**Abstract**

Objectives: To examine the effects of computerized requests for pharmacist-to-dose (PTD), an advanced clinical decision support tool for dosing guidance, on antimicrobial therapy with vancomycin and aminoglycosides, describe PTD request utilization, and identify factors that may prolong this process.

Design: A retrospective review was conducted of patients hospitalized from Jan 2004 to Jun 2006 with suspected pneumonia who received vancomycin, tobramycin, or gentamicin via PTD (study) or routine provider order entry (control).

Measurements: The primary endpoint was time to pharmacist completion of PTD request. Secondary data points included medication turn-around times for first doses of vancomycin or aminoglycosides and for first doses of any antibiotic, dose adjustment for renal dysfunction, medication errors, and time of order entry. Multivariate analysis was conducted to identify predictors of total time to pharmacist verification and time to administration of first doses of vancomycin or aminoglycosides.

Results: Median time for pharmacist completion of PTD requests was 29 minutes. Delays were noted in the study group (n = 49) by comparison with the control group (n = 48) for median time to first dose of vancomycin or aminoglycoside (185 vs. 138 min, p = 0.45) and for any antibiotic (134 vs. 118 min, p = 0.42), respectively. Fewer medication errors were reported in the study group (5 vs. 18 errors, p = 0.002). In a multivariate model, PTD was not significantly predictive of time to pharmacy verification or medication turn-around time.

Conclusions: Pharmacists completed pharmacist-to-dose consultations for dosing guidance of vancomycin and aminoglycosides within a median of 30 minutes. Implementation of a computerized request for clinical pharmacists to provide medication-related clinical decision support increased medication turn-around time of vancomycin and aminoglycosides and reduced medication errors. Consultation of clinical pharmacists by computerized request for initial antibiotic dosing of medications with narrow therapeutic windows is an option for medication-related clinical decision support but providers should be aware that consultation may delay medication turn-around time.

**Introduction**

Clinical decision support (CDS) for computerized provider order entry (CPOE) systems can improve medication safety. The Report of the Joint Clinical Decision Support Workgroup supports inclusion of an indication for medication use and dosing guidance based on patient-specific characteristics and physiological parameters including age, weight, and renal function. Further, advanced medication-related CDS includes dosing guidance for renal insufficiency and geriatric patients and guidance for laboratory monitoring of pharmacotherapy regimens. Medications with narrow therapeutic windows are more apt to cause adverse events and may be more prone to medication errors. Dosing decision support may therefore be of particular value for high-risk medications.

**Background**

Vancomycin and aminoglycosides are frequently prescribed antibiotics for the management of serious hospital-acquired infections. Patients with renal insufficiency, of advanced age, and treated with concomitant nephrotoxic agents are at greater risk for experiencing adverse events from these medications, due to their narrow therapeutic windows. Therapeutic drug monitoring (TDM) is commonly used for vancomycin and aminoglycosides to optimize safety and efficacy. Pharmacists commonly collaborate with providers to offer TDM and dosing guidance for vancomycin and aminoglycosides, which has been referred to as drug protocol management. Drug protocol management services for
vancomycin and aminoglycosides have demonstrated positive clinical and economic benefits and are the fastest growing clinical pharmacy services in the United States.\textsuperscript{3,4} Pharmacist-managed drug therapy may offer effective clinical decision support for dosing assistance with vancomycin and aminoglycosides.

At our 473-bed, tertiary, academic medical center, pharmacist-managed drug therapy is provided via routine therapeutic drug monitoring, participation of clinical pharmacists on patient care rounds, the 24-hour on-call pharmacy resident,\textsuperscript{9} and by informal consultation at decentralized satellites. Following the initiation of CPOE, an electronic request for pharmacist-managed drug therapy, called pharmacist-to-dose (PTD), was implemented. Under this drug therapy protocol approved by the Pharmacy & Therapeutics Committee, providers may request PTD via CPOE, and a clinically trained pharmacist provides evidence-based, patient-specific recommendations for an initial dose, relevant laboratory tests, and subsequent dose adjustments as needed. Initial anecdotal reports suggest most PTD requests are for vancomycin, aminoglycosides, and other antimicrobial agents.

Consensus guidelines on the management of hospital-acquired, ventilator-associated, and healthcare-associated pneumonia recommend prompt, appropriate empiric antimicrobial therapy with adequately dosed agents and subsequent therapeutic drug monitoring for vancomycin and aminoglycosides.\textsuperscript{5} However, dosing guidance via PTD for the treatment of pneumonia includes an added step of pharmacist assessment and recommendