Recognizing and responding to hyperglycaemic emergencies

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Abstract

Diabetic ketoacidosis (DKA) and hyperglycaemic hyperosmolar state (HHS) are both diabetic emergencies associated with hyperglycaemia and can be fatal if healthcare professionals fail to recognize and intervene appropriately. While many students and qualified nurses may be able to recall common signs and symptoms related to DKA and HHS – for example polyuria, polydipsia and elevated blood sugars – understanding the physiological mechanisms behind abnormal observations and restoring homeostasis through appropriate management is far more complex. Health educators can play a significant role in contextualizing difficult concepts, such as DKA and HHS, so that these complex conditions can be recognized with greater confidence and competence in clinical practice.

Key words: Education ■ Glucose homeostasis ■ Hyperglycaemic emergencies ■ Recognition and response

Diabetes appears to be an ever-increasing problem that can affect anyone regardless of age, race or gender. It is a common metabolic condition that is characterized by elevated blood glucose levels (hyperglycaemia).

Blood glucose levels need to be kept within acceptable parameters, and the body usually manages to do this. Normal fasting blood glucose levels are between 3.5 mmol/litre and 5.5 mmol/litre (Clancy and McVicar, 2009), fluctuating to 7–9 mmol/litre after a meal, depending on the level of carbohydrates eaten; the peak in blood glucose levels typically occurs 30–60 minutes following a meal (Higgins, 2001).

Figure 1 outlines normal glucose homeostasis. It is essential that nurses understand this mechanism if they are to recognize and respond appropriately to elevations in blood glucose levels.

Glucose is an essential source of energy for body tissues and organs, especially the brain and nervous system. The two key hormones involved in the regulation of glucose are insulin and glucagon. Several other hormones, often referred to as counter-regulatory hormones, can increase blood glucose levels (*Table 1*).

Insulin is the only hormone to lower blood glucose. It has three essential actions: first, it promotes the uptake of glucose by target cells and facilitates excess glucose to be stored as glycogen (a quick energy reserve in the liver); second, it increases protein synthesis (the build-up of proteins); and, finally, it inhibits gluconeogenesis (synthesis of glucose from non-carbohydrate sources) by preventing fat and glycogen breakdown (Porth, 2007).

Once glucose levels increase, the beta cells in the islets of Langerhans in the pancreas secrete insulin so that tissue cells can take up glucose and glucose levels in the blood fall. Conversely, when blood glucose levels fall, the alpha cells secrete glucagon, which converts glycogen stores in the liver to glucose.

Within minutes, glucagon can initiate glycogenolysis (the breaking down of the polysaccharide glycogen into molecules of the sugar glucose) thereby increasing glucose levels. Glucagon also helps promote gluconeogenesis by transporting amino acids to the liver and stimulating their conversion into glucose.

It is important to remember that glucagon secretion is inhibited by glucose levels rising, but only when insulin is present (Hinchcliff et al, 2000). This is essential when understanding diabetes where there is a relative or absolute lack of insulin produced. When insulin is scarce in diabetic ketoacidosis (DKA) and hyperglycaemic hyperosmolar state (HHS), glucagon secretion will not be inhibited, so already elevated blood glucose levels will continue to rise.

Diabetics are extremely susceptible to continual hyperglycaemia because they have either a total lack of insulin production (type 1) or there is a resistance to the insulin produced (type 2) for the requirements of tissues. Although there are several types of diabetes, including diabetes insipidus and gestational diabetes, only type 1 and type 2 diabetes will be discussed in this article.

Type 1 diabetes

It is estimated that this type of diabetes accounts for approximately 5–10% of individuals diagnosed with diabetes (Nair, 2007). This type of diabetes is predominately associated with the gradual autoimmune destruction of the beta cells within the pancreas where insulin is produced. The body's own immune response does not recognize the beta cells as its own and targets them for destruction, leading to an eventual lack of insulin production (Huether and McCance, 2004). Insulin impairment means that this type of diabetes requires the patient to take insulin for the rest of their lives; they are consequently more at risk of developing hyperglycaemia than type 2 diabetics.

Type 1 diabetics are at a significantly higher risk of developing DKA than people with type 2 diabetes. However, type 2 diabetics can develop DKA due to catabolic stress during an episode of critical illness.

