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Learning from errors

Continuous renal replacement treatment and the 'bleeding patient'

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A woman suspected of intra-abdominal bleeding with end-stage renal failure requiring maintenance haemodialysis was treated with continuous veno-venous haemodiafiltration in the intensive care unit. The use of citrate restricted to the extracorporeal circuit maintained continuity of treatment and avoided the adverse affects of systemic anticoagulation. Regional citrate anticoagulation was achieved using the 'modified' Alabama Protocol. A description of the protocol is included along with troubleshooting instructions. Violations of the protocol challenged the adequacy of workforce training and patient monitoring, which saw systemic ionised calcium level reach 0.62 mmol/litre and base deficit drop −14.7. After protocol transgressions were corrected the patient was successfully treated and satisfactory biochemical control achieved without placing the patient at increased risk of bleeding. Training and vigilance in the use of citrate is essential to maintain patient safety.

BACKGROUND

The use of citrate is an effective strategy for the anticoagulation of the continuous renal replacement treatment (CRRT) circuit.[1 2] The success of the technique depends on careful monitoring of citrate and supplemental calcium to prevent the development of metabolic derangements. A number of protocols are reported in the literature that have been designed to deliver regional citrate anticoagulation for continuous veno-venous haemodiafiltration (CVVHDf).[3 4] The 'Alabama Protocol' (AP) for pre-dilutional CVVHDf developed by Tolwani and associates[5] has been modified for use in an Australian medical-surgical intensive care unit (ICU).[6] Modifications to the original AP include differences in the preparation of the replacement fluid and dialysate solution and in the preparation of the calcium gluconate infusion, a number of minor alterations in the setup and operation of CVVHDf, and several changes in the desired range of values used to monitor the effect of citrate metabolism and coagulation activity. An overview of the 'modified' AP is shown in table 1 with a detailed description on what is required to operate the technique. The purpose of the case report is to describe a patient who required renal support and was actively bleeding and to emphasise the need for vigilance when using citrate. The project was registered as a quality assurance initiative with the relevant hospital quality improvement committee.

CASE PRESENTATION

A 69-year-old woman presented to the emergency department having collapsed at home with severe generalised abdominal pain. CT scan showed a large intraperitoneal bleed. She had a recent medical history of multiple myeloma and end-stage renal failure secondary to diabetic nephropathy for which she received regular intermittent haemodialysis. She was intubated and transferred to the ICU where she required positive pressure ventilation, supplementation of intravascular volume and vasopressor support (noradrenaline 0.2 µg/kg/min). Her worst (APACHE) III score in the first 24 h of admission was 148 points.

On admission to ICU, her arterial blood gas was pH 7.31, $PaCO_2$ 30 mm Hg, PaO_2 266 mm Hg and base excess (BE) −10, with a serum sodium of 137 mmol/litre, potassium 4.5 mmol/litre and creatinine 286 µmol/litre. Two hours later, arterial pH was 7.16 and her serum potassium concentration was 5.9 mmol/litre. She was coagulopathic with an international normalised ratio (INR) of 1.6 and an activated partial thromboplastin time (aPTT) of 84.1 s. Her haemoglobin level had dropped from 100 g/litre at ICU admission to 79 g/litre. A mesenteric angiogram confirmed intraperitoneal haemorrhage mandating surgery but did not show the source of bleeding. It was judged that renal insufficiency and the biochemical abnormalities would increase the risks of surgery, but anticoagulants would increase the risk of further bleeding. The problem was addressed using the modified AP.

A pre-existing 14.5-Fr double-lumen haemodialysis catheter (HemoGlide; Bard Access Systems Inc., Salt Lake City, Utah, USA) tunnelled into the right internal jugular vein was used for vascular access, and pre-dilutional CVVHDf performed using the Prismaflex CRRT machine (Gambro AB, Stockholm, Sweden) with a Hospal 100ST haemofilter (Lyon, France). The layout of the circuit is shown in figure 1. Before treatment her total calcium concentration (Ca_{TOTAL}) was 1.53 mmol/litre, systemic ionised calcium concentration (iCa^{2+}) 0.86 mmol/litre and BE −9.4. In accordance with the protocol in table 1, arterial and post-haemofilter blood was taken for analysis after 1 h's treatment. The results were outside the recommended parameters with a post-haemofilter iCa^{2+} of 0.46 mmol/litre, a systemic iCa^{2+} of 0.75 mmol/litre and a BE of −14.5. Supplemental calcium was given in excess of the protocol to correct systemic ionised hypocalcaemia. Following the administration of blood and replacement of haemostatic components, a decision was made to perform an exploratory laparotomy; the first circuit was electively terminated after 2 h.

At laparotomy the patient was found to have a large haemoperitonium and bleeding from a diseased spleen.

Table 1 Overview of the 'modified' Alabama Protocol (AP)

Indications:
- Patients at high risk of bleeding
- Patients suspected of heparin-induced thrombocytopenia (HIT)
- Rapid clotting of circuit without anticoagulation or recurrent clotting despite alternative anticoagulation strategy

Contraindications:
- Acute liver failure
- High volume haemofiltration >50 ml/kg
- High blood flow rates >200 ml/min

Solutions:
The modified AP uses solutions commercially available in Australia manufactured by Edwards Lifesciences (Toongabbie, Australia) but require additives to meet concentration specifications

0.5% Citrate replacement fluid

Citrate 14 mmol/litre
Na^+ 140 mmol/litre
Cl^- 99 mmol/litre
K^+ 1 mmol/litre
→ Haemofiltration solution citrate 14 mmol/l (AHK6022) 5 litre bag

Citrate 22.6 mmol
Na^+ 44.8 mmol
→ Add 200 ml of anticoagulant citrate dextrose solution formula A (ACDA-A) from 500 ml bag (AHB7898)

Final concentration:
92.6 mmol citrate in 5.2 litre (18 mmol/litre)
744.8 mmol Na^+ in 5.2 litre (143 mmol/litre)

K^+, Mg^{2+}, PO_4
→ Optional additives required to correct abnormalities as part of routine blood sampling

Note: citrate also chelates with Mg^{2+} – extra Mg^{2+} may be required

'No calcium' dialysate solution

Acetate 4.5 mmol/litre
Na^+ 110 mmol/litre
Cl^- 108 mmol/litre
K^+ 1 mmol/litre
Mg^{2+} 0.75 mmol/litre
Glucose 10 mmol/litre
→ Haemofiltration replacement fluid – No calcium (AHK6031) 5 litre bag

HCO_3 100 mmol
Na^+ 100 mmol
→ Add 100 ml 8.4% $NaHCO_3$

Na^+ 78 mmol
→ Add 20 ml 20% NaCl

Final concentration:
122.5 mmol base equivalent (acetate and HCO_3)
in 5.12 litre (24 mmol/litre)
720 mmol Na^+ in 5.12 litre (142 mmol/litre)

K^+, PO_4
→ Optional additives required to correct abnormalities as part of routine blood sampling

10% Calcium gluconate infusion (1 g/10 ml ampule):
Prepare a 50 ml syringe of undiluted 10% calcium gluconate (5 g/50 ml) and run as a continuous infusion using a separate central line (1 ml = 0.22 mmol of calcium ions)

Circuit priming:
Prime circuit with heparin 5000 U in 1 litre of 0.9% saline (contraindicated in patients diagnosed with HIT or if considered a high-risk of bleeding otherwise prime only with 0.9% saline). The priming solution can either be delivered to the patient or discarded before the return blood line is connected to the double lumen venous catheter

Initial settings
0.5% citrate replacement fluid:
- Run 0.5% citrate replacement fluid at flow rates between 1000 and 2000 ml/h

Note: 0.5% citrate replacement fluid at flow rates of 1000–2000 ml/h accompanied by blood flow rates of 100–200 ml/min results in extracorporeal circuit blood citrate levels of 3–6 mmol/litre and iCa^{2+} <0.35 mmol/litre sufficient to inhibit coagulation[5]

- Initiate 0.5% citrate replacement fluid at 1:1 ratio with 'no calcium' dialysate solution

