CASE REPORT

Supraventricular tachycardia as a complication of severe diabetic ketoacidosis in an adolescent with new-onset type 1 diabetes

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SUMMARY

Diabetic ketoacidosis (DKA) is one of the most common causes of morbidity and mortality in new-onset type 1 diabetes (T1D). Supraventricular tachycardia (SVT), however, is a very rare complication of DKA. We present the case of a patient with new-onset T1D who presented with DKA. He received intravenous fluid resuscitation, insulin and potassium supplementation and subsequently developed SVT, confirmed on a 12-lead electrocardiograph despite a structurally normal heart. Vagal manoeuvres and adenosine failed to restore sinus rhythm, but flecainide was successful. We conclude that SVT can occur as a complication of DKA, including in new-onset T1D. Our case is the first of this phenomenon occurring in new-onset childhood diabetes, as the few prior documented cases had established diabetes. Furthermore, a combination of potassium derangement, hypophosphataemia and falling magnesium levels may have precipitated the event.

BACKGROUND

There are 65 000 children diagnosed with type 1 diabetes (T1D) every year, with an incidence in Ireland of 28.8 cases/100 000/year, a population incidence, which according to a recent publication, has stabilised in recent years. This confirms Ireland as a high-incidence country for diabetes, with the highest incidence in the 10–14-year age group.^{1 2} Diabetic ketoacidosis (DKA) is one of the most serious and common complications of diabetes, with between 15% and 70% of new-onset T1D worldwide, presenting in DKA.^{3–5} In new-onset T1D, 83% of deaths are due to DKA (66%) or hyperglycaemia (33%), with cerebral oedema, a complication of DKA, the most common cause of death in children under 12 years.⁶ A small proportion succumbs to a 'dead in bed' syndrome, where nocturnal hypoglycaemia has been hypothesised as a cause of dysrhythmias, especially if the patient has recently commenced insulin.⁷

Arrhythmias are a rare complication of DKA with only three other published case reports of supraventricular tachycardia (SVT), one other case of ventricular tachycardia and one of atrial fibrillation.^{8–11} SVT is the most common childhood arrhythmia with an incidence of 35 per 100 000 person-years in the general population and a prevalence of 0.1%–0.4% in the paediatric population.^{12–14} In children, SVT is most commonly caused

by either an atrioventricular reentrant tachycardia (AVRT) (72%–73%) or an atrioventricular nodal reentrant tachycardia (AVNRT) (9%–13%).^{15 16} An AVRT is caused by an accessory pathway bypassing the AV node and is the most common mechanism in infants.^{12 13} This can be a visible accessory pathway, for example, Wolff-Parkinson-White Syndrome or a concealed pathway.^{12 13} An AVNRT is confined to the AV node and surrounding myocardium.^{12 13} The AV node has both a fast and a slow anatomical pathway. The electrical impulse moves through the fast pathway to reach the ventricles but to prevent a re-entry circuit, the impulse meets the impulse coming from the slow pathway and they cancel each other out. However, if there is a premature atrial contraction, for instance, it may enter the slow pathway, whereas the fast pathway is still refractory following a sinus discharge. By the time the impulse reaches the end of the slow pathway, the fast pathway is no longer refractory, and it may ascend the fast pathway. This slow-fast AVNRT recycles around the AV node resulting in SVT. SVT may also fall under the category of ectopic tachycardia, where enhanced atrial pacemaker automaticity arises from disturbed electrolytes and produces atrial extrasystoles.^{12 13}

CASE PRESENTATION

An 11-year-old boy presented to the emergency department with a 5-day history of lethargy, intermittent vomiting and a self-limiting 24-hour history of diarrhoea. He was febrile on the day of admission and subsequently collapsed with no loss of consciousness. Polydipsia and polyuria were not major symptoms. On admission, he had a Glasgow Coma Scale of 14/15 responding to voice only. He was pale, tachypnoeic with Kussmaul breathing and showed signs of shock (poor perfusion and tachycardia), but he was not hypotensive.