Early recognition of DKA is essential to promote a positive patient outcome; it can develop in less than 24 hours (Trachtenbarg, 2005). It is characterized by three coexisting abnormalities: hyperglycaemia, hyperketonaemia (high ketone bodies in the blood) and metabolic acidosis (an accumulation of too much acid in the blood and a deficit of bicarbonate); this is often referred to as the biochemical triad (Kitabchi, 2001). Nurses should be alert to the coexisting abnormalities and respond with early fluid and insulin therapy.

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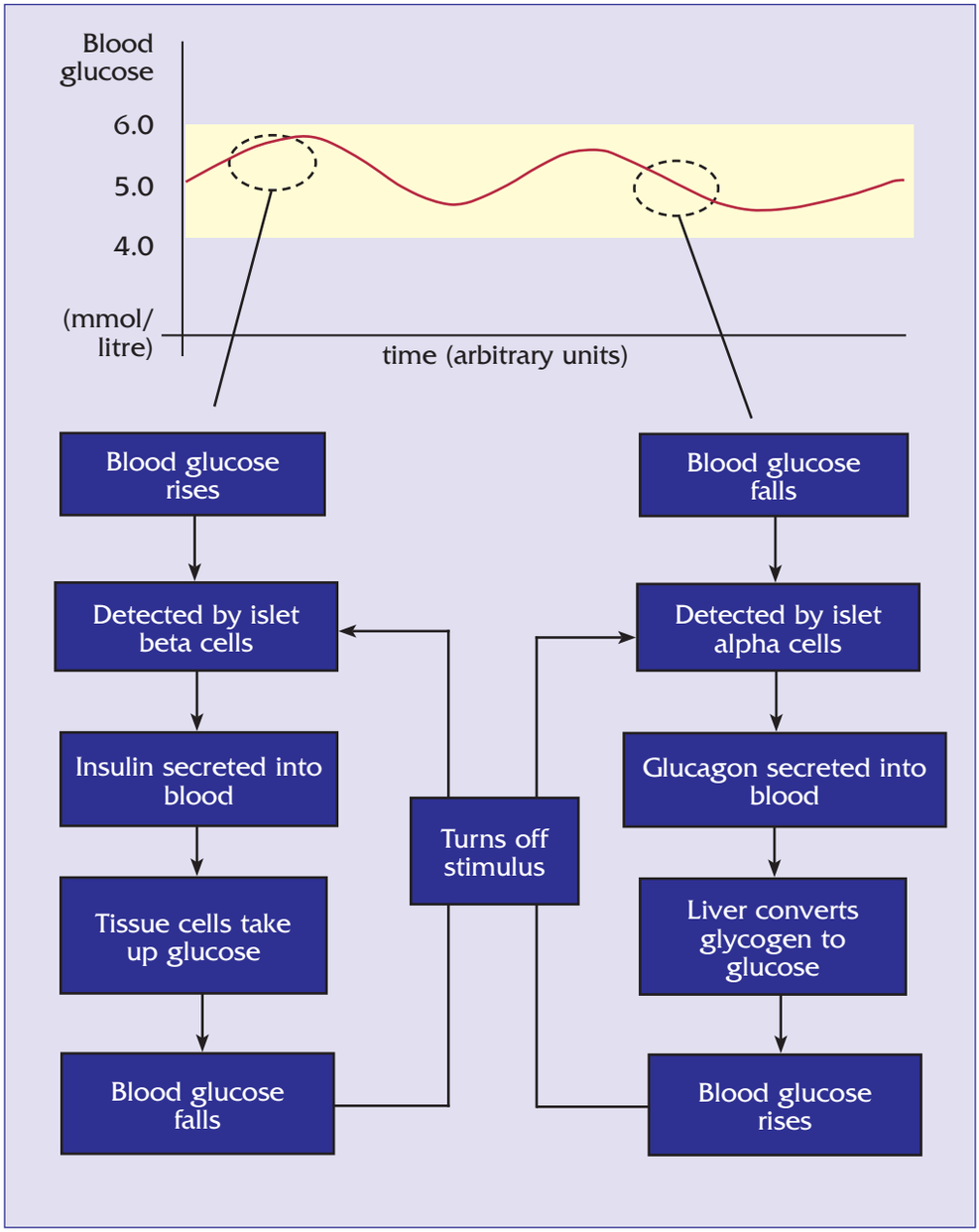
Accepted for publication: September 2009

Figure 1. Regulation of blood glucose. Summary of role of insulin and glucagon in the control of blood glucose. (Reproduced with kind permission of Roger McFadden BCU.)



