Severe Vancomycin Intoxication in an Infant Not Needing Dialysis: A Case Report and Literature Review

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Abstract

Vancomycin nephrotoxicity is a major clinical concern. We report the case of an infant with severe vancomycin intoxication. A literature review was conducted due to the paucity of reported pediatric cases. An infant was treated for suspected meningitis based on cerebrospinal fluid (CSF) cell count and was empirically started on intravenous ceftriaxone and vancomycin while awaiting the results of culture and meningitis/encephalitis polymerase chain reaction (PCR) tests. Day 2 vancomycin trough level was within the target range; however, the repeat day 4 levels were beyond the upper limit of measurement at >400 µg/mL and associated with acute kidney injury (AKI). Vancomycin was immediately discontinued. The child was treated with intravenous hydration and furosemide and did not require dialysis. The short-term kidney function outcome was reassuring. We identified 25 pediatric cases from 1992 to 2021 with high vancomycin serum levels. Vancomycin level ranges between 32–427 µg/mL. Toxic vancomycin serum levels >400 µg/mL were reported in only two patients. Nephrotoxicity developed in 73.9% of cases. Hemodialysis is the most common management intervention while some patients received watchful management. Kidney function impairment is transient in most reported cases, even in those who received no intervention. However, long-term data are lacking. An intervention is not indicated for all cases of vancomycin intoxication, regardless of serum level. However, in cases of severe nephrotoxicity resistant to medical measures or pre-existing kidney dysfunction, kidney replacement therapy (KRT) is needed to manage severe AKI and speed-up vancomycin clearance.

Introduction

Vancomycin is a glycopeptide antibiotic almost entirely excreted in urine [1]. Vancomycin exhibits variable protein binding with a median unbound fraction of 81.3% [2]. The volume of distribution is ~0.4–1.0 L/kg in adults and 0.57–0.69 L/kg in neonates [1,3]. Vancomycin clearance falls between 0.05 and 0.38 L/h/kg in critically ill children and largely depends on kidney function [4].

Measuring the minimum inhibitory concentration and targeting the “therapeutic range” of either the serum trough levels or the area under the curve can enhance efficacy and minimize the potential toxicity [5].

The incidence of vancomycin nephrotoxicity was 12.2% in a large pediatric cohort, and 19.9% if therapy lasted >3 days [6]. The risk of acute kidney injury (AKI) was linked to specific therapeutic vancomycin trough levels [7]. However, other studies did not find this association [6]. Additional risk factors for AKI in vancomycin-treated patients were reported [7].

We report the case of an infant with severe toxic vancomycin serum level >400 µg/mL who developed acute kidney injury (AKI). We defined toxic vancomycin level (TVL) as serum trough vancomycin level >50 µg/mL. The paucity of reported TVL in pediatric patients prompted us to conduct a literature review.

Case Presentation

A four-month-old girl presented to the emergency room (ER) of our center for fever. Oral cefprozil was prescribed. She was brought back the following day. She had no clear focus of infection and her C-reactive protein level was 113 mg/L. A full septic workup was performed, including a lumbar puncture. The patient did not show clinical signs of dehydration. Complete blood count results showed a white blood cell count (WBC) of 19.3 x 10^9/L, a neutrophil count of 7.14 x 10^9/L, and a lymphocyte count of 10.6 x 10^9/L. The patient was started empirically on a meningitis dose of intravenous ceftriaxone. Vancomycin 15 mg/kg/dose intravenously every six hours was added (5 mg/ml, infused over 120 min). Cerebrospinal fluid (CSF) analysis demonstrated WBC 22 x 10^6/L with 20% segmented cells, 54% lymphocytes, and 26% monocytes. CSF protein...
and glucose levels were normal, and the gram stain was negative. A decision was made to continue on antibiotics until the final CSF culture and meningitis/encephalitis polymerase chain reaction (PCR) results are obtained due to suspicion of partially treated bacterial meningitis. Respiratory viral PCR multiplex (RVM) results were negative. Initial urine analysis and microscopy showed specific gravity 1.005, WBC 3-5 /hpf, red blood cells 3-5 /hpf, negative nitrite and ketone, and protein trace.

