evidence as to the continuation of self-monitoring in the in-patient setting. Whilst some authors highlight the complexity of hospital treatment and its effect on normal glucose control as a factor which makes self-monitoring beyond the ability of the individual to manage their own blood glucose (Shah and Rushakoff, 2015); others counter this argument highlighting that removing self-monitoring may place the person at increased risk of hypo or hyperglycaemia (Mabrey and Setji, 2015).

However, there is consensus that cooperative management and partnership with people with diabetes should be encouraged to maximise satisfaction, patient empowerment and clinical outcome.

Equipment:

- Blood glucose meter
- Single use lancet
- Test strips
- Cotton wool / low linting gauze
- Sharps box

(Adapted from Delves-Yates 2018b)

Table 3 outlines the correct procedure for people with diabetes to perform blood glucose monitoring.

<u>Table 3: 'How to' perform SMBG finger prick testing</u>

<table>
<tr><th>Step</th><th>Procedure</th><th>Rationale</th></tr>
<tr><td>1</td><td>Turn on the machine and ensure correct date and time are displayed and that there is adequate battery.</td><td>To ensure safety
To ensure accuracy of result recorded</td></tr>
<tr><td>2</td><td>Ensure the unit of measurement is mmol/L</td><td>To ensure accurate measurement</td></tr>
<tr><td>3</td><td>Ensure equipment set up, this may vary according to the device or if automated systems are used. Always follow manufacturer guidelines and local policy. Checks may include:
Test strips are in date and have not been left exposed to air
The monitor and strips are calibrated together
Any quality control testing is checked and carried out if required
The screen and display are intact</td><td>To minimise failure of device / equipment</td></tr>
<tr><td>4</td><td>Selection of appropriate site, consider:
Skin condition – site should be well perfused and free of callouses
Avoid burns, cuts, scars, bruises, rashes
Avoid areas that have been subject to continual testing
Usual sites include the distal segment of the 3rd or 4th finger</td><td>Rotating sites and avoiding previous puncture areas reduces soreness and callous formation
Tips, pads of fingers and the index finger should be avoided as they have a dense supply of nerve endings and testing may be more painful</td></tr>
<tr><td>5</td><td>Person should wash hands with soap and water and dry</td><td>Removes any contaminant which may give misleading readings</td></tr>
<tr><td>6</td><td>Ensure the correct setting is used if depth setting can be adjusted on the lancet</td><td>Single use lancets minimise cross contamination and limit needle stick injury</td></tr>
</table>

		• Adjusting the depth setting ensures minimal discomfort
7	Remove the lancet device cap if present; activate the lancet as per manufacturer's guidance at the selected site. Utilise the side of the finger. Rotate sites Single use devices should be used in the in-patient setting to avoid cross contamination. In the persons own environment a reusable device may be used If there is difficulty obtaining the blood sample, 'milking' from the palm of the hand will increase droplet size, do not milk the finger alone	• The side of the finger is less sensitive and is easier to obtain blood from • Sites are rotated to avoid infection, callous formation and to minimise pain • Milking the finger alone can cause contamination of the sample by interstitial fluid leading to a low reading
8	Dispose of the lancet as required with regard to correct disposal of sharps within the relevant setting	• To minimise cross contamination • To minimise risk of sharp injury
9	Insert the test strip into the blood glucose meter. Ensure meter is ready for droplet. Apply the first drop of blood and ensure the window is entirely covered with blood	• Inadequately filled strips leads to inaccurate results or error reports
10	Apply gauze and pressure to puncture site, monitor for excessive bleeding	• To ensure safety • To minimise bleeding
11	Person should document results on a paper record. Alternatively, some smart meters can facilitate the downloading of blood glucose data	• To ensure accurate record keeping
12	The person should be encourage to act on any results outside of their own, individualised normal range. Adjustments in insulin dosing / medications may be required. Individuals should seek help / contact their care team immediately if there is significant hyper / hypo glycaemia or indeed if blood glucose trends are persistently problematic.	• To ensure changes in blood glucose are treated appropriately to maximise glycaemic control

Reference: Adapted from Dougherty and Lister (2015)

Errors in results:

Potential sources of error include:

- Incorrect meter calibration
- Poor meter maintenance
- Incorrect operator technique
- Inadequate quantity of blood on test strip (gives false low readings)
- Out of date / improperly stored test strips (give false low readings)
- Potential for error in low blood glucose range
- Contamination of the sample may arise from substances present on the test-finger:
    - Alcohol gel or wipes used to clean the finger
    - Newspaper print, perfumes, hand creams, hairspray, hair gel
    - Residues of food and drink

(Dougherty and Lister, 2015; Hortensius *et al* 2011; Trend UK, 2017)

Any blood glucose measurement which does not correlate with the persons clinical presentation should be re-checked with consideration of potential sources of error.