Common causative triggers include infection, myocardial infarction, diarrhoea and vomiting, or treatment errors with giving too little insulin. However, in 40% of DKA cases, there is no obvious cause (Palmer, 2004).

Physiologically, blood glucose levels are elevated because the patient is not producing insulin and therefore can not transfer it out of the bloodstream into tissue cells. Tissues and cells become starved of glucose and cannot produce energy. The liver's increased secretion of glycogen and increased synthesis of amino acids in an attempt to generate more glucose for cellular energy only serves to further increase serum glucose levels.

While the serum is rich in glucose, the cells have a serious deficit in glucose because insulin is not being produced to enable the glucose to enter the cells. Fats from adipose tissue are mobilized in an attempt to create cellular energy, but ketone bodies such as acetone and beta-hydroxybutyric acid are formed as a byproduct of fat metabolism, causing further acidosis. A smell of acetone on a patient's breath may be present, which is a classic sign of ketoacidosis associated with ketone bodies.

Type 2 diabetes

The majority of diabetics in the UK have type 2 diabetes. Here, insulin is produced, but its effects do not regulate glucose levels correctly. There is a resistance to the insulin produced; it is seen as a relative lack of insulin rather than an absolute lack of insulin. The effects are similar to those of type 1 diabetes, where glucose is unable to be transported into the cells for energy production; it therefore accumulates in the blood causing hyperglycaemia.

Hyperglycaemic hyperosmolar state is predominately associated with type 2 diabetes managed by diet and/or oral medication. Hyperosmolar indicates that the patient will have an abnormal increase in the osmolarity of blood as a result of dehydration. It is primarily observed in older patients and may be the first presentation for an undiagnosed diabetic (Chiasson et al, 2003).

It develops more insidiously than DKA, usually evolving over days or weeks. As with DKA, precipitating factors include infection and medications that may affect carbohydrate metabolism, e.g. diuretics, antipsychotics and corticosteroids (Moore, 2004). The slow evolution of HHS and the potential coexisting underlying disease often make this condition difficult to recognize and diagnose. Ketosis, a dominant feature in DKA, is minimal in HHS because there are small amounts of insulin present which suppress lipolysis so avert ketone formation (Kitabchi, 2001).

Although there are important differences in the pathogenesis of DKA and HHS, many of which are not fully understood, the principle underlying problem is the reduction in circulating insulin and the elevation of the counter-regulatory hormones such as adrenaline/noradrenaline, glucagon, cortisol and growth hormone.

The counter-regulatory hormones are released in an attempt to provide cells with fuel. The sympathetic nervous system plays a crucial role in this as adrenaline acts on the liver, smooth muscle and adipose tissue to mobilize fats and promote glycogenolysis. However, this only exacerbates the hyperglycaemia further – glucose still can not enter cells without insulin (Hand, 2000).

Box 1 shows signs and symptoms that are common to both HHS and DKA. Noticeable differences between them are shown in *Box 2*.

Recognizing and responding to clinical signs and symptoms

Recognition of hyperglycaemia

Once nurses are able to recognize that hyperglycaemia can lead to significant dehydration because of the osmotic effects of glucose in the urine, they can develop a greater appreciation of the physiological changes in patient observations. In DKA, the total deficit of water is typically 5–7 litres; in HHS, the water deficit is usually greater at 7–12 litres (Chiasson et al, 2003). The lack of

Table 1. Counter-regulatory hormones

Hormone	Function
Catecholamines – including adrenaline and noradrenaline	Promotes glycogenolysis by stimulating the conversion of glycogen in the liver and muscle to glucose
	Inhibits insulin release from beta cells
	Increase mobilization of fatty acids to preserve glucose
	Adrenaline stimulates glucagon secretion, increasing glucose levels further
Glucocorticoid hormones – including cortisol Levels increase during times of stress, infection, trauma and acute anxiety	Stimulate gluconeogenesis, increasing hepatic glucose production up to 10 times
Growth hormones – normally inhibited by insulin	Decrease the uptake of glucose by cells – glucose therefore remains in the blood

insulin in itself may contribute to further loss of water. Insulin stimulates water reabsorption in the proximal and distal tubule of the nephron so, if it is lacking or absent, more water will be lost into the urine (Kitabchi, 2001). Hyperglycaemia in HHS is generally higher than that found in DKA. Although residual insulin limits ketone formation, it is not enough to control hyperglycaemia. The resulting dehydration sustained over days or weeks leads to poor renal function and less glucose is excreted. This, combined with the presence of a stressful condition, can further increase hyperglycaemia (Kitabchi, 2001).

Response: The administration of insulin

The kidney filters and reabsorbs glucose. When blood glucose levels are elevated because of insufficient insulin, the kidneys are required to filter more glucose.

Once the serum blood glucose exceeds the renal threshold of 10–12 mmol/litre, patients will exhibit glucose in their urine (glycosuria). This is because there are insufficient transport molecules to reabsorb glucose back into the blood from the renal tubules. Glycosuria will exert an osmotic pull, leading to an osmotic diuresis generating greater urine output (polyuria). As the osmotic diuresis continues, severe intracellular and extracellular dehydration will occur. If left untreated, the uncontrolled fluid loss precipitates acute circulatory failure and a medical emergency.

Insulin administration will help restore glucose homeostasis by allowing the high circulating levels of glucose in the blood to enter the cells and decrease hepatic glucose production. It will also inhibit the release of free fatty acids from the adipose tissue and decrease ketogenesis which will help diminish ketone body formation (Umpierrez et al, 2000).

There is no overall recognized protocol for the administration of insulin in DKA or HHS. Clinical studies over previous decades have suggested differing doses, so there is no clear consensus. Treatment protocols are generally devised by regional hospital Trusts so may have subtle variations.

Intravenous administration is generally recommended because of the prolonged half-life of subcutaneous insulin (McHoy, 2003). Hardern and Quin (2003) concur, stating that, because circulating insulin has a half-life of 15 minutes, intravenous administration has an advantage over intermittent boluses in controlling blood glucose levels. However, some protocols may recommend that a bolus dose of insulin is given subcutaneously.

The dose of insulin administered must be titrated against the blood glucose levels. Generally, low-dose insulin can be effective because most protocols advocate aggressive fluid resuscitation immediately, prior to or during insulin therapy. There is robust consensus that aggressive fluid replacement, even before insulin is administered, significantly helps decrease levels of cortisol, catecholamines, aldosterone and glucagon, thereby decreasing blood glucose levels (Kitabchi, 2001).

Nurses need to be vigilant in checking blood glucose levels to ensure that insulin is titrated accurately, to measure response to insulin therapy and avoid the risk of hypoglycaemia. Glucometer readings may indicate 'high' when levels are above 26 mmol/litre, so laboratory

Box 1. Common signs and symptoms of diabetic ketoacidosis and hyperglycaemic hyperosmolar state

Diabetic ketoacidosis

- Elevated blood glucose – greater than 12mmols/litre
- Polyuria – osmotic diuresis
- Tachycardia associated with fluid loss
- Polydipsia – increased thirst
- Glucose in urine positive
- Acidosis variable – pH 7.30–7.00, depending on the severity of DKA

Hyperosmolar state

- Usually grossly elevated blood glucose – 34mmol/litre or higher (Chiasson et al, 2003)
- Polyuria – osmotic diuresis
- Tachycardia associated with fluid loss
- Polydipsia – increased thirst
- Glucose in urine positive
- Acidosis present – pH not less than 7.30

Box 2. Differences in diabetic ketoacidosis and hyperglycaemic hyperosmolar state

Diabetic ketoacidosis

- Serum ketones positive – acetone smell on breath
- Deep rapid respirations – Kussmau breathing
- Urine ketones positive
- Can be alert or drowsy, coma in severe case
- Increased or decreased serum sodium
- Initially increased serum potassium
- Abdominal pain typically present – related to the metabolic acidosis (Umpierrez and Freire, 2002)