The initial serum creatinine level was 36 µmol/L. The vancomycin trough level was within the target (17.1 µg/mL) prior to the fourth dose. On day 2 of therapy, the patient developed irritability and skin reaction. Redman syndrome was suspected. Dexamethasone and diphenhydramine were administered. Vancomycin infusion time was increased to 150 min. Her symptoms did not recur. The final CSF culture and meningitis/encephalitis PCR results were still pending. On day 3, she vomited a few times, after which she could tolerate oral nutrition. She also had a fever and was administered paracetamol. She was fairly hydrated and underwent repeat vancomycin trough level and kidney function tests on day 4 for routine monitoring. The vancomycin serum level was >158 µg/mL, which was beyond the upper limit of measurement (BULM) and serum creatinine had increased to 92 µmol/L; vancomycin was discontinued. On the same day, the final CSF culture and meningitis/encephalitis PCR results were negative. She was given one intravenous isotonic saline bolus of 10 ml/kg and then admitted to the pediatric intensive care unit for close monitoring and management. During the furosemide and fluid therapy, repeat vancomycin random serum levels continued to be BULM (>400 µg/mL after sample dilution) and serum creatinine was rising (Figure 1). The kidneys were enlarged on ultrasonography but with preserved cortico-medullary differentiation. Repeat RVM results were positive for rhinovirus which explains the development of transient fever during day 3 of admission.

FIGURE 1: Serum levels of vancomycin and creatinine of the patient in relation to intervention

The parent was counseled regarding hemodialysis (HD) but refused. Another two intravenous isotonic saline boluses were administered, one as 10 ml/kg and the other 20 ml/kg, within the first 12 hours after admission to PICU, in addition to continuous intravenous isotonic saline for hydration, and a 5 mg intravenous furosemide dose which resulted in a good diuresis response. Urine output (UOP) was not monitored accurately before the TVL was discovered but the patient was having normal wet diapers. Close monitoring of UOP was started after the first TVL. UOP was 2.0 ml/kg/h after the first isotonic saline bolus preceding any further treatment. Furosemide IV 5 mg was then given (0.83 mg/kg) followed by UOP 4.2 ml/kg/h during the first six hours, furosemide infusion (FI) was then started almost 11 hours later when UOP was 5.5 ml/kg/h. FI starting dose 0.07 mg/kg/h and fluid balances were monitored to avoid dehydration and overhydration. The dose range of FI was between 0.05-0.07 mg/kg/h for the first two days during which UOP ranged between 4.8-6.2 ml/kg/h. In the following two days, FI was decreased to 0.04 then 0.02 mg/kg/h, and then stopped on day 5 of furosemide therapy. The following day after stopping was FI 2.6 ml/kg/h. The calculated estimated insensible water losses were ~ 92 ml/day. Fluid balances during FI days ranged between negative 52 ml to positive 179 ml. The patient was kept on IV fluid and was allowed for adlib breastfeeding. IV fluid was decreased gradually until it was stopped a day after FI discontinuation. The patient remained well hydrated during FI therapy and maintained normal hemodynamic status. Serum creatinine level peak was at 134 µmol/L on day 5 after starting vancomycin therapy, then it gradually decreased to 45 µmol/L and vancomycin level decreased to 3.2 µg/mL on day 11. Since audiology service was unavailable, the hearing was to be assessed in an outpatient clinic to evaluate for ototoxicity but the patient was a no-show for the appointment. No proof of medication preparation or administration errors was identified. After discharge, the patient was lost to follow-up.
Discussion

Our literature review of pediatric patients with TVL identified 23 cases from 1992 to 2021 [8-27]. Table 1 presents a summary of the collected data.

