Impact of Pharmacy Practice Model Expansion on Pharmacokinetic Services: Optimization of Vancomycin Dosing and Improved Patient Safety

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ABSTRACT

Background: The impact of pharmacy interventions on optimizing vancomycin therapy has been described, however interventions vary among studies and the most optimal pharmacy practice model (PPM) for pharmacokinetic (PK) services has not been established.

Objective: The purpose of this study is to demonstrate the value of 24 hours a day, 7 days a week (24/7) PK services.

Methods: New PK services were implemented in 2 phases with institutional PPM expansion. Phase 1 included universal monitoring by pharmacists with recommendations made to prescribers during business hours. Phase 2 expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service. We compared vancomycin therapeutic trough attainment, dosing, and clinical and safety outcomes between phases 1 and 2 in adult inpatients receiving therapeutic intravenous vancomycin.

Results. One hundred and fifty patients were included in each phase. Phase 2 had a greater proportion of vancomycin courses with therapeutic initial trough concentrations (27.5% vs 46.1%; $p = 0.002$), higher initial trough concentrations (10.9 mcg/mL vs 16.4 mcg/mL; $p < 0.001$), and optimized initial vancomycin dosing (13.5 mg/kg vs 16.2 mg/kg; $p < 0.001$). Phase 2 also saw significant reduction in the incidence of vancomycin-associated nephrotoxicity (21.1% vs 11.7%; $p = 0.038$). Dose optimization and improvement in initial target trough attainment were most notable among intensive care unit (ICU) patients.

Conclusions. Our study demonstrated that 24/7 PK services implemented with institutional PPM expansion optimized vancomycin target trough attainment and improved patient safety.

Key Words—nephrotoxicity, pharmacy practice, pharmacokinetics, vancomycin

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Vancomycin is widely used for infections caused by methicillin-resistant *Staphylococcus aureus* (MRSA).¹ Therapeutic drug monitoring is recommended to optimize efficacy and minimize toxicities and is frequently performed given the availability of assays with rapid turnaround times and established pharmacodynamic (PD) target.¹⁻³ Vancomycin exhibits time-dependent

bactericidal activity with area under the concentration time curve (AUC) divided by the minimum inhibitory concentration (MIC) (AUC/MIC) of at least 400 as the PD target predictive of clinical effectiveness.^{3,4} Serum trough concentration is a surrogate marker of AUC and is the most practical method of monitoring vancomycin therapy in clinical practice.³

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Vancomycin serum trough concentrations of 15 to 20 mcg/mL are recommended for bacteremia, endocarditis, osteomyelitis, meningitis, and MRSA hospital-acquired pneumonia.³⁻⁶ Achieving trough concentrations of 15 to 20 mcg/mL was associated with less treatment failures and reduced duration of therapy for complicated MRSA infections.^{1,2,7} However, higher trough concentrations have also been associated with nephrotoxicity.^{8,9}

The Pharmacy Practice Model (PPM) Summit recommends the implementation of a credentialing and privileging process that enables pharmacists to document interventions and recommendations in medical records and write medication orders as part of a collaborative practice team.¹⁰ The impact of pharmacy interventions on optimizing vancomycin therapy had been described, however interventions vary among studies and were not consistently defined.¹¹⁻¹⁴ The most optimal PPM for pharmacokinetic (PK) services has not been established. This study aims to demonstrate the value of 24 hours a day, 7 days a week (24/7) PK services by evaluating vancomycin dosing, initial therapeutic trough attainment, clinical outcomes, and safety.

METHODS

Study Design and Setting

This was a retrospective cohort study conducted at a 596-bed academic medical center. Our institution underwent a PPM transformation leading to the implementation of a comprehensive PPM that expanded clinical pharmacy programs and integrated operational and clinical services.

Intervention

With institutional PPM expansion, new PK services were implemented in 2 phases. In phase 1, all inpatients receiving therapeutic vancomycin were evaluated daily by clinical pharmacists and recommendations were communicated to prescribers during usual business hours, 7 days per week. Phase 2 expanded clinical pharmacist coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service. PK consult orders were entered by prescribers, which then allowed credentialed clinical pharmacists to order vancomycin doses, serum concentrations, and pertinent laboratory values (eg, serum creatinine [Scr]). As part of the PK consult service, pharmacists also documented their interventions and recommendations as consult notes in patients' electronic medical records (EMR).

Study Population and Data Collection

Inpatients at least 18 years of age who received intravenous vancomycin between May 2009 to April 2010 (phase 1) and November 2010 to October 2011 (phase 2) were identified via a drug utilization report generated through our computerized order entry system. These 12-month time frames were chosen to account for variations in pharmacists' experiences during an academic year and for a transitional period after implementation of the PK consult service. Vancomycin for periprocedural prophylaxis was excluded.

Data collected included demographics and clinical characteristics within 24 hours of vancomycin initiation to the end of therapy, vancomycin indication, duration, Scr, and vancomycin serum concentrations. This study was approved by the institutional review board. Collected data were de-identified to comply with the Health Insurance Portability and Accountability Act standards.

Endpoints

Primary endpoint was the proportion of vancomycin courses with therapeutic initial serum trough concentrations. Secondary endpoints included time to first therapeutic serum trough concentration, all-cause in-hospital mortality, hospital length of stay (LOS), intensive care unit (ICU) LOS, and incidence of vancomycin-associated nephrotoxicity.

Subgroup analysis was performed for ICU, hematology/oncology (HONC), and medicine/surgery floor patients, as well as for patients with MRSA bacteremia (MRSAB). Additional endpoints analyzed in the MRSAB subgroup included duration of bacteremia, incidence of persistent bacteremia, metastatic complications, and vancomycin treatment failure.

Definitions

Initial vancomycin serum trough concentration was defined as those obtained prior to the third, fourth, or fifth dose. Trough concentrations obtained within 1 hour of the scheduled dose were considered to be drawn appropriately. Serum trough concentrations were defined per national and institutional guidelines and were considered therapeutic if they were 15 to 20 mcg/mL for complicated infections (bacteremia, febrile neutropenia, pneumonia, osteomyelitis, abscesses, endovascular infections, central nervous system infections, and infections involving prosthetic materials) and 10 to 20 mcg/mL for all other indications. Appropriate initial dosing interval was defined per institutional dosing guideline.

according to patients' creatinine clearance (CrCL) (Cockcroft-Gault): every 8 to 12 hours (CrCL ≥ 100 mL/min), every 12 hours (CrCL 60-99 mL/min), every 12 to 24 hours (CrCL 40-59 mL/min), every 24 to 48 hours (CrCL 15-39 mL/min), intermittent dosing (CrCL <15 mL/min or acute renal failure). Appropriate initial vancomycin maintenance dose (MD) was 15 to 20 mg/kg of actual body weight (or 10-15 mg/kg if CrCL <60 mL/min and the more aggressive dosing interval is selected in the recommended range). Vancomycin loading dose (LD) was a 25 to 30 mg/kg one-time dose prior to scheduled doses. Vancomycin doses were considered separate courses if they were more than 3 days apart (or 5 days for patients requiring intermittent hemodialysis). LOS was calculated from the date of vancomycin initiation to the date of discharge. Vancomycin-associated nephrotoxicity was defined as increase in Scr by ≥ 0.5 mg/dL or $\geq 50\%$ from baseline on ≥ 2 consecutive days during the period from vancomycin initiation to 72 hours after therapy completion.⁸ Days of therapy (DOT), sepsis, persistent MRSAB, duration of bacteremia, metastatic complications, and vancomycin treatment failure were defined according to criteria previously described.^{2,15-19}

Statistical Analysis

Data were entered and analyzed using Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA) and SPSS version 11.0 for Windows (SPSS, Chicago, IL). Descriptive statistics, Mann-Whitney *U* test (continuous variables), and chi-square test (categorical variables) were used. *P* values <0.05 were considered statistically significant.