Hyperosmolar state

- Serum ketones usually mild or absent
- Shallow rapid respirations
- Urine ketones negative
- Stupor/coma more likely due to hyperosmolar state. Neurological problems such as seizures or transient haemiparesis
- Serum sodium elevated
- Serum potassium normal or slightly low
- Abdominal pain can be identified in some cases but not a typical presentation

results will also be required. Initially, glucose levels may need to be checked every 30–60 minutes. It is important that blood glucose levels are not lowered too rapidly to avoid the potential complication of cerebral oedema (Brenner, 2006).

Even with insulin, blood glucose levels in HHS patients may not decline initially; this usually suggests renal impairment or inadequate fluid resuscitation rather than insulin resistance (Matz, 1999). Replacing adequate fluid volumes and monitoring urea and creatinine levels are therefore fundamental when assessing the effectiveness of insulin therapy.

Recognition of dehydration

It is imperative that urine is tested for glucose during episodes of hyperglycaemia to ensure that the possibility of osmotic diuresis is recognized early and the risk of severe dehydration averted.

Patients with DKA and HHS, despite being dehydrated, will experience polyuria rather than having the clinical observation of oliguria, which is usually associated with dehydration. Nurses therefore need to be able to interpret other signs and symptoms for clues of dehydration such as tachycardia, a furred tongue, dry skin and a considerable thirst (polydipsia). However, it is important to remember that many HHS patients do not respond to the stimulus of thirst because of incapacity or confusion. Patients with excessive urine output should have their fluid balance assessed and started on appropriate fluid administration. It may be necessary to catheterize the patient to accurately assess urine output and insert a central venous catheter line to enable an exact measurement of their intravascular volume.

Skin turgor and capillary refill time should also be assessed for indications of dehydration; skin turgor would show less elasticity and capillary refill would be more than 2 seconds. A full assessment of pulse, including rate, depth and rhythm, should also be undertaken to assess for further confirmatory signs of dehydration; the pulse may well be weak or thready, and may feel irregular.

Response: The administration of intravenous fluid

Although the administration of fluid is essential and a prime treatment objective, there is some debate about the type of fluid that should be administered as well as the exact volume and rate to be infused. Fluid choice tends to be between an isotonic fluid such as 0.9% saline or a hypotonic fluid such as 0.45% saline, depending upon serum sodium levels. Choice of fluid often depends upon the level of dehydration, blood chemistry results and pre-existing medical conditions such as heart failure. The overall goal is to replace half of the fluid deficit over the first 8 hours and the remaining fluid over the next 16 hours (Brenner, 2006). There is general consensus that one litre of 0.9% saline should be administered over the first hour for both DKA and HHS patients to help replace intracellular and extracellular volume and restore renal perfusion (Kitabchi, 2006). However, subsequent administration of fluids can vary in treatment protocols. Nurses should take responsibility in developing an awareness of their hospital Trusts' protocols to be more confident in treatment decisions.

There is also some disparity about exactly when 5% dextrose should be commenced to avoid hypoglycaemia and replenish glucose stores in the liver and muscles; 13–15 mmol/litre appears to be the general consensus (Urden et al, 2002).

Bicarbonate administration remains controversial in DKA patients and studies have failed to show any benefit (Umperriez et al, 2002). Although severe metabolic acidosis can lead to impaired myocardial contractility, abdominal pain, cerebral vasodilatation and coma, potential alkalinization from the bicarbonate can worsen intracellular acidosis. The administration of bicarbonate may be considered on treatment protocols when pH is extremely low at below 7.0.

Recognition of electrolyte imbalance

In DKA patients, serum sodium levels can be increased or decreased, whereas, in HHS, patients' sodium levels are usually elevated. The degree of imbalance often depends on the water deficit levels and the amount of aldosterone released during hormonal compensation in an attempt to retain water.

Serum potassium levels in DKA patients are often initially elevated, but can be low. The initial elevation observed in DKA is attributed to the high levels of hydrogen ions. Potassium and hydrogen ions are freely exchangeable across the cell membrane so, as more hydrogen enter the cell, more potassium moves out. It is important to remember that there is often a total body deficit of potassium in DKA, but this is not observed until fluid and insulin therapy have been established.