| Article                  | Age (months) | Sex | Body Weight in kg | Pre-existing Abnormal Baseline Serum Creatinine and/or Abnormal Baseline Kidney Structure | AKI Risk Factor other than Vancomycin Dose | Peak Vancomycin Level (µg/mL) | AKI During Vancomycin Toxicity | Oligo-aneurysma | Intervention | Kidney Function Short Term Outcome | Irreversible Hearing Loss |
|--------------------------|--------------|-----|-------------------|-------------------------------------------------------------------------------------------|---------------------------------------------|-------------------------------|-----------------------------|-------------------------|--------------------------|-------------------------------|--------------------------|
| Present Case Report      | 4            | F   | 6.1               | NO                                                                                        | NO                                          | T >400                        | YES                         | NO                      | Furosemide/Hydration        | NL                          | UNK                      |
| Panzarino et al. [8]     | 14           | F   | 8                 | YES (CKD)                                                                                 | YES                                         | O                             | 337.6                       | YES                     | UNK                      | IHD/CHARC HP                | AB                        | NO                      |
| Bunchman et al. [9]      | UNK          | F   | 22                | UNK                                                                                       | YES                                         | UNK                           | 345                         | YES                     | YES                      | IHD                          | UNK                      | UNK                      |
| Bunchman et al. [9]      | UNK          | M   | 5.6               | YES (CKD)                                                                                 | YES                                         | UNK                           | 313                         | UNK                     | NO                       | IHD/CHARC HP                | UNK                      | UNK                      |
| Goyal et al. [10]        | 0.20         | M   | 3.73              | YES (ESKD)                                                                                | NA                                          | O                             | 240                         | NA                      | NA                       | CVVHDF                      | NA                       | UNK                      |
| Akil et al. [11]         | 204          | F   | 38                | YES (AKI)                                                                                 | YES                                         | O                             | 101                         | YES                     | YES                      | IHD (conventional)          | NL                       | NO                       |
| Wu et al. [12]           | 156          | M   | UNK               | YES (AKI)                                                                                 | YES                                         | T                             | 88.6                        | YES                     | UNK                      | NONE                         | NL                       | UNK                      |
| Stojil et al. [13]       | 26           | F   | 10                | YES (AKI)                                                                                 | YES                                         | O                             | 146                         | YES                     | YES                      | IHD (conventional)          | NL                       | NO                       |
| Wicklow et al. [14]      | 96           | M   | UNK               | NO                                                                                        | NO                                          | T                             | 45.8                        | YES                     | YES                      | IHD                          | NL                       | UNK                      |
| Bushori et al. [15]      | 1.53         | M   | UNK               | YES                                                                                        | YES                                         | O                             | 427                         | YES                     | YES                      | EBT/NGT CHARCOAL            | NL                       | NO                       |
| Miner et al. [16]        | 1.76         | F   | UNK               | YES                                                                                        | YES                                         | T                             | 305                         | UNK                     | NO                       | NONE                         | NL                       | NO                       |
| Miner et al. [16]        | 0.3          | F   | UNK               | YES                                                                                        | YES                                         | T                             | 368                         | YES                     | NO                       | NONE                         | NL                       | NO                       |
| Teising et al. [17]      | 1            | F   | UNK               | YES                                                                                        | YES                                         | T                             | 63.3                        | YES                     | NONE                     | NL                          | NO                       | NO                       |
| Muller et al. [18]       | 0.2          | M   | 2.39              | YES                                                                                        | YES                                         | O                             | 34.5                        | UNK                     | UNK                      | NONE                         | NL                       | NO                       |
| Muller et al. [18]       | 0.2          | F   | 1.685             | YES                                                                                        | YES                                         | O                             | 32                          | UNK                     | UNK                      | NONE                         | NL                       | NO                       |
| Baek et al. [19]         | 6            | F   | 5.34              | YES                                                                                        | YES                                         | O                             | 154                         | YES                     | UNK                      | NONE                         | NL                       | NO                       |
| Lemaire et al. [20]      | 2.4          | UNK | 3.3               | YES                                                                                        | YES                                         | O                             | 222                         | YES                     | NO                       | IHD                          | NL                       | NO                       |
| Sillhans et al. [21]     | 84           | F   | UNK               | YES                                                                                        | YES                                         | T                             | 213                         | YES                     | YES                      | IHD/SAINE/ALBUM/FUROSEMIDE | NL                       | NO                       |
| Urol et al. [22]         | 0.53         | F   | 1.38              | YES                                                                                        | YES                                         | O                             | 84                          | NO                      | NO                       | EBT                          | NL                       | NO                       |
| Lo et al. [23]           | 55           | M   | 15.5              | YES                                                                                        | YES                                         | T                             | 86                          | YES                     | YES                      | CVVHDF                      | NL                       | UNK                      |