'No calcium' dialysate solution:
- Initiate 'no calcium' dialysate solution at 1:1 ratio with 0.5% citrate replacement fluid (1000–2000 ml/h)
- Once treatment has commenced adjustments to the flow rate of the 'no calcium' dialysate solution can range from 1000–2500 ml/h

10% Calcium gluconate infusion:
Run 10% calcium gluconate infusion at:
- 10 ml/h if systemic iCa^{2+} <1.1 mmol/litre
- 8 ml/h if systemic iCa^{2+} >1.1 mmol/litre
- Adjust calcium gluconate infusion rate by increments of 1.5 ml/h

Note: termination of circuit *must* coincide with discontinuation of 10% calcium gluconate infusion

Blood flow:
- Initially run blood flow at 150 ml/min (once treatment has commenced adjustments to blood flow can range from 120–170 ml/min)

Monitoring
Baseline measurements (taken 1 h prior to commencement of treatment):
- Arterial blood gases (ABGs), urea and electrolytes (U&Es), liver function tests (LFTs), ionised calcium (iCa^{2+}) and total serum calcium (Ca_{TOTAL})

Measurements 1 h after commencement of treatment:
- Systemic iCa^{2+} and base excess (BE) (values obtained from ABGs taken from patient's arterial line)
- Post-haemofilter iCa^{2+} (value obtained from ABGs taken from return line of continuous renal replacement treatment (CRRT) circuit)

Note: blood samples taken from patient's arterial line and from return line of CRRT circuit must be drawn within 5 min of each other using an ABG syringe

Measurements 1 h post-change in either 0.5% citrate replacement fluid, 'no calcium' dialysate solution or 10% calcium gluconate infusion rates:
- Systemic iCa^{2+} and BE
- Post-haemofilter iCa^{2+}

Six hourly measurements once 0.5% citrate replacement fluid, 'no calcium' dialysate solution and 10% calcium gluconate infusion rates are stable:
- Systemic iCa^{2+} and BE
- Post-haemofilter iCa^{2+}

Twice daily formal laboratory blood tests (eg, at 05:00 and 20:00):
- ABGs, Ca_{TOTAL} (required to calculate 'calcium gap' – refer to 'citrate accumulation') and albumin

Daily formal laboratory blood tests (eg, at 05:00):
- U&Es, LFTs, PO_4, Mg^{2+}, full blood count, coagulation profile

Note: it is important iCa^{2+} measurements are derived using ion-specific electrode analysis available on some blood gas analysers. Measurement of plasma albumin by formal laboratory blood sampling is used to record Ca_{TOTAL} levels

Citrate accumulation:
Citrate accumulation can occur when not adequately metabolised by the liver or removal of citrate bound to calcium by diffusion/filtration is decreased due to a decline in membrane performance. The possibility of citrate accumulation can be determined by measurement of the 'calcium gap'. The term refers to the difference between iCa^{2+} levels versus Ca_{TOTAL} levels derived from plasma albumin and is calculated by subtracting the iCa^{2+} value from the Ca_{TOTAL} measurement (Ca_{TOTAL} minus iCa^{2+} = calcium gap). A calcium gap that is widening (>1.6 mmol/litre) suggests accumulation of calcium/citrate molecules is maintaining or increasing Ca_{TOTAL} levels but masking low levels of iCa^{2+} levels necessary for clotting to occur. The accumulation of free citrate ions leading to a metabolic acidosis can also be detected when blood gas analysis show the development of a high anion gap

Continued

Table 1 Continued

Desired range of values:
► BE −5 to +5 (fluctuations in blood pH due to alternative causes make the value less reliable as a marker of citrate activity)
► Systemic iCa^{2+} 0.9–1.2 mmol/litre
► Post-haemofilter iCa^{2+} 0.2–0.4 mmol/litre
Trouble shooting
Premature clotting (post-haemofilter $iCa^{2\pm} \geq 0.4$ mmol/l):
► ↓ 10% Calcium gluconate infusion rate by 1.5 ml/h (if systemic $iCa^{2+} > 1.1$ mmol/litre)
or
► ↑ 0.5% Citrate replacement fluid rate by 100 ml/h (if systemic $iCa^{2+} < 1.1$ mmol/litre)
consider
► ↓ 'No calcium' dialysate solution rate by 100 ml/h
Infinite clotting time (post-haemofilter $iCa^{2\pm} \leq 0.2$ mmol/l):
► ↓ 0.5% Citrate replacement fluid rate by 100 ml/h
Hypocalcaemia ($iCa^{2\pm} \leq 0.9$ mmol/l):
► ↑ 10% Calcium gluconate infusion by 1.5 ml/h (if systemic $iCa^{2+} < 0.8$–0.9 mmol/litre)
or
► ↑ 10% Calcium gluconate infusion by 3 ml/h (if systemic $iCa^{2+} < 0.8$ mmol/litre) and exclude citrate accumulation
Hypercalcaemia (systemic $iCa^{2\pm} \geq 1.2$ mmol/litre):
► ↓ 10% Calcium gluconate infusion by 1.5 ml/h
Metabolic alkalosis (pH ≥7.50, ↑BE≥ ±5):
► ↑ 'No calcium' dialysate solution rate by 100 ml/h
► ↓ 0.5% Citrate replacement fluid rate by 100 ml/h
Metabolic acidosis (pH ≤7.30, ↓BE ≤−5):
► Exclude possibility of citrate accumulation (refer to 'specific actions required for citrate accumulation')
otherwise
► ↑ 0.5% Citrate replacement fluid rate by 100 ml/h
► ↓ 'No calcium' dialysate solution rate by 100 ml/h
Note: adjustments made to the flow rate of the 0.5% citrate replacement fluid or the 'no calcium' dialysate solution can alter the proportion of solute clearance that is achieved by filtration or diffusion. Although the distribution between filtration and diffusion may change, the total effluent rate prescribed will remain the same provided an increase/decrease in the 0.5% citrate replacement fluid is matched by a similar decrease/increase in the 'no calcium' dialysate solution
Citrate accumulation:
► Citrate accumulation may cause worsening acidosis
Investigate:
► ↓ pH/BE and ↑ anion gap (exclude other possible causes, eg, lactic acidosis)
► Calcium gap ($Ca_{TOTAL} - iCa^{2+}$) >1.6 mmol/litre
Note: the production of a natural buffering system due to citrate accumulation will resist changes in blood iCa^{2+} levels. This may result in a systemic iCa^{2+} level <0.9 mmol/litre and post-haemofilter $iCa^{2+} > 0.4$ mmol/litre
Management:
► ↓ 0.5% Citrate replacement fluid rate by 200 ml/h
► ↑ 'No calcium' dialysate solution rate by 200 ml/h
► Recheck systemic iCa^{2+}, Ca_{TOTAL}, pH, BE in 1 h post-change
► Consider alternative anticoagulant strategy if problem persists

The 'modified' Alabama Protocol is designed to deliver regional citrate anticoagulation for pre-dilutional continuous veno-venous haemodiafiltration using a wide range of haemodialysis/haemofiltration dose prescriptions (effluent range 2000–4500 ml/h). Regional anticoagulation is achieved with a 0.5% citrate concentrate in the replacement fluid along with a bicarbonate-based, calcium-free solution as the dialysate. The subsequent chelation of calcium impedes the coagulation cascade in the extracorporeal circuit. On return of blood to the patient, citrate bound to calcium is diluted (extracorporeal blood flow 120–170 ml/min mixes with central venous blood of approximately 5000 ml/min) and ionised calcium released when citrate is rapidly metabolised by the liver. To replace lost calcium diffused/filtered across the membrane bound with citrate supplemental calcium is delivered through a separate central line and systemic anticoagulation avoided by maintaining adequate ionised calcium levels. Alterations to the replacement fluid and dialysate solution are made in 100 ml/h increments and normal systemic ionised calcium levels maintained by changing the infusion rate of replacement calcium in 1.5 ml/h adjustments. The action of citrate as a buffering agent and the effect on acid-base balance when metabolised by the liver, along with the monitoring of systemic and post-haemofilter ionised calcium levels on coagulation activity, is central to the management of the protocol.

Histopathology showed marked congestion and white pulp atrophy with extensive destruction of lymphoid follicles. After surgery she remained unstable and needed further replacement of intravascular volume and vasopressor support. Fresh frozen plasma and platelets were administered in response to ongoing bleeding and the abnormal coagulation (INR 1.5; aPTT 55.4). Despite continuous haemoserous seepage from the wound, minimal drainage was observed from the two abdominal drain sites. On day 2 she was given a second course of CVVHDf using regional citrate anticoagulation. Four adjustments to the original settings were necessary until the circuit was electively taken down after 16.5 h. The systemic iCa^{2+} concentration outside the desired range of values was attributed to violations in the application of the protocol (systemic iCa^{2+} of 0.62 mmol/litre; BE of −13.7). The blood flow had operated at 200 ml/min with the dialysate solution (containing no calcium) at 2000 ml/h and the 0.5% citrate replacement fluid at 1000 ml/h. This had created a mismatch between the delivery rate of blood and exchange of dialysate beyond the capacity of the protocol. After review of the protocol, the dialysate flow rate was decreased to establish a 1:1 ratio with the replacement fluid; blood flow was reduced to 150 ml/min and the calcium gluconate infusion to 16 ml/h higher than the suggested 10 ml/h to correct systemic ionised hypocalcaemia. Four hours later, post-haemofilter iCa^{2+} was 0.39 mmol/litre, a systemic iCa^{2+} of 0.83 mmol/litre and BE of −6.3.

A continuing drop in haemoglobin concentration and the suspicion of ongoing bleeding despite supplementation of coagulation factors throughout day 2 led to a return to the operating room. Generalised seepage was observed from the splenic bed and subhepatic space, a large clot was removed and gauze packs were placed. On return from surgery she was haemodynamically stable and no longer required vasopressor support. A third CVVHDf circuit was established on day 3 for 13.5 h until high negative pressures suggested insufficient flow from the blood line 'access' port. A fourth circuit was suspended after 3 h for the same reason.

Her postoperative recovery was complicated by severe bradycardia and requirement for insertion of a temporary

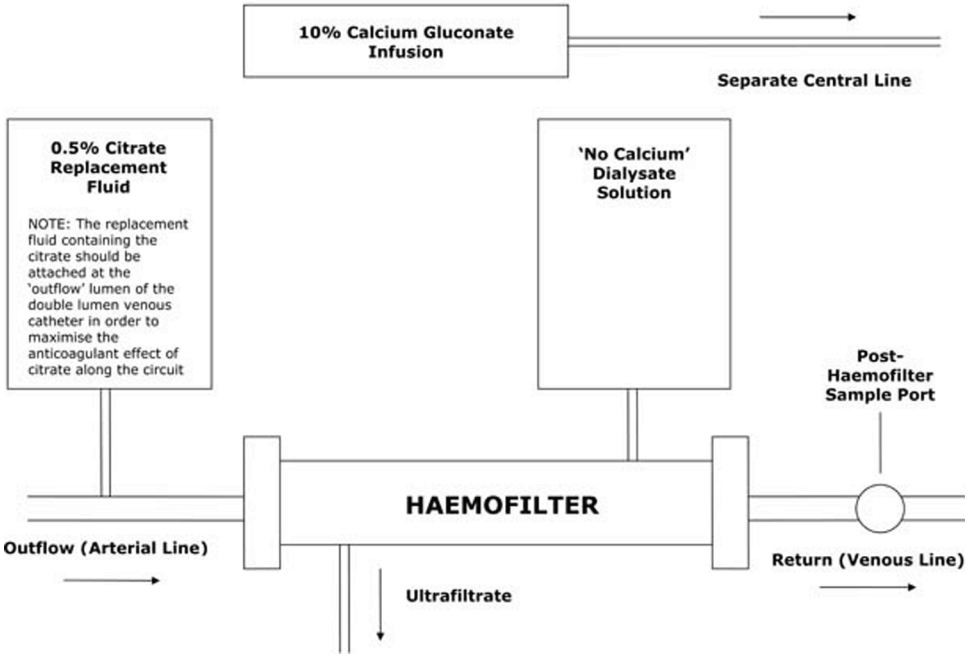

Figure 1 The 'modified' Alabama Protocol set-up for pre-dilutional continuous veno-venous haemodiafiltration (CVVHDf).