Patients with HHS often have normal or slightly low potassium levels. It is critical to assess serum potassium level before insulin is commenced in these patients, as it can further reduce the levels of extracellular potassium (De Beer et al, 2008).

Phosphate levels can be altered in DKA and HHS patients and should therefore be investigated; phosphate replacement is not routinely given unless levels are below 1.0 mg/decilitre and patients show signs of cardiac compromise or associated hypoxia (Kitabchi, 2001).

Response

Electrolyte levels are closely monitored in DKA and HHS patients. Once dehydration has been corrected with the appropriate fluid regimen, normal serum sodium levels are usually restored. If potassium levels are high or low, cardiac monitoring should be in place as there is a greater chance of cardiac arrhythmias. The treatment protocols for the administration of potassium for DKA and HHS are similar (*Table 2*).

It is essential that any decisions to give potassium take into account the most recent potassium serum levels and the patient's urine output. Fluids containing potassium should be infused through an intravenous pump to avoid the risk of arrhythmias associated with incorrect rate delivery.

Recognition of impaired levels of consciousness

As a result of cellular dehydration, hyperglycaemic patients may also display altered levels of consciousness. There is a strong correlation between serum osmolality and mental status in DKA and HHS; the higher the serum osmolality, the greater the deterioration in sensoria (Kitabchi, 2001). Patients with mild to moderate DKA may remain relatively alert; coma is more often seen in patients with severe DKA because of the acidosis. Patients with HHS tend to have a higher incidence of coma on clinical presentation due to their hyperosmolar state.

Response

Patients whose levels of consciousness vary should be nursed in a high-visibility area with an increased nurse-to-patient care ratio in case they lose their ability to maintain their own airway. An assessment tool such as the Glasgow Coma Scale should be used to measure and monitor a patient's level of consciousness. Oxygen should be administered to improve organ perfusion and reduce anaerobic activity.

Unventilated patients should have their respiratory rate, rhythm and depth monitored for signs of respiratory distress. Respiratory assessment is a key essential observation

Table 2. Administration of potassium

Potassium level	Treatment decision
Potassium above 5.5 mmol/litre	No potassium therapy commenced
Potassium levels 3.3–5.5 mmol/litre	Commence potassium therapy at 20–30 mmol/litre saline
Potassium levels below 3.3 mmol/litre	Insulin therapy not given. Commence potassium therapy at 40 mmol/litre saline until level reaches 3.5 mmol/litre

Adapted from: Kitabchi (2001)

in identifying early episodes of critical illness and any deviations from normal parameters should be observed and acted upon if appropriate. Patients with DKA often exhibit Kussmaul breathing, with deep rapid breaths. This is associated with acid-base regulation; the respiratory system is activated in an attempt to lower the levels of carbonic acid formed from carbon dioxide (a weak acid), to compensate for the overwhelming acidosis. Patients with HHS often have rapid shallow breaths, a more typical sign of failing respiratory compensation which lowers further the already reduced oxygen in the blood. A number of patients with DKA and HHS may be electively ventilated and transferred to critical care in response to the severity of their condition.

Conclusion

Nurses can play a pivotal role in recognising and responding to diabetic emergencies. If nurses perceive that they only take, record and monitor observations, they may not develop the clinical insight into how to respond appropriately to them. There is a professional accountability to be able to rationalize the 'what', the 'how' and the 'why' of nursing. Both clinical areas and nurse education have key roles to play to ensure that these are achievable. BJN

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KEY POINTS

- It is imperative that nurses understand normal blood glucose homeostasis so they are able to appreciate the differences between and similarities in type 1 and type 2 diabetes.
- Blood glucose levels that exceed the renal threshold (10–12 mmol/litre) can precipitate an osmotic diuresis, leading to life-threatening dehydration.
- Diabetic ketoacidosis and hyperglycaemic hyperosmolar state are hyperglycaemic diabetic emergencies associated with increased mortality and morbidity.
- Nurses have a professional responsibility to record, recognize, interpret and appropriately respond to changes in patient observations.