RESULTS

Baseline Demographics

A total of 5,217 patients were identified through a query of pharmacy informatics database (phase 1: *n* = 2,379 patients; phase 2: *n* = 2,838 patients). Of patients identified, a total of 342 were selected through random number generation. Forty-two patients who received vancomycin for periprocedural prophylaxis were excluded, leaving 150 patients in each of phase 1 and phase 2. Patients were well matched in baseline demographic and clinical characteristics with the exception of more neutropenic patients in phase 1 (Table 1). Patients in phase 1 received 223 courses of vancomycin (empiric: 109 [48.9%]), and patients in phase 2 received 221 courses of vancomycin (empiric: 99 [44.7%]; *p* = 0.39). Both phases were similar in suspected or confirmed site of infection,

Table 1. Baseline demographics and clinical characteristics^a

	Phase 1 (<i>n</i> = 150)	Phase 2 (<i>n</i> = 150)	<i>p</i>
Age, years	59.0 (48.3-70.0)	57.0 (50.3-68.0)	0.61
Male	86 (57.3)	86 (57.3)	1.00
Immunocompromised ^b	28 (18.7)	21 (14.0)	0.27
Neutropenia ^c	25 (16.7)	11 (7.3)	0.013
Intensive care unit	62 (41.3)	61 (40.7)	0.91
Sepsis ^d	39 (26.0)	33 (22.0)	0.42
Vasoactives ^e	30 (20.0)	25 (16.7)	0.46
Mechanical ventilation	40 (26.7)	39 (26.0)	0.90
Renal replacement therapies ^f	30 (20.0)	30 (20.0)	1.00

Note: Data are presented as median (interquartile range) or *n* (%). Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

^aWithin 24 hours prior to vancomycin initiation to end of vancomycin therapy.

^bHuman immunodeficiency virus (HIV) positive, use of tumor necrosis factor- α (TNF- α) inhibitor, cyclosporine, tacrolimus, mycophenolate, prednisone ≥ 20 mg/day or equivalent dose of other corticosteroid.

^cAbsolute neutrophil count $\leq 1,000$.

^dProbable or documented presence of infection with systemic manifestations of infection defined by Surviving Sepsis Campaign.¹⁷

^eNorepinephrine, vasopressin, epinephrine, phenylephrine, dopamine.

^fIntermittent hemodialysis, peritoneal dialysis, or continuous renal replacement therapy.

with the exception of more bone and joint infections in phase 2 (Table 2).

Vancomycin Serum Trough Concentrations

Hemodialysis patients and others receiving vancomycin by intermittent dosing were monitored by obtaining random levels and were excluded from the analysis of serum trough concentrations. This left 126 patients in phase 1 who received 153 courses of vancomycin (142 of which had initial serum trough concentrations obtained) and 123 patients in phase 2 who received 143 courses of vancomycin therapy (128 of which had initial serum trough concentrations obtained). Frequency in which initial vancomycin trough concentrations were obtained was similar between phases 1 and 2 (142/153 [92.8%] vs 128/143 [89.5%]; *p* = 0.32). Considering all vancomycin levels obtained, phase 2 had more appropriately drawn vancomycin serum trough concentrations (232/458 [50.7%] vs 215/341 [63.0%];

Table 2. Vancomycin indication by suspected or confirmed site of infection

	Phase 1 (Courses = 223)	Phase 2 (Courses = 221)	<i>p</i>
Blood	119 (53.4)	105 (47.5)	0.22
Lung	37 (16.6)	32 (14.5)	0.54
Skin and soft tissue	30 (13.5)	33 (14.9)	0.66
Intraabdominal	20 (9.0)	15 (6.8)	0.39
Bone and joint	5 (2.2)	14 (6.3)	0.033
Neutropenic fever	6 (2.7)	10 (4.5)	0.30
Central nervous system	5 (2.2)	7 (3.2)	0.55
Other	1 (0.4)	5 (2.3)	0.12

Note: Data are presented as *n* (%). Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

$p < 0.001$). Phase 2 had a greater proportion of vancomycin courses with initial therapeutic trough concentrations (39/142 [27.5%] vs 59/128 [46.1%]; $p = 0.002$) and higher initial serum trough concentrations (10.9 mcg/mL vs 16.4 mcg/mL; $p < 0.001$). Median time to first therapeutic serum trough concentration was 4 days in both phases ($p = 0.55$). Table 3 outlines the distribution of initial vancomycin serum trough concentrations.