Hyperglycaemia (blood glucose 41.6 mmol/L) was noted on the venous blood gas which also showed a pH of 6.9 (7.35–7.45), pCO₂ 3.4 kPa (4.7–6.0), lactate of 4.2 mmol/L (0.4–1.3), base excess –27.3 mmol/L (–2 to +2) and bicarbonate of 4.9 mmol/L (21–28) consistent with severe DKA. He had hyperkalaemia (potassium 6.8 mmol/L (3.5–5)), but no electrocardiography (ECG) changes were noted.

A resuscitation 10 mL/kg bolus of normal saline was given, and maintenance fluids with a

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Table 1 Renal profiles

Hours since admission	3	6	10	15	17	20	22	24	26	30
Sodium mmol/L (135–145)	149	150	150	155	158	160	158	157	156	153
Corrected sodium	148.0	147	–	154	155.6	161	–	155.5	155.4	151.5
Potassium (3.5–5.1)	4.1	4.5	4.3	4.7	3.8	–	3.8	4	4.1	3.8
Urea (2.8–8.4)	17.8	14.7	12.5	9.9	9.2	7.7	7.5	7.5	6.9	6.5
Creatinine (49–90)	118	128	64	57	53	53	54	54	53	56
Phosphate (1–1.8)	0.75		0.64	0.87	0.64	0.66	0.64	0.52	0.5	0.51
Magnesium (0.7–1)	1.27		1.04	0.97	0.91	0.9	0.93	0.97	0.95	0.89
Calcium (2.1–2.65)	2.93		2.75	2.71	2.72	2.71	2.75	2.65	2.63	2.6

replacement for the deficit were commenced, calculated to correct over a 48-hour period. Insulin was started at 0.1 units/kg/hour as per the British Society of Paediatric Endocrinology and Diabetes (BSPED) 2009 guidelines for the management of DKA, which includes pre-emptive potassium chloride supplementation once urine has been passed and potassium is falling to within normal ranges. The child was transferred to the general intensive care unit. Prerenal failure secondary to severe dehydration was noted, with creatinine 293 $\mu\text{mol/L}$ and urea 18.2 mmol/L, but this quickly improved with rehydration (table 1). The acidosis was gradually corrected as expected (table 2). The thyroid function tests suggested a sick euthyroid state (table 3). The corrected sodium levels remained satisfactory (table 1). Subsequently, brief runs of SVT were noted on the cardiac monitor 19 hours since admission, the longest of 5 min duration with no haemodynamic compromise. This was confirmed by a 12-lead ECG (figure 1). He remained asymptomatic. There was no history of arrhythmias or family history of cardiac events. He had a normal echocardiogram, and the SVTs were attributed to the preceding metabolic disturbances associated with DKA. Occasional ectopic atrial extrasystoles were noted in between the runs of self-limiting SVT (figure 2). There was a brief decrease in systolic blood pressure (baseline BP 114/71 mm Hg fell to 102/69 mm Hg) when the extrasystoles occurred. A sustained episode of SVT >1 hour duration occurred that evening, 30 hours since the initial presentation. Valsalva manoeuvres were unsuccessful. Electrolytes were confirmed as being normal (table 1). Adenosine was administered starting at 100 $\mu\text{g/kg}$ and then 150 $\mu\text{g/kg}$ and 300 $\mu\text{g/kg}$, all of which were unsuccessful in achieving sustained normal sinus rhythm (figure 3). He was haemodynamically stable throughout (BP 119/82 mm Hg via an indwelling arterial line). Flecainide (2 mg/kg) was commenced and successfully converted the child back to normal sinus rhythm after 10 min. Thereafter, he continued to receive intravenous flecainide and was switched to 50 mg 8 hours orally by the following morning. An asymptomatic SVT recurred the following morning, 7 hours since the previous SVT and 1 hour prior to when his first oral dose of flecainide was due. This subsequently resolved after administration of

flecainide. The ECG was closely examined for signs of an accessory pathway consistent with Wolff-Parkinson-White syndrome, but none were evident.

OUTCOME AND FOLLOW-UP

The DKA fully resolved (table 3), and he was commenced on the standard management for patients with newly diagnosed T1D; subcutaneous insulin using multiple daily injections (basal/bolus). Since then, he has a normal sinus rhythm with no further atrial extrasystoles, but he continued to take oral flecainide for some weeks.

DISCUSSION

Thomas *et al* describe two teenage girls (13 and 14 years, respectively) who were diagnosed during childhood with T1D.⁹ The first girl had hyperkalaemia (potassium 7.3 mmol/L), was severely acidotic (pH 6.93, bicarbonate 6.8 mmol/L) and after 4 hours of insulin and fluid resuscitation, developed SVT with a heart rate of 220 beats per minute (bpm). The SVT was terminated with ice water to the face. The second 14-year-old presented with a pH of 7.26 and potassium 4.4 mmol/L and developed an SVT similar to the case above, which responded to adenosine. Faruqi *et al* described a 12-year-old girl with known T1D who was admitted with severe DKA and after 6 hours of insulin therapy, fluid resuscitation and potassium supplementation, developed SVT at a rate of 270 bpm, which failed to respond to adenosine and required synchronised cardioversion.⁸ All three cases demonstrate a history of T1D, whereas to our knowledge, our case is the first of a patient with new-onset T1D who presented with severe DKA and SVT.

The question these cases, including our own, raise is what role do ketoacidosis and electrolyte abnormalities play in the development of arrhythmia? Our case differs from previous cases in both gender and age but remains similar biochemically with a similarly severe degree of acidosis. Furthermore, all four cases in total had received supplemental potassium, and the acidosis was resolving prior to SVT onset, which may suggest a precipitating clinical

Table 2 Blood gas results and fingerprick capillary blood glucose and ketone results

Hours since admission	0	1	5	18	20	22	25	29	31	32	33
Glucose (3.8–6)	54.3	41.6	26.4	17.4	–	–	7.5	4.5	6.4	7	10.4
Ketones			5.1	2.9	0.7	–	0.3	–	–	–	0.1
pH (7.35–7.45)			6.9	7.37	–	7.38	7.41	7.42	7.41	7.42	7.39
pCO ₂ (4.7–6.0)			–	4.1	–	–	–	4.3	4.6	4.1	4.8
HCO ₃ (21–28)			4.9	17.3	–	19.5	20.3	20.8	21.6	20.1	21.8
Lactate (0.4–1.3)			–	0.7	–	–	–	0.8	0.8	0.9	1.2

HCO₃, bicarbonate; pCO₂, partial pressure of carbon dioxide.

Table 3 Blood test results—the thyroid function tests suggest a sick euthyroid state

Hours since admission	48	72	168
Glucose (3.8–6)	8.9	13.4	6.7
Ketones	0.2	0.1	
HbA1C (20–42)	80 mmol/mol		
Free T4 (8.7–15.8)	9.5 pmol/L		
TSH (0.73–3.9)	0.16 mIU/L		
Antithyroid peroxidase antibodies (0–5.6)	94.5 IU/mL		

HbA1C, glycosylated haemoglobin; T4, thyroxine; TSH, thyroid-stimulating hormone.

picture, which requires further study. The possible precipitating factors are the acidosis slowing the conduction pathways enabling a re-entry circuit to form, the electrolyte abnormalities sensitising the conduction pathways or a combination of both.¹⁷ DKA can also produce hypomagnesaemia and hypophosphataemia which can trigger SVT.¹⁸ In the current recommended guidelines for management of DKA, however, correction of hypomagnesaemia and hypophosphataemia are not recommended due to a lack of evidence.^{19–22} Regarding phosphate, prospective studies involving relatively small numbers of patients did not show clinical benefit from routine phosphate replacement.^{23–25} Phosphate therapy did not affect the duration of DKA, the dose of insulin required to correct the acidosis, speed of recovery and speed at which glucose, bicarbonate, pH and mental alertness returned to within normal ranges nor abnormal muscle enzyme levels or morbidity and mortality.^{24 25} The circulating phosphate levels in our case were quite low (table 1). DKA is associated with varying degrees of intracellular phosphate depletion.^{26 27} This is due to a combination of phosphate shifting across the cell membrane from the intracellular to the extracellular and severe hyperphosphaturia.^{26 27} Phosphate serum levels subsequently drop profoundly as a consequence of insulin administration.²⁸ The greater the initial acidosis, the greater the subsequent hypophosphataemia.²⁸ Our patient's profound serum hypophosphataemia suggests an even greater total body phosphate depletion. Severe hypophosphataemia can occur but is usually asymptomatic due to the absence of prior chronic phosphate deficiency. Moreover, phosphate supplementation may precipitate hypocalcaemia.^{29 30} There is no reference to magnesium supplementation in any of

Figure 2 Presence of atrial extrasystoles.

the current guidelines including National Institute for Health and Care Excellence, BSPED and the International Society of Paediatric and Adolescent Diabetes.