cardiac pacing wire. She continued to receive CVVHDf using regional citrate anticoagulation until biochemical markers on day 4 indicated normalisation of blood parameters (pH 7.38; BE –3; K^+ 4.3 mmol/litre; Na^+ 138 mmol/litre; creatinine 177 µmol/litre; urea 6.8 mmol/litre). The abdominal packs were removed on day 5. CVVHDf using low-dose heparin was recommenced on day 6. She was extubated after 8 days. On day 13 she was transferred to the high dependency unit (HDU) and scheduled to receive conventional intermittent haemodialysis.

OUTCOME AND FOLLOW-UP

A pleural effusion and gastrointestinal bleeding from colonic polyps prolonged the patient's recovery in HDU. The temporary cardiac pacing wire was removed and a permanent pacemaker inserted. She was admitted to the general medical ward on day 18 but continued to experience complications related to the effects of multiple myeloma and end-stage renal failure. She expressed a wish not to escalate the treatment. There was deterioration in her condition and following instigation of a programme of palliation the patient died 26 days after admission to hospital.

DISCUSSION

The use of anticoagulation in CRRT is usually necessary to sustain circuit life and maximise continuity of treatment.[7] In cases of suspected or high-risk of bleeding the use of anticoagulant agents can have adverse consequences for the patient. Several strategies may be used to reduce the risk of systemic anticoagulation but have limited success or are difficult to implement. Anticoagulation-free CRRT is an option in patients who are severely coagulopathic but may deliver unsatisfactory circuit life should the patient's coagulation profile change following the administration of clotting factors.[8] The alternative strategy of regional anticoagulation attempts to reduce the risk of systemic bleeding by restricting the effect of the anticoagulant agent to the circuit. This strategy has been applied to the administration of heparin delivered pre-haemofilter, but demands careful adjustment of the antagonist protamine delivered post-haemofilter and requires the close monitoring of coagulation parameters to ensure the anticoagulant effect of heparin is restricted to the circuit.[9] The benefit of regional anticoagulation has also been practised using citrate to anticoagulate the circuit by the chelation of calcium. Systemic anticoagulation is prevented by the removal of citrate bound to calcium during diffusion/filtration, and after dilution has occurred, when blood is returned to the patient, citrate is rapidly metabolised by the liver. The use of citrate with CRRT has not been widely adopted in Australia due to apprehension over increased treatment complexity, risks of metabolic complications and availability of suitable replacement fluid/dialysate solution. The modified AP is an attempt to address the concerns raised in regards to its application.[6]

The relation between acid-base balance and the metabolism of citrate is important to understand before choosing to use regional citrate anticoagulation. Upon entering the body, citrate (tri-sodium citrate) is converted to citric acid prior to its metabolism (Na_3 citrate + $3H_2CO_3$ ↔ citric acid + $3NaHCO_3$). The metabolism of citrate will also provide additional bicarbonate (1 mmol of citrate = 3 mmol of bicarbonate). Citric acid is then metabolised rapidly (plasma half-life ~5 min) in the mitochondria of the liver, skeletal muscle and the kidney as part of the Kreb's cycle to produce H_2O and CO_2 (citric acid ↔ $3H_2CO_3$ + H_2O + $3CO_2$ ↔ $4H_2O$ + $6CO_2$).[10] An excessive amount of citrate will be quickly broken down by a normal liver and may lead to a metabolic alkalosis. The presence of significant liver impairment will limit the metabolism of citric acid causing the development of a metabolic acidosis and a raised anion gap. It is not uncommon that a mild metabolic

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alkalosis will result when the modified AP is followed correctly, but while the protocol can be used on patients who have chronic stable liver impairment, a metabolic acidosis due to citrate accumulation will occur in patients with acute liver failure and is a contraindication in the use of the protocol.

The case report deals with the management of a patient with end-stage renal failure actively bleeding secondary to an underlying diagnosis of multiple myeloma. This was achieved using the modified AP to deliver regional citrate for pre-dilutional CVVHDf without aggravating an existing coagulopathy and the return of near normal coagulation parameters (aPTT 38.4 s and INR 1.4). Overall metabolic stability (acid-base and electrolyte control) was achieved within 48 h despite suspension of treatment for surgery on two occasions (pH 7.38; BE −4; K^+ 4.6 mmol/litre; Na^+ 138 mmol/litre). A major concern was the development of systemic ionised hypocalcaemia (systemic iCa^{2+} 0.62 mmol/litre), which may have been accelerated by mild hypocalcaemia on admission to hospital. Explanation as to why the patient was hypocalcaemic is not known but may have been caused by poor dietary intake and chronic renal insufficiency. Nevertheless, the profound drop in systemic iCa^{2+} concentration observed can be attributed to the 'calcium free' dialysate initially running at double the rate of the replacement fluid with a higher dialysis flow rate causing an increase in the diffusion of iCa^{2+} out of the blood. The blood flow operated at 200 ml/min outside the 120–170 ml/min limit allowed in the protocol. This caused the concentration of citrate within the circuit to become diluted and the anticoagulant effect of citrate to be diminished. As a result post-haemofilter iCa^{2+} concentration was higher (0.62 mmol/litre) than desired when reference was made to the protocol (post-haemofilter iCa^{2+} <0.4 mmol/litre). Transgressions away from the protocol also created a large systemic base deficit to develop (−14.7) suggesting the accumulation of free citrate ions a possible factor that contributed to the patient's worsening metabolic acidosis. The accumulation of citrate in the body was possibly caused by blood flow through the circuit being set at a higher rate than allowed in the protocol. Citrate contained in the replacement fluid was delivered through the circuit and entered the patient above the capacity of a normal functioning liver to prevent the accumulation of free citrate ions. The patient had no recent history of significant liver impairment, which could otherwise account for a reduction in the metabolism of citrate. Measurement of the anion gap and the gap between total and ionised calcium levels is recommended in the protocol to indicate the possibility of citrate accumulation. Although the calcium gap (Ca_{TOTAL} 1.86 mmol/litre – systemic iCa^{2+} 0.88 mmol/litre = 0.98 mmol/litre) was not above the protocol's threshold of >1.6 mmol/litre, the anion gap recorded on the blood gas analysis machine was high (26 mmol/litre).

The case report highlights the advantages of regional citrate anticoagulation and the effectiveness of the modified AP for pre-dilutional CVVHDf in patients who are coagulopathic and have evidence of bleeding. It also focuses attention on the need for medical and nursing staff to receive adequate training before regional citrate anticoagulation is introduced as an alternative anticoagulant strategy. The development of a training programme must include theoretical understanding and operational experience in using the modified AP. Once introduced into clinical practice continued vigilance in the application of the protocol is required along with the correct interpretation of blood sampling used to monitor the metabolism of citrate and coagulation activity. The approach increases the complexity of CRRT and, as shown in this example, serious derangement of calcium homeostasis can result when protocols are violated. Once adjustments were made that conformed to the modified AP, the cause of systemic ionised hypocalcaemia was quickly reversed, while at the same time localised the maximum anticoagulatory effect of citrate to the extracorporeal circuit. As a result we were able to deliver adequate renal replacement treatment for the patient without increasing the risk of systemic bleeding.

Learning points

- The use of citrate restricted to the CRRT circuit is an effective anticoagulant to sustain circuit life while the adverse consequences of patient anticoagulation are avoided.
- The use of citrate increases the complexity of CRRT and requires adequate training and vigilance in its application.
- Protocols designed to deliver regional citrate with CRRT must be strictly followed to avoid derangement of calcium homeostasis and the potential for other metabolic disturbances.

Competing interests None.

Patient consent Obtained.

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