Initial serum trough concentrations were analyzed in the 4 subgroups (Table 4). In phase 2, significant improvement in initial therapeutic trough attainment was noted among ICU patients (28.9% vs 56.8%; $p = 0.01$) and medicine/surgery floor patients (20.6% vs 44.2%; $p = 0.03$). Initial serum trough concentration was also significantly higher in phase 2 in these 2 subgroups (ICU: 11.6 mcg/mL vs 19.2 mcg/mL, $p = 0.002$; medicine/surgery: 10.0 mcg/mL vs 16.7 mcg/mL; $p = 0.02$).

Vancomycin Dosing

All patients were included in vancomycin dosing analysis. Phase 2 had higher initial MD (13.5 mg/kg vs 16.2 mg/kg; $p < 0.001$) and greater proportion of vancomycin courses with appropriate initial MD (66.8% vs 85.5%; $p < 0.001$). LDs were also utilized more frequently in phase 2 (1.8% vs 10.0%; $p < 0.001$) and the greatest increase was observed among ICU patients (1.6% vs 21.7%; $p < 0.001$).

Table 3. Initial vancomycin serum trough concentrations

	Phase 1 (Courses = 142)	Phase 2 (Courses = 128)	<i>p</i>
Proportion with therapeutic initial trough concentrations	39 (27.5)	59 (46.1)	0.002
Initial trough, mcg/mL	10.9 (7.0-16.8)	16.4 (10.2-20.8)	< 0.001
<10 mcg/mL	61 (43.0)	31 (24.2)	0.001
10-15 mcg/mL	36 (25.4)	26 (20.3)	0.33
15-20 mcg/mL	24 (16.9)	36 (28.1)	0.027
20-25 mcg/mL	14 (9.9)	16 (12.5)	0.49
25-30 mcg/mL	1 (0.7)	11 (8.6)	0.002
>30 mcg/mL	6 (4.2)	8 (6.3)	0.45

Note: Data are presented as median (interquartile range) or *n* (%). Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

Most other subgroups also received higher and more appropriate initial MDs of vancomycin (Table 5).

Safety and Clinical Outcomes

All patients were included in the safety analysis. There was significant reduction in the incidence of vancomycin-associated nephrotoxicity in phase 2 (21.1% vs 11.7%; $p = 0.04$) despite similar duration of vancomycin (measured as DOT per course) between phases 1 and 2 (9 days vs 7 days; $p = 0.19$).

Clinical outcomes were analyzed in patients who received vancomycin for at least 72 hours. All-cause, in-hospital mortality and ICU LOS were similar between the 2 phases. Reduced hospital LOS was observed in phase 2 (15 days vs 14 days; $p = 0.04$), driven primarily by the HONC subgroup (Table 6). Outcomes specific to the MRSAB subgroup were comparable between phases 1 and 2 (Table 7).

DISCUSSION

Our study demonstrated that 24/7 PK services optimized vancomycin dosing, improved initial therapeutic trough attainment, and reduced vancomycin-associated nephrotoxicity. To our knowledge, this is the first study that evaluated the impact of expanded 24/7 clinical pharmacy services on optimizing vancomycin therapy.

Table 4. Vancomycin trough analysis in patient subgroups

	Phase 1 (Courses = 142)	Phase 2 (Courses = 128)	<i>p</i>
<i>Proportion of courses with therapeutic initial trough concentration</i>			
MRSAB	9/30 (30.0)	6/18 (33.3)	0.809
ICU	11/38 (28.9)	25/44 (56.8)	0.011
HONC	12/40 (30.0)	9/23 (39.1)	0.459
General medicine/ surgery floor	7/34 (20.6)	19/43 (44.2)	0.030
<i>Initial serum trough concentration</i>			
MRSAB	14.2 (9.7-18.8)	14.1 (10.2-21.7)	0.662
ICU	11.6 (6.9-17.2)	19.2 (11.7-22.6)	0.002
HONC	8.6 (5.8-13.8)	13.8 (7.5-19.2)	0.056
General medicine/ surgery floor	10.0 (6.7-17.7)	16.7 (9.9-20.6)	0.016
<i>Proportion of therapeutic courses</i>			
MRSAB	18/30 (60.0)	15/18 (83.3)	0.091
ICU	19/38 (50.0)	36/44 (81.8)	0.002
HONC	25/40 (62.5)	14/23 (60.9)	0.898
General medicine/ surgery floor	18/34 (52.9)	34/43 (79.1)	0.015