Interferences and contraindications to finger prick testing are detailed in table 4.

Table 4: Contraindications / interferences in blood glucose testing:

Contra-indication	**Example**
Dialysis treatment	Some fluids may contain Maltose which can interfere with test strip methodology
Peripheral circulatory failure	Severe dehydration, DKA, hypotension, shock, peripheral vascular disease
Severe dehydration	Vomiting or diarrhoea, diuretics, uncontrolled diabetes
Variations in blood oxygen tension	People receiving intensive oxygen therapy
High concentrations of non-glucose reducing substances in the blood	Intravenous infusion of ascorbic acid
High bilirubin values	Jaundice
Extremes of haematocrit	Neonatal blood samples, pregnancy
Hyperlipdaemia	Total parenteral nutrition, hyperlipidaemia

Reference: MHRA (2013)

Diabetes Monitoring and Management Technologies

SMBG and insulin dosing technologies are constantly developing and it is important to remain up to date regarding the technologies available, to ensure people living with diabetes are offered the most up to date and evidence based equipment and education to manage their blood glucose levels.

Smart meters

Choosing the right meter and strips is dependent on a number of factors including availability, cost, individual suitability and prescribing restrictions. There are currently 43 smart meters currently on the market (Diabetes UK 2020b). Modern smart meters have the capability to record up to 1000 readings and provide 30, 60 or 90 day data averages with optional data download. A number of meters have an integrated finger prick lancet and some can also test for ketones.

Rationalisation of the provision of meters and strips in some areas has led to challenges in accessing the necessary equipment to SMBG for some individuals living with diabetes. Diabetes UK (2017a) highlights that it is essential that people are prescribed sufficient SBGM testing strips for their clinical need. This enables people with diabetes to self-manage, including understanding 'sick day rules', recognising the symptoms of DKA / HSS, early action and how to seek help, and any specific considerations in light of any job they may carry out, especially if it involves driving. In light of this, DUK have compiled an advocacy pack to assist people with diabetes to get the right equipment for their needs https://www.diabetes.org.uk/resources-s3/2017-09/1092C_Test_strips_advocacy%20report_WEB.pdf.

Insulin Pens

Insulin pens are designed to be easy to use and are either disposable or reusable with accompanying cartridges. There are a huge variety of insulin pens available, some of which have smart functionality enabling the following:

- Record date and time of insulin dosing
- Record dose administered
- Can deliver half-unit dosing
- Pen cap can inform the user of time since last dose
- Can interface with smart devices such as smart phones

Continuous glucose monitoring (CGM)/ flash blood glucose monitoring (flashGM):

Technologies are available which now enable people with diabetes to continuously monitor and manage their blood glucose. Result can be reviewed via scanners or connected smart devices without the need for painful finger-prick testing (Leelarathna and Wilmot, 2018, Yoo *et al.*, 2008, Diabetes UK, 2017b) providing glucose readings with accompanying trend arrows (Messer *et al.*, 2018) via an implanted device.

FlashGM measures glucose levels within interstitial fluid, utilising a sensor applied to the skin and a reader; an optional companion app for mobile devices is also available. The sensor remains in place for 14 days (NICE, 2017). Whilst some research classifies flashGM under the umbrella term 'continuous glucose monitoring' (CGM) because the device records continuously (Blum, 2018), it should be noted that the data is not transmitted continuously. FlashGM is sometimes classified as 'intermittently viewed continuous glucose monitoring' (iCGM). Other devices are available which do provide ‘real-time’ CGM (rtCGM) with continuous data transmission which also give accompanying alarm warnings, a feature that flashGM does not have. Both rtCGM and flashGM facilitate monitoring of time spent in target glucose range, however, with flashGM these trends can only be observed after physically scanning the sensor (Danne *et al.*, 2017).

