

Diabetic Ketoacidosis (DKA)

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Lecture's Outlines:

- **Diabetic Complications**

- **Ketone bodies metabolism**

- **DKA:**

 - Definition

 - Causes and Mechanisms

 - Manifestations

 - Precipitating Factors

- **Hyperosmolar hyperglycaemic state (HHS) = Hyperosmolar non-ketotic acidosis (HONK):**

 - Definition

 - Causes and Mechanisms

 - Manifestations

- **Hypoglycemia:**

 - Causes

 - Manifestations

 - Hormonal mechanisms preventing or correcting hypoglycemia

- **A case of DKA:** (Presentation, Examination, Lab results & their interpretation)

- **Metabolic changes in DKA:**

 - Changes in CHO, protein and lipid metabolism

 - Changes in water, electrolytes, and pH

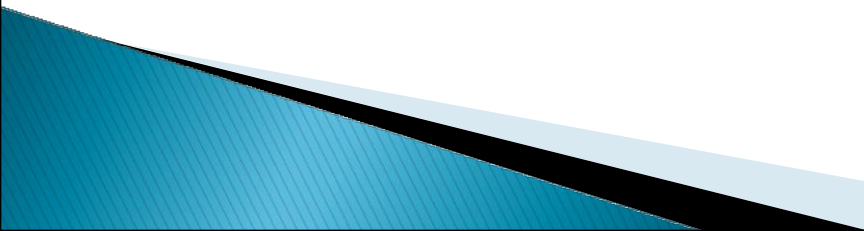
Diabetic emergencies

1. **Diabetic Ketoacidosis (DKA)**
2. **Hyperosmolar hyperglycaemic state (HHS)=
Hyperosmolar non-ketotic acidosis (HONK)**
3. **Hypoglycemia**

Diabetic Ketoacidosis (DKA)



Diabetic Ketoacidosis (DKA):

- **Triad of hyperglycemia, high anion gap metabolic acidosis, and ketonemia**
 - **Characteristically associated with T1 DM**
 - **It has become increasingly common in T2DM**
 - **DKA may be the first presentation of T1 DM**
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Ketone Bodies

1. Acetoacetate

2. Acetone

3. β -Hydroxybutyrate

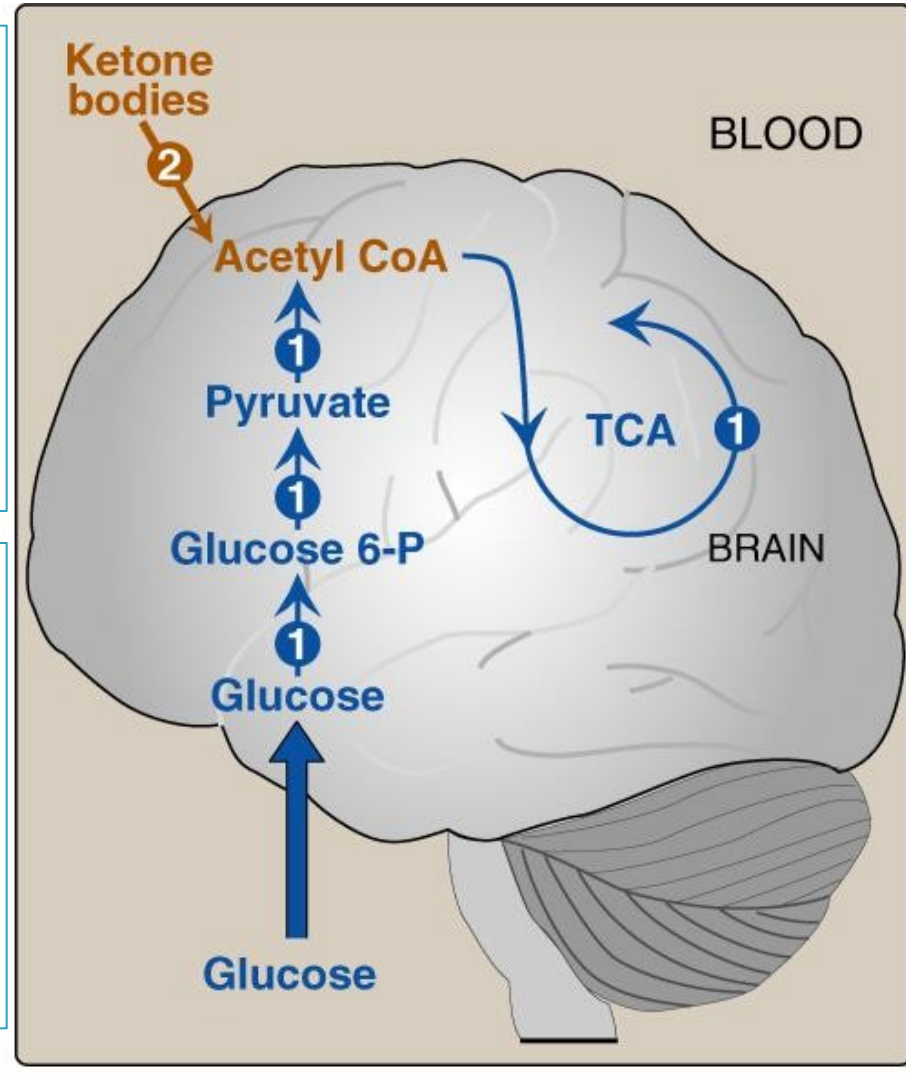
- They are produced by the liver (ketogenesis) and utilized for energy production by peripheral tissues (Ketolysis)

Normally, glucose is the primary fuel for the brain.

It can penetrate the blood brain barrier.

The brain's GLUT is insulin-independent.

If glucose is not available for the brain, the brain can utilize plasma ketone bodies, that can penetrate the blood brain barrier, and serve as fuel molecules.



Ketone bodies synthesis = Ketogenesis

- ▶ Occurs in the hepatocyte mitochondria
- ▶ In uncontrolled DM there is ↑ lipolysis in adipose tissue → ↑ [FFA] mobilization to liver
→ ↑ hepatic FA oxidation → ↑ acetyl CoA which will be **channeled** into KB synthesis
- ▶ **HMG CoA synthase** is the rate limiting enzyme
- ▶ The first KB to be synthesized is **acetoacetate**.
- ▶ Acetoacetate can be:
 - ▶ reduced to **β-Hydroxybutyrate**, or
 - ▶ spontaneously decarboxylated to **acetone**.

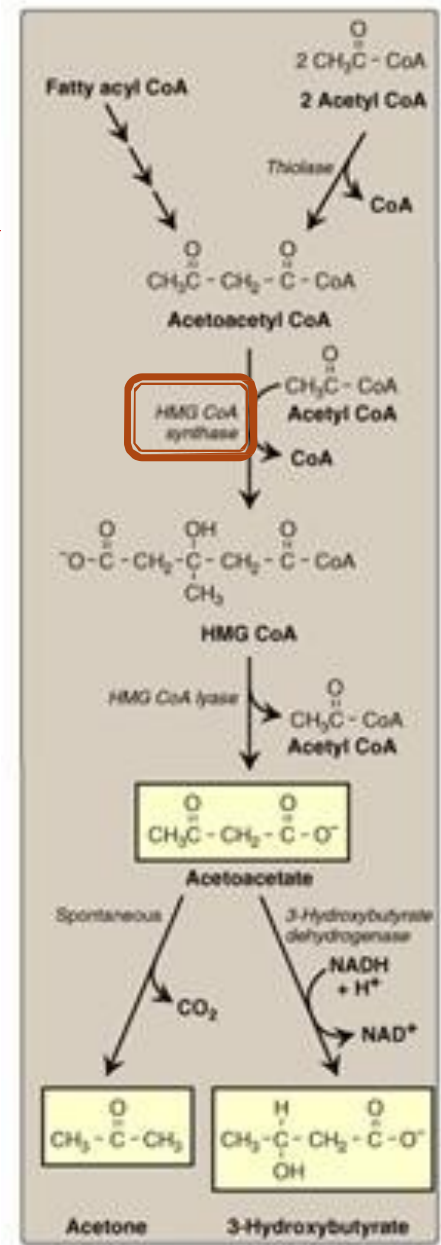


Figure 16.22
Synthesis of ketone bodies. HMG = hydroxymethylglutaryl CoA.

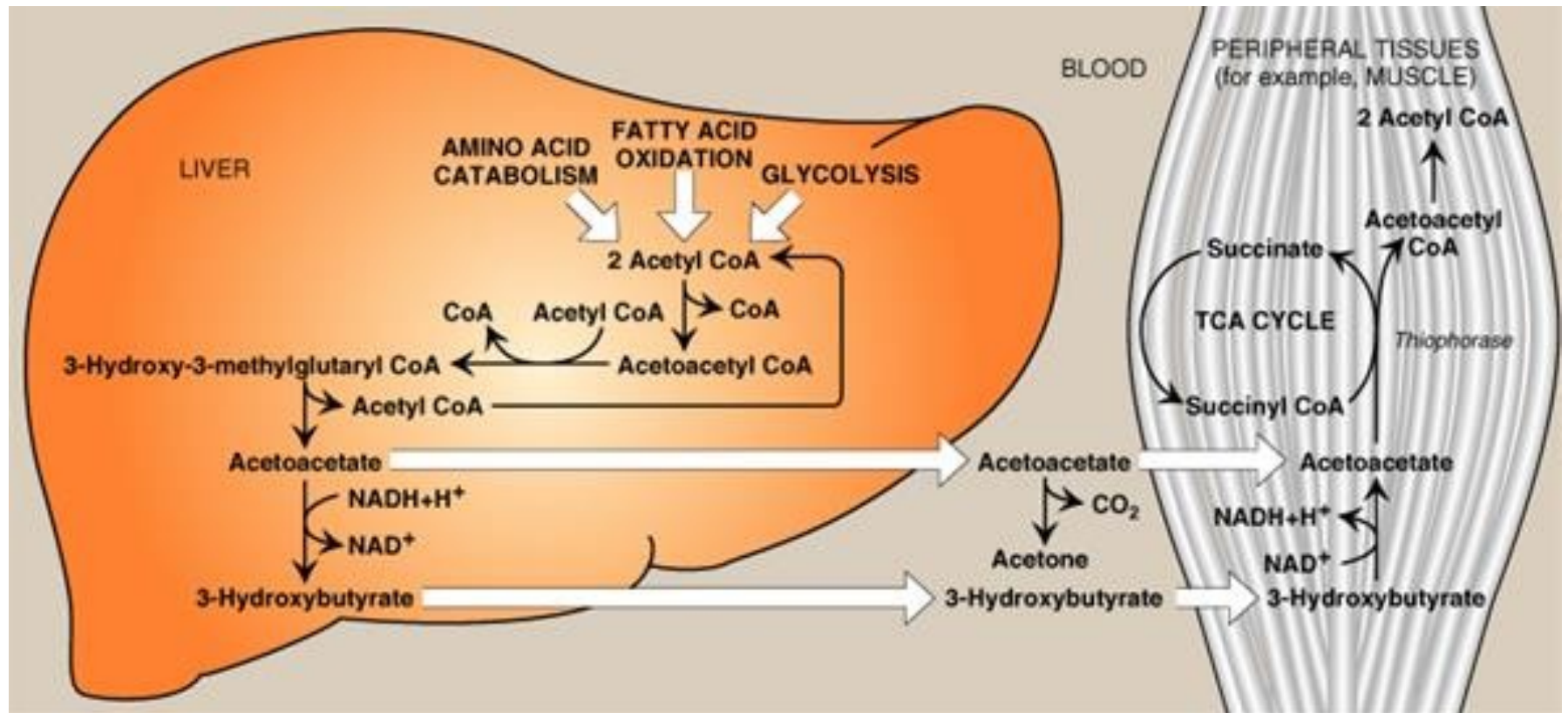
Ketogenesis

- ▶ ↑ hepatic FA oxidation → ↑ acetyl CoA which will be **channeled** into **KB synthesis**
- ▶ Acetyl CoA + oxaloacetate (OAA) → Krebs cycle
- ▶ ↑ Acetyl CoA production activates pyruvate carboxylase
- ▶ Pyruvate carboxylase converts pyruvic acid into OAA
- ▶ OAA is used for gluconeogenesis (rather than Krebs cycle)
- ▶ Acetyl CoA is **channeled** into **KB synthesis**