Note: Data are presented as median (interquartile range) or *n* (%). HONC = hematology/oncology; ICU = intensive care unit; MRSAB = MRSA bacteremia; Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

Improvement in initial therapeutic trough attainment may be explained by optimized dosing. Although national and institution-specific vancomycin dosing recommendations remained consistent during the study time frame (May 2009 to October 2011), clinical pharmacists' interventions with 24/7 PK services enhanced compliance with dosing recommendations and reduced inappropriately drawn levels. Higher and more appropriate initial doses did not increase adverse events; rather, 24/7 PK services reduced vancomycin-associated nephrotoxicity despite similar durations of vancomycin therapy in phases 1 and 2.

The implementation of dosing guidelines and educational interventions in optimizing vancomycin dosing had also been demonstrated at other institutions.^{13,14} In

Table 5. Vancomycin dosing in patient subgroups

	Phase 1 (Courses = 142)	Phase 2 (Courses = 128)	<i>p</i>
<i>Proportion of courses with LD</i>			
MRSAB	0/52 (0.0)	2/38 (5.3)	0.176
ICU	1/61 (1.6)	15/69 (21.7)	< 0.001
HONC	2/57 (3.5)	1/41 (2.4)	1.000
General medicine/ surgery floor	1/53 (1.9)	4/73 (5.5)	0.397
<i>Proportion of courses with appropriate initial MD</i>			
MRSAB	35/52 (67.3)	34/38 (89.5)	0.014
ICU	36/61 (59.0)	63/69 (91.3)	0.016
HONC	29/57 (50.9)	35/41 (85.4)	< 0.001
General medicine/ surgery floor	39/53 (73.6)	57/73 (78.1)	0.558
<i>Initial MD, mg/kg</i>			
MRSAB	15.2 (12.7-17.6)	15.4 (13.2-18.4)	0.450
ICU	12.9 (11.1-15.7)	16.5 (14.0-18.6)	< 0.001
HONC	14.0 (11.0-15.8)	17.1 (15.3-18.2)	< 0.001
General medicine/ surgery floor	13.7 (11.9-16.9)	15.5 (13.3-18.4)	0.006

Note: Data are presented as median (interquartile range) or *n* (%). HONC = hematology/oncology; ICU = intensive care unit; LD = vancomycin loading dose; MD = vancomycin maintenance dose; MRSAB = MRSA bacteremia; Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

a pre- and post-implementation study, the proportion of appropriate initial vancomycin dose increased from 51% to 78% ($p < 0.0001$). However, the impact on therapeutic trough attainment and patient outcomes were not reported.¹³ No difference in mortality and ICU LOS was observed in our study. These results were in contrast to a previous study that demonstrated decreased mortality and LOS at hospitals with pharmacist-managed PK services.¹⁴ However, this previous study evaluated approximately 200,000 patients from a Medicare database and thus was powered to detect a much smaller effect size. A recent study evaluating outcomes in 200 patients pre- and post-implementation of vancomycin dosing guidelines also demonstrated higher initial serum trough concentrations without difference in hospital LOS.¹ In our study, decreased

Table 6. All-cause, in-hospital mortality and length of stay (LOS)