The Abbot Freestyle Libre is a form of flashGM which has been shown to reduce time spent in hypo / hyperglycaemia and improves time in glucose range (Campbell *et al.*, 2018). Further, Tyndall *et al.* (2019) have demonstrated flashGM confers significant improvements in HbA1c (HbA1c being an indicator of glucose control over preceding 12 weeks). Recent evaluations in a ‘real world’ sample by Dunn *et al.* (2018) demonstrated that higher rates of scanning using flashGM are associated with improvements to markers of glycaemic control related to time in blood glucose target range. Daily costs are lower compared with rtCGM systems and calibration is not required as it is with rtCGM (Petrie, Peters, Bergenstal *et al.*, 2017).

In November 2017, the Abbott Freestyle Libre continuous glucose monitor device was made available through the NHS formulary for people with T1DM who meet specific NHS England criteria. The device continuously measures glucose levels within interstitial fluid, utilising a sensor applied to the skin (NICE, (2017). These devices will become increasingly prevalent in coming years.

Insulin pumps

Insulin pumps are battery operated devices that provide a person with regular insulin delivered via a small sub-cut cannula. The delivery cannula remains in situ for 2-3 days. Extra insulin is delivered via “bolus dosing” when the individual is carbohydrate counting. Insulin pumps are not recommended by NICE for people with type 2 diabetes. They are recommended for individuals under 12 years if multiple daily injections (MDI) are considered impractical or inappropriate. Children would be expected to undergo a trial of MDI between age 12 and 18 for continuing access to this technology.

Insulin pumps are recommended for adults and children 12 years and over with type 1 diabetes if the individual, in achieving HbA1c targets with MDI person is experiencing disabling hypos (repeated and unpredictable occurrence that results in anxiety and effects quality of life), or their HbA1c is 69 mmol/mol or above despite high level care with MDI and demonstrating commitment to control. They may be further indicated as a strategy for managing impaired awareness of hypoglycaemia (NICE, 2008).

A full up to date resource of Medications and Kit by Diabetes UK (2020b) is available here https://cdn.shopify.com/s/files/1/1922/6045/files/diabetes-uk-meds-and-kit-2020.pdf?883

Closed Loop Artificial Pancreas

Increasingly, the online type 1 diabetes community are supporting one another in building DIY closed loop artificial pancreas systems (APS). These systems utilise existing technology (pumps and wearable sensors) alongside bespoke, wearable miniature computers with built in dosing algorithms to deliver continuous insulin and automated dosing adjustment. This means the user relies entirely on the insulin pump, sensor and algorithm to manage blood glucose levels automatically.

Instructions for building these systems at home, alongside the dosing algorithms required, are freely available via the internet in open source format. Devices used in DIY closed loop APS are used outside of their licensed purpose and also manufacturers warranty and those that use their devices in such a way, do so at their own risk. Such systems could potentially lead to hypo / hyper glycaemia and diabetic ketoacidosis (Diabetes UK, 2020c).

The rise in such DIY systems has been driven not only by a supportive and connected online diabetes community, but is also borne out of the frustration experienced by people living with diabetes waiting for advancements in technology. MedTech companies are developing similar devices but the time to market is still some way off. Users of such systems report more time in blood glucose range and less hypoglycaemia, with overall improved control. However there is currently no empirical research to support these findings.

Although users of such devices are relatively few, numbers are growing. In light of this, Diabetes UK (2020c) has produced a position statement, endorsed by the Royal College of Nursing, in relation to DIY closed loop APS. There has been concern from healthcare professionals that they risk legal or regulatory body actions in advising people in relation to using these off-license systems. The position statement recommends clinical rather than legal guidance and provides a number of recommendations regarding on-going clinical care, assessment of competence and appropriate documentation.

Conclusion:

All practice nurses should be familiar with the importance of blood glucose monitoring and the procedure to carry out testing safely and effectively in order to ensure people with diabetes are appropriately educated. Appropriate and timely monitoring of blood glucose will allow for the effective management of blood glucose levels, which fall out of target ranges. This will ensure ongoing safety during episodes of acute illness and effective management of diabetes mellitus in the longer term, minimising serious diabetic related health complications.

The development of technologies will empower people living with diabetes to be further engaged in their disease management and nurses must ensure they maintain their knowledge in relation to this dynamic area of healthcare.

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