Ketone Bodies Utilization=Ketolysis

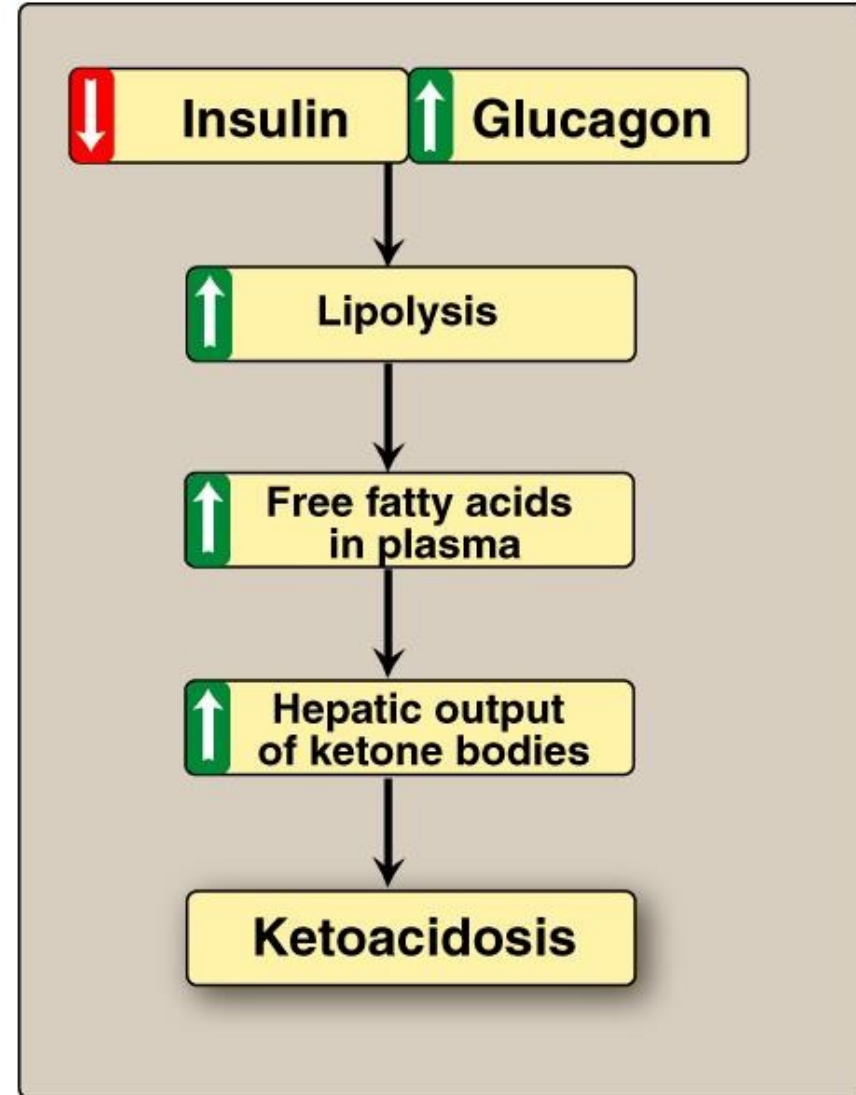
- ▶ Takes place in extrahepatic tissues
- ▶ Occurs in the mitochondria (so cannot occur in RBCs)
- ▶ Does not occur in the liver (as the liver lacks the **thiophorase** enzyme required for ketolysis)
- ▶ β -Hydroxybutyrate is oxidized to acetoacetate (by a dehydrogenase)
- ▶ Acetoacetate is converted to acetoacetyl CoA (catalyzed by **thiophorase**)
- ▶ Acetoacetyl CoA is converted to acetyl CoAs.

Ketone Bodies Utilization=Ketolysis



Mechanisms of DKA:

In uncontrolled DM there is
↑ lipolysis in adipose tissue → ↑
[FFA] → ↑ mobilization of FFA
to liver → ↑ hepatic FA
oxidation → ↑ hepatic acetyl
CoA which will be utilized in
KB synthesis (ketogenesis)
→ ketoacidosis



Mechanisms & Manifestations of DKA

▶ In uncontrolled DM the rate of ketogenesis is $>$ the rate of ketolysis \rightarrow ketonemia (\uparrow [KB] in blood) \rightarrow ketonuria (\uparrow [KB] in urine).

▶ Manifestations of DKA:

- Fruity odor on the breath (acetone)
- Acidosis (low pH of blood because KBs are acids)
- Dehydration (due to glucosuria)

Precipitating factors for DKA

- ▶ Infection (30–40%)
- ▶ Inadequate insulin treatment or non-compliance (20%)
- ▶ Severe illness e.g., Myocardial infarction
- ▶ Trauma
- ▶ Drugs: e.g., steroids

Hyperosmolar hyperglycaemic
state (HHS)= Hypperosmolar
non-ketotic acidosis (HONK)



Hyperosmolar hyperglycaemic state (HHS)= Hyperosmolar non-ketotic acidosis (HONK)

- **Little or no accumulation of ketone bodies**
- **Serum [glucose] is often >50 mmol/L**
- **Plasma osmolality may reach 380 mosmol/Kg (normal 275–295)**
- **Neurological abnormalities are frequently present**
- **Insulin levels are insufficient to allow appropriate glucose utilization but are adequate to prevent lipolysis and subsequent ketogenesis**
- **Usually occurs in elderly patients with T2DM**
- **Has a substantially higher mortality than DKA (up to 15%)**

Hypoglycemia



Hypoglycemia:

- **Common complication of treatment with insulin or oral hypoglycaemics**
- **More common in patients with T1DM**
- **Manifestations: Characterized by:**
 - 1. CNS Symptoms (confusion, aberrant behavior, or coma):**
see details later
 - 2. Low blood [Glucose]**
 - 3. Symptoms resolved within minutes following the administration of glucose**

Hypoglycemia is a medical emergency, Why ?

- The brain has absolute requirement for a continuous supply of glucose
- Transient hypoglycemia → cerebral dysfunction
- Severe, prolonged hypoglycemia → brain death

Hypoglycemia, continued..

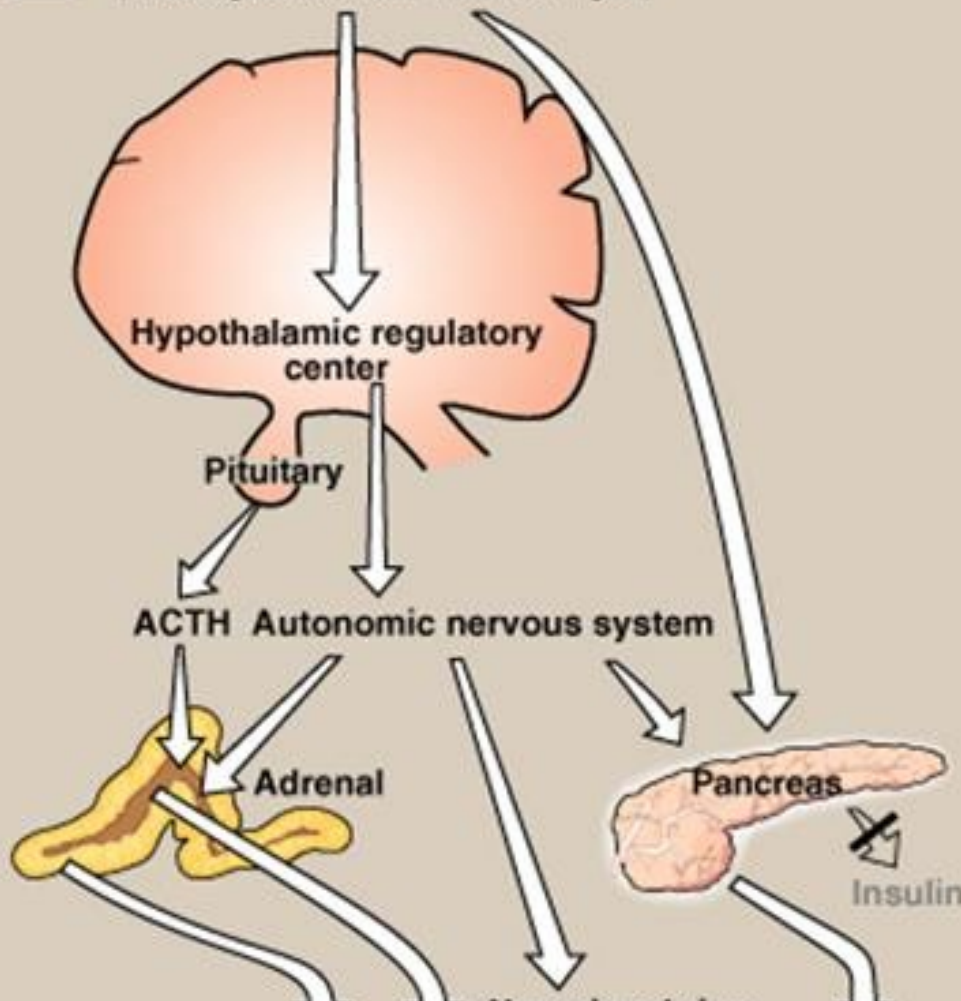
- ▶ **Hypoglycemia occurs due to impaired protective responses to hypoglycemia:**
 - **Insulin is supplied exogenously and its release cannot be turned off**
 - **Glucagon & adrenaline response to hypoglycemia becomes impaired later in the course of DM**

Hypoglycemia, continued..

▶ Clinical presentation:

- **Symptoms of sympathetic overactivity** (plasma [glucose] <3.6 mmol/L, abrupt fall): anxiety, tremors, sweating & palpitation
- **Symptoms of neuroglycopenia** (plasma [glucose] <2.6 mmol/L, gradual fall): headache, confusion, drowsiness and ultimately loss of consciousness or seizures (at plasma [glucose] <1.5 mmol/L)

A **LOW BLOOD GLUCOSE**
 (Blood glucose less than 40 mg/dl) i.e. <2.22 mmol/L

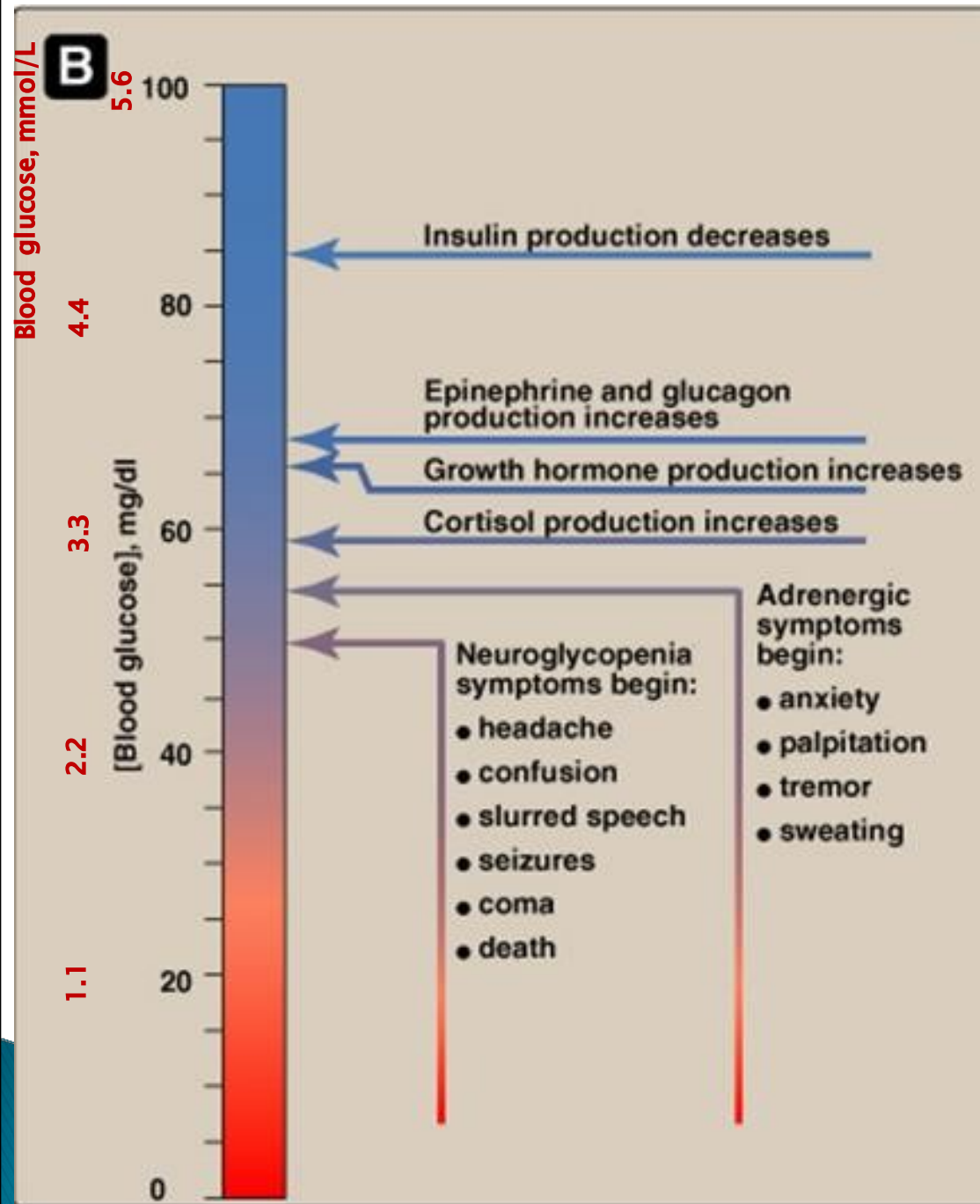


| | Cortisol | Epinephrine | Glucagon |
|----------------------|----------|-------------|----------|
| Glyco- genolysis | 0 | +++ | ++ |
| Gluconeo- genesis | ++ | 0 | ++ |

Hormonal mechanisms to prevent or correct hypoglycemia:

← ↓ Production of insulin

← ↑ production of:
 - Epinephrine & glucagon
 - Growth hormone
 - Cortisol



Glycemic thresholds for the various responses to hypoglycemia:

A CASE of DKA

- ▶ A 14-year-old girl was admitted to a children's hospital in coma. Her mother stated that the girl had been in good health until approximately 2 weeks previously, when she developed a sore throat and moderate fever. She subsequently lost her appetite and generally did not feel well.

A CASE of DKACont'd

- ▶ **Several days before admission she began to complain of undue thirst and also started to get up several times during the night to urinate. However, on the day of admission the girl had started to vomit, had become drowsy and difficult to arouse, and accordingly had been brought to the emergency department.**

A CASE of KDA, continues..

On examination:

- ▶ She was dehydrated
- ▶ Her skin was cold
- ▶ She was breathing in a deep sighing manner (Kussmaul respiration)
- ▶ Her breath had a fruity odor
- ▶ Her blood pressure was 90/60 mmHg (N: 120/80)
- ▶ Her pulse rate 115/min.
- ▶ She could not be aroused

A provisional diagnosis of T1DM with complicating ketoacidosis and coma (DKA) was made by the intern on duty

Laboratory findings: blood results

The admitting diagnosis was confirmed by the laboratory findings shown below:

| Plasma analytes | Patient's results | Normal levels |
|--------------------------|-------------------|---------------|
| Glucose (mmol/L) | 50 | 3.9–5.6 |
| Ketoacids | ++++ | (trace) |
| Bicarbonate (mmol/L) | 6 | 22–30 |
| Arterial blood pH | 7.07 | 7.35–7.45 |
| Na ⁺ (mmol/L) | 136 | 136–146 |
| Cl ⁻ (mmol/L) | 100 | 102–109 |

Laboratory findings : blood results, *continued..*

| Plasma analytes | Patient's results | Normal levels |
|----------------------------------|-------------------|---------------|
| PCO ₂ (kPa) | 2.7 | 4.3–6.0 |
| *Anion gap (mmol/L) | 35.5 | 7–16 |
| K ⁺ (mmol/L) | 5.5 | 3.5–5.0 |
| Urea nitrogen (mmol/L) | 15 | 2.5–7.1 |
| Creatinine (μmol/L) | 200 | 44–80 |
| Albumin (g/L) | 50 | 41–53 |
| Osmolality (mOsm/kg serum water) | 325 | 275–295 |
| Hematocrit | 0.500 | 0.354–0.444 |

*Anion gap (A⁻) = (Na⁺ + K⁺) - (HCO₃⁻ + Cl⁻)

Laboratory findings: Urine results

| Urine analyte | Patient's results | Normal level |
|---------------|-------------------|--------------|
| Glucose | ++++ | - |
| Ketoacids | ++++ | - |

Interpretation of Laboratory findings

| Results | Interpretation |
|------------------------------------|--|
| Hyperglycemia | Confirm the diagnosis of DKA |
| Glucosuria | |
| Ketonemia | |
| Ketonuria | |
| ↓ pH | Severe metabolic acidosis due to ↑ production of ketone bodies |
| ↓ bicarbonate and PCO ₂ | Metabolic acidosis with partial respiratory compensation (the hyperventilation) |
| ↑ anion gap | Due to ↑ ketone bodies in the blood |
| ↑ urea & creatinine | <ol style="list-style-type: none">1. Renal impairment (dehydration → ↓ blood volume → ↓ renal perfusion)2. Dehydration3. Degradation of protein (for urea) |
| ↑ K ⁺ | ↓ Uptake of potassium by cells in the absence of insulin |
| ↑ Plasma osmolality | Due to hyperglycemia and fluid loss |

Metabolic Changes in DM and DKA

Multiple effects

CHO metabolism

- ↓ glucose uptake by certain tissues (adipose tissue & muscle)
- ↑ glycogenolysis
- ↑ gluconeogenesis

Lipid metabolism

- ↑ lipolysis
- ↑ fatty acid oxidation
- ↑ production of Ketone bodies

Protein metabolism

- ↓ protein synthesis
- ↑ protein degradation

K⁺, Water & pH

- ↓ entry of K⁺ into the cells
- Water loss secondary to glycosuria
- Acidosis due to ↑ production of ketone bodies

DM

DKA

Take Home Message

Acute complications of DM include: DKA, HHS, and hypoglycemia ▶

DKA is a triad of hyperglycemia, ketonemia and high anion gap ▶
metabolic acidosis, and can be precipitated by several stressful ▶
factors.

Ketone bodies (KB) are synthesized in the liver (HMG CoA synthase is ▶
the rate limiting enzyme) and utilized by peripheral organs and not ▶
the liver (liver lacks thiophorase enzyme)

KB can serve as energy source (this is important for the brain in case ▶
of hypoglycemia) ▶

Take Home Message

In DKA there is excessive ketogenesis (more than ketolysis) (*details of the mechanisms and consequences are required*)

HHS is a serious condition, usually occurs in elderly with T2DM, and has high mortality rate. ▶

Hypoglycemia is a medical emergency that might be caused by DM treatment (intensive) and impaired protective mechanisms against hypoglycemia. Its clinical manifestations are due to sympathetic overactivity and neuroglycopenia.

Case presentation, examination of DKA can provide provisional diagnosis, and should be confirmed by comprehensive blood and urine lab investigation including measuring blood glucose, KB, pH, pCO₂, electrolytes, osmolality, protein, and kidney function test; anion gap calculation; hematocrit; and urine glucose and KB.

THANK YOU!