	Phase 1 (n = 147)	Phase 2 (n = 148)	p
<i>All-cause, in-hospital mortality</i>			
Overall patient population	12/147 (8.2)	15/148 (10.1)	0.557
MRSAB	0/42 (0.0)	2/32 (6.3)	0.184
ICU	11/47 (23.4)	8/42 (19.0)	0.617
HONC	0/25 (0.0)	2/24 (8.3)	0.235
General medicine/ surgery floor	1/33 (3.0)	3/50 (6.0)	0.536
<i>Hospital LOS</i>			
Overall patient population	15.0 (9.0-31.0)	14.0 (7.0-26.0)	0.042
MRSAB	15.0 (7.8-26.3)	14.0 (9.0-28.0)	0.840
ICU	19.0 (9.0-37.0)	15.5 (9.8-28.0)	0.622
HONC	25.0 (10.0-34.0)	7.0 (4.0-18.0)	0.002
General medicine/ surgery floor	10.0 (6.5-17.0)	9.0 (6.0-21.0)	0.834
<i>ICU LOS</i>			
Overall patient population	5.0 (0.0-24.5)	2.0 (0.0-11.0)	0.080
MRSAB	0.0 (0.0-13.5)	0.0 (0.0-8.8)	0.907
ICU	12.0 (4.0-26.0)	10.5 (4.0-20.0)	0.559
HONC	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.440
General medicine/ surgery floor	0.0 (0.0-0.0)	0.0 (0.0-0.0)	0.748

Note: Data are presented as median (interquartile range) or n (%). HONC = hematology/oncology; ICU = intensive care unit; MRSAB = MRSA bacteremia; Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

hospital LOS in phase 2 was driven by HONC patients, which could be reflective of the lower proportion of neutropenic patients in phase 2.

The resources and manpower required to sustain 24/7 PK services may not be feasible in all practice settings. To increase applicability to other institutions, subgroup analysis was conducted to identify patient populations in which 24/7 PK services had the greatest impact. Among ICU patients, there was greatest impact on dose optimization leading to

Table 7. Outcomes in MRSAB subgroup

	Phase 1 (n = 42)	Phase 2 (n = 32)	p
Duration of bacteremia, days	2.0 (1.0-4.3)	4.0 (1.3-5.8)	0.057
Persistent MRSA bacteremia	7 (16.7)	6 (18.8)	0.816
Metastatic complications	9 (21.4)	6 (18.8)	0.776
Vancomycin treatment failure	9 (21.4)	7 (21.9)	0.963

Note: Data are presented as median (interquartile range) or n (%). MRSA = methicillin-resistant *Staphylococcus aureus*; MRSAB = MRSA bacteremia; Phase 1 = universal monitoring by pharmacists with recommendations made to prescribers during business hours; Phase 2 = expanded clinical pharmacists' coverage to 24/7 and provided an optional 24/7 pharmacist-managed PK consult service.

significant improvement in initial therapeutic trough attainment. ICU could be a priority for other institutions interested in implementing similar PK services.

There are several limitations to our study. First, a power calculation was not performed prior to beginning data collection. Twenty-four hours a day, 7 days a week PK services have not been described previously. Its impact on vancomycin therapeutic trough attainment is unknown, thus limiting our ability to accurately estimate an effect size for power calculation. The decision to include 150 patients in each group was based on feasibility of data collection and analysis within the time frame that was allowed for the study. Despite this, a significant difference was found between the 2 groups for the primary endpoint. Second, data collection relies upon the accurate documentation in EMR. It might be difficult to retrospectively determine whether certain vancomycin levels were meant to be drawn as random levels or true troughs but were drawn inappropriately. In these instances, pharmacist documentation in PK consult notes or monitoring plans were utilized. Additionally, small sample size increases the risk for type II errors especially in the MRSAB subgroup. As previously noted, hemodialysis patients were excluded from the analysis of trough concentrations. However, these patients were at increased risk for MRSAB; excluding these patients limited our sample size in the MRSAB subgroup. Finally, confounding variables other than vancomycin dosing might have influenced mortality and LOS.

Larger studies in the future are necessary to better define the association between optimized vancomycin trough concentrations and outcomes.

The impact of PPM expansion with 24/7 PK services on dose optimization, monitoring, and safety should also be evaluated at other institutions.

CONCLUSION

In our experience, PPM expansion with 24/7 PK services optimized vancomycin dosing, improved therapeutic trough attainment, and enhanced safety of vancomycin therapy. Largest impact on dose optimization was seen among ICU patients.

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