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Four patients had pre-existing chronic kidney disease (CKD) or AKI [8,9,12,13], two had end-stage kidney disease (ESKD) maintained on kidney replacement therapy (KRT) [10,11], and three had unknown data [9,16,25].

After excluding two patients with ESKD, 95.2% had one or more risk factors for AKI other than vancomycin which included admission to the intensive care unit (ICU), birth <32 weeks of gestation, hypotension, sepsis, nephrotoxic medications, pre-existing AKI or CKD, extracorporeal membrane oxygenation, and liver transplantation. Sixteen patients (75.9%) developed AKI [8,9,12,17,19-21,25-27] based on the definition by the Kidney Disease Improving Global Outcomes (KDIGO) 2012. One patient had almost unchanged serum creatinine [22].

TVL >100 µg/mL was reported in 14 cases. Ten patients had medication overdose, one of which had inadvertently received an undiluted dose [16]. Only two had TVL >400 µg/mL [15,25].

KRT can help increase vancomycin clearance and hemodialysis assists with relatively better clearance compared to peritoneal dialysis which provides slow clearance because of the high molecular weight of the drug (~1450 Da) [1,28]. Twelve patients received KRT in the form of intermittent hemodialysis (IHD) in nine patients [8,9,11,15,14,20,21,25] or continuous KRT in three patients [10,23,24], versus seven patients who received watchful management [12,16-19]. The intended meaning of watchful management is that no intervention was done for TVL and the patient continued to be monitored. Median TVL in patients who received KRT was 231 µg/mL (IQR 123.5-525.3) compared to the median TVL of 85.6 µg/mL (IQR 34.5-305) in patients who received watchful management. Patients who received KRT included two patients with pre-existing CKD [8,9], two with ESKD; one received hemodiafiltration [11] and the other received continuous KRT [10], and two with unknown kidney function or structure status [9,25]. The patients who received watchful management had normal baseline kidney function and/or structure except one patient [12] and one had unknown kidney function and structure status [16]. All patients who received KRT, after excluding patients with ESKD [10,11], had developed AKI [8,9,15,14,20,21,25-27] except one in whom the status of kidney function was unknown [9]. Four of the seven patients who received watchful management had developed AKI [12,16,17,19] and kidney function data during intoxication was unavailable for the remaining three patients [16,18]. Of the nine patients who received IHD, high flux dialyzer was used in seven, a conventional membrane dialyzer was used in one [13], and an unclear membrane type in one [8]. In patients who received IHD, most of them needed 2-5 sessions of treatment; vancomycin levels dropped 70%-90% from pre-intervention to sub-therapeutic ranges after completing treatment. A rebound increase in the vancomycin levels was observed between the IHD sessions. IHD using the conventional membrane reduced TVL from 131 µg/mL to <20 µg/mL [13]. Continuous KRT decreased vancomycin level by 70%-87% after 22-41 h of treatment [10,23,24]. In patients who received KRT, the short-term kidney function outcome improved in nine patients [14,20,21,25-27], was unknown in two other patients [9], and one patient with CKD became dialysis dependent [8]. On the other hand, all patients who received watchful management had normal serum creatinine in the short term [12,16-19].

Two babies underwent exchange blood transfusion (EBT) [15,22]. One had TVL with AKI and received in addition charcoal via a nasogastric tube [15]. The measured TVL immediately before EBT and 30 minutes after EBT were the same. Afterwards, the vancomycin level gradually dropped to < 20 µg/mL over the following three days while AKI is resolving [15]. Subsequently, serum creatinine was restored to normal levels [15]. The other patient had TVL with no AKI [22]. TVL immediately after EBT decreased by 79.7% and then to <1 µg/mL over the following 36 hours. Therefore, no conclusion can be drawn regarding the use of EBT or charcoal via nasogastric tube for clearance of TVL.

| Study            | Gender | Age | AKI | TVL | EBT | No | IHD | KRT | CVVH | CVVHDF | F/UNK | NA | NL | UNK |
|------------------|--------|-----|-----|-----|-----|----|-----|-----|------|--------|-------|----|----|-----|
| Shah et al. [24] | 14 y   | F   | 39  | YES | T   | 250| YES | YES | CVVH | NA     | NL    | UNK | NL | UNK |
| Ulbrich et al. [25] | 10 y  | F   | 17  | YES | O   | 420| YES | NO  | IHD  | NL     | UNK   | NL | UNK | NL |
| Bash et al. [26]  | 9 y    | F   | 28.9| NO  | T   | 37 | YES | YES | FUREODIEME | NL     | UNK   | NL | UNK | NL |
| Pokorná et al. [27] | 0.1   | UNK| 3.5 | NO  | T   | 47 | YES | YES | FUREODIEME | UNK    | NL   | UNK | NL |

### TABLE 1: Literature review of pediatric patients with vancomycin intoxication

AKI, acute kidney injury; UNK, unknown; M, male; F, female; ESKD, end stage kidney disease; CKD, chronic kidney disease; NA, not applicable; NL, normal; AB, abnormal; O, overdose; T, therapeutic; IHD, intermittent hemodialysis; CHARC HP, charcoal hemoperfusion; CVVHDF, continuous veno-venous hemodiafiltration; CVVH, continuous veno-venous hemofiltration; IHDF, intermittent hemodiafiltration; EBT, exchange blood transfusion; NGT, nasogastric tube.
Two patients were treated with furosemide without dialysis [26,27]. One received furosemide infusion for several days, with serum creatinine being restored to normal [26]; the other had TVL of 47 μg/mL on day 6 with oliguric AKI on day 5. She was managed with furosemide. Vancomycin levels decreased to 30.6 μg/mL and serum creatinine level was 114 μmol/L on day 7, but no further data were available.

Watchful management was followed for seven patients, of whom six were between six days and six months of age [16-19] and one was older [12]. Four had associated nephrotoxicity (TVL 63-368 μg/mL) [12,16,17,19] and kidney function data during intoxication (TVL 32-305 μg/mL) was unavailable for three [16,18]. All patients had normal serum creatinine in the short term.

Our case had severe TVL and developed AKI stage 3 based on KDIGO AKI staging and had no other risk factors for AKI. The patient was started on furosemide therapy and intravenous fluid hydration. The short-term kidney function outcome was reassuring which is the same outcome in 17 (80.9%) of the reported 23 cases, after excluding patients with ESKD, regardless of whether intervention occurred and regardless of the severity of TVL. Only one patient with pre-existing CKD became dialysis-dependent [8]. The combination of vancomycin and furosemide therapy is thought to increase the risk of AKI [29]. We believe that such increased risk could be related to intravascular volume depletion caused by diuresis during concomitant vancomycin treatment. The use of furosemide in our patient was done while the patient’s hydration status was maintained to avoid intravascular depletion by using intravenous fluid in addition to allowing adlib breastfeeding.

Acute tubular necrosis is the most common histopathological finding in the kidneys of patients with vancomycin toxicity. However, acute tubulointerstitial nephritis (AIN) has been described [30]. Because skin rash is seen in both vancomycin reaction and AIN, assessment for kidney function should be considered in vancomycin-treated patients if skin rash develops. Direct toxicity to the kidney caused by vancomycin has been questioned by experts in nephrology [31]. However, in our reported case, the patient did not have any other AKI risk factors apart from TVL. Hence, our case could support the argument of vancomycin direct kidney injury.