Acidosis has a well-known effect on cardiac rhythms.¹⁴ Reducing the extracellular pH from pH 7.4 to more acidic values, for example, pH 6.95 or pH 6.5 produces a small decrease in the rate of action potential upstroke, for example, at a pH of 6.5, the upstroke velocity is reduced by 9% as demonstrated in animal studies.^{31 32} Furthermore, the junctional resistance between myocardial cells is increased by about 30% if the pH falls by 0.4 units.^{31 32} This reduction in conduction velocity can enable a reentrant arrhythmia to form in a structurally normal heart in which an acidic region is present.¹⁴ However, as the acidosis was resolving in this and the previous cases, this suggests that electrolyte shifts, and hypophosphataemia and hypomagnesaemia are more likely to cause SVT.

As all cases in these studies had a normal echocardiogram, the likely cause is an atrioventricular nodal re-entry tachycardia without an accessory pathway which is more associated with adolescence and can be triggered by hypo/hyperkalaemia.¹⁵ Re-entry describes a constant unidirectional conduction around regions of the myocardium which have pathologically or, as in this case, physiologically altered conduction forming

Figure 1 SVT run which self resolved—19 hours since admission. bpm, beats per minute; SVT, supraventricular tachycardia. **Figure 3** The effect of the first dose of adenosine—31 hours since admission. bpm, beats per minute; SVT, supraventricular tachycardia.

an incessant short circuit.¹⁵ It may also fall under the category of ectopic tachycardia with the atrial extrasystoles where enhanced atrial pacemaker automaticity arose from disturbed electrolytes, for example, potassium.¹⁵ The atrial extrasystoles may have originated from the metabolic derangements and then precipitated the SVT.¹⁵ In this case, hypokalaemia would explain both the premature atrial contractions and the SVT through enhanced atrial automaticity, but the potassium was only at the lower limits of normal at its nadir. DKA, however, can result in very rapid potassium derangements which may be undetected.¹⁵ Although serum potassium levels were generally well controlled, intracellular potassium homeostasis was likely to be seriously disturbed and is probably a major contributor to the genesis of the arrhythmia. Furthermore, with appropriate insulin and fluid therapy as the acidosis reversed, potassium is concomitantly forced into cells resulting in rebound hypokalaemia.¹⁵ Our patient's falling magnesium levels could also have precipitated the SVT.³⁰ ATPase pumps in the myocardium are dependent on magnesium, and reduced magnesium alters membrane potential, irritates the myocardium and results in an increased frequency of supraventricular beats.³³ Finally, a recent prospective case-control study by Dahlqvist *et al* was the first to demonstrate an increased incidence of atrial fibrillation in T1D in adults, suggesting that atrial fibrillation and other arrhythmias may be another manifestation of end organ damage in chronic diabetes.³⁴ This demonstrates the impact which prolonged hyperglycaemia can have on the cardiac conduction system despite the fact that this particular study focused on adults with long-standing diabetes.

Overall, our patient has profound and complex derangements, which suggest a greater risk for cardiac complications. One could argue that phosphate and magnesium supplementation may have prevented the SVT despite the lack of evidence for routine supplementation in DKA. Furthermore, future patients with complex derangements may benefit from continuous ECG monitoring although there is a lack of evidence to support this. In the profoundly unwell patient with severe DKA, cardiac monitoring forms a routine part of intensive care. Ultimately, prevention and cure of these arrhythmias depend on correction of these metabolic and electrolyte derangements. Predicting their occurrence is more challenging.

Learning points

- Supraventricular tachycardia (SVT) can occur as a complication of diabetic ketoacidosis in the absence of underlying heart disease, and the risk is increased by the electrolyte, acid-base and fluid balance disturbances, as in previous case reports.
- Flecainide is the next most appropriate step after adenosine in cases of refractory SVT in paediatric cases due to a faster response time when compared with amiodarone.
- Although evidence for phosphate and magnesium supplementation is lacking, a case could be made for administering these electrolytes if a spontaneous arrhythmia occurs.

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