Twelve out of 23 cases underwent formal hearing assessment. Eleven had normal hearing [13,15-22], except for one patient who had transient impairment which resolved in a follow-up repeat assessment [8]. A retrospective case series showed similar results [32]. The remaining eleven cases did not report hearing assessment.

This case report of a very rare event is limited by the lack of data on long-term outcomes. Such cases may be underreported—hence, more cases are needed to help standardize how to approach such patients and to help in predicting long-term outcomes.

Conclusions
In conclusion, TVL >400 μg/mL is rare in the pediatric literature. Children with TVL were managed differently and KRT was the most common intervention with encouraging short-term kidney function outcomes. Moreover, cases that received watchful management had favourable short-term outcomes, despite TVL >100 μg/mL in a few. Long-term kidney function outcome data were lacking. No irreversible hearing loss was found with TVL. Reporting of TVL in pediatric patients is recommended to help devise a protocol for the management of such cases and for predicting outcomes.

Additional Information

Disclosures

Human subjects: Consent was obtained or waived by all participants in this study. Institutional Review Board of King Abdullah International Medical Research Center, Riyadh, Saudi Arabia issued approval IRB/1216/22. The Institutional Review Board approved the study as a retrospective anonymized audit and waived the requirement of informed consent. No patient identity information, images, or videos are included in this study. Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: Payment/services info: All authors have declared that no financial support was received from any organization for the submitted work. Financial relationships: All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. Other relationships: All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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References
1. Rybak MJ: The pharmacokinetic and pharmacodynamic properties of vancomycin. Clin Infect Dis. 2006,
Kidney360. 2022, 3:1491-3.
Perazella MA:

Downes KJ, Hayes M, Fitzgerald JC, et al.: Development of vancomycin nephrotoxicity in children

Nielsen HE, Sørensen I, Hansen HE: 10.1177/0267659120973595

Ibach BW, Henry ED, Johnson PN: 10.1093/ndt/gfh900

Ulinski T, Deschênes G, Bensman A: Nephrol. 2000, 14:912-5.
Shah M, Quigley R: 10.1111/jcpt.13181
Lv M, Ma S, Chen N, Liu Y, Yu Z: 10.22038/APJMT.2016.6883
Panzarino VM, Feldstein TJ, Kashtan CE: Charcoal hemoperfusion in a child with vancomycin overdose and chronic renal failure. Pediatr Nephrol. 1998, 12:63-4. 10.1007/s004670050405
Bunchman TE, Valentinii RP, Gardner J, Mottes T, Kudelka T, Maxvold NJ: Treatment of vancomycin overdose using high-efficiency dialysis membranes. Pediatr Nephrol. 1999, 13:773-4. 10.1007/s004670050607
Goebel J, Ananth M, Lewy JE: Hemodialfiltration for vancomycin overdose in a neonate with end-stage renal failure. Pediatr Nephrol. 1999, 13:425-5. 10.1007/s004670050263
Akił IO, Mir S: Hemodialfiltration for vancomycin overdose in a patient with end-stage renal failure. Pediatr Nephrol. 2001, 16:1019-21. 10.1007/s00467000016
Wu CY, Wang JS, Chiou YH, Chen CY, Su YT: Biopsy proven acute tubular necrosis associated with vancomycin in a child: case report and literature review. Ren Fail. 2007, 29:1059-61. 10.1080/0886020701647775
Soyha A, Kasap B, Türkmen M, Kavuksu S: Hemodialysis with polysulfone membrane for vancomycin overdose in a child with acute renal failure already on acute peritoneal dialysis. Turkish J Nephrol. 2010, 19:154-6. 10.5262/trndt.2010.1002.71
Wicklow BA, Ogborn MR, Gibson IW, Blydt-Hansen TD: Biopsy-proven acute tubular necrosis in a child attributed to vancomycin intoxication. Pediatr Nephrol. 2006, 21:1194-6. 10.1007/s00467-006-0152-0
Burchart KK, Metcalf S, Shurnas E, O'Meara O, Brent J, Kulig K, Rumack BH: Exchange transfusion and multidose activated charcoal following vancomycin overdose. J Toxicol Clin Toxicol. 1993, 30:285-94. 10.3109/15563699209038639
Miner LJ, Faix RG: Large vancomycin overdose in two premature infants with minimal toxicity. Am J Perinatol. 2004, 21:433-8. 10.1055/s-2004-835959
Tissuing WJ, Uman's-Eekenhausen MA, van den Anker NJ: Vancomycin intoxication in a preterm neonate. Eur J Pediatr. 1993, 152:700. 10.1007/BF01955255
Müller D, Huftagel M, Suttorp M: Accidental overdose of vancomycin in preterm twins. Pediatr Infect Dis J. 1999, 18:744-5. 10.1097/00006454-199908000-00025
Balen RM, Betts T, Ensom MH: Vancomycin overdose in a 6-month-old girl. Can J Hosp Pharm. 2000, 53:32-5. 10.4212/cjhp.v53i1.692
Lemaire M, Connolly B, Harvey E, Licht C: Treatment of paediatric vancomycin intoxication: a case report and review of the literature. NDT Plus. 2010, 5:260-4. 10.1093/ndtplus/nfp016
Ståhlan T, Reiter PD, Ford DM, Lum GM, Albietz J: Successful utilization of high-flux hemodialysis for treatment of vancomycin toxicity in a child. Case Rep Pediatr. 2011, 2011:678724.
Unal S, Turkyilmaz C, Kayiloluoglu H, Aktas S, Atalay Y: Severe apnea in a premature infant after accidental vancomycin overdose responsive to treatment with exchange transfusion. Asia Pac J Med Toxicol. 2016, 5:28-31. 10.22038/APJMT.2016.6883
Lv M, Ma S, Chen N, Yin Y, Yu Z: Effective treatment of vancomycin nephrotoxicity with continuous venous-venous haemodialfiltration (CVHVF) in a paediatric patient. J Clin Pharm Ther. 2020, 45:832-5. 10.1111/jcpt.13181
Shah M, Quigley R: Rapid removal of vancomycin by continuous veno-veno hemofiltration. Pediatr Nephrol. 2000, 14:912-5. 10.1007/s004670000317
Ulinski T, Deschênes G, Bersman A: Large-pore haemodialfiltration membranes: an efficient tool for rapid removal of vancomycin after accidental overdose. Nephrol Dial Transplant. 2005, 20:1517-8. 10.1093/ndt/gjh900
Bach BW, Henry ED, Johnson PN: Acute kidney injury in a child receiving vancomycin and nafcillin. J Pediatr Pharmacol Ther. 2016, 21:169-75. 10.26856/jpht.1775.21.169
Pokorna P, Šima M, Tiboš D, Slanař O: Impact of haemofiltration on vancomycin disposition in a full-term neonate treated with extracorporeal membrane oxygenation. Perfusion. 2021, 36:664-7.
10.1177/02676919120973595
Nilsen HE, Sorensen I, Hansen HE: Peritoneal transport of vancomycin during peritoneal dialysis. Nephron. 1979, 24:274-7. 10.1159/000181735
McKammy S, Hernandez E, Jalang M, Moriwaki T, Devecik A, Le J: Incidence and risk factors influencing the development of vancomycin nephrotoxicity in children. Pediatr Nephrol. 2011, 25:422-6. 10.1007/s00467-010-1801-z
Downes KJ, Hayes M, Fitzgerald JC, et al.: Mechanisms of antimicrobial-induced nephrotoxicity in children. J Antimicrob Chemother. 2020, 75:1-13. 10.1093/jac/dkz325
Perazella MA: Vancomycin should be considered a nephrotoxic antimicrobial agent: commentary. Kidney S60. 2022, 3:1491-3. 10.34067/KID.0008112021
52. Uda K, Suwa J, Ito K, Hataya H, Horikoshi Y: Ototoxicity and nephrotoxicity with elevated serum concentrations following vancomycin overdose: a retrospective case series. J Pediatr Pharmacol Ther. 2019, 24:450-5. 10.5863/1551-6776-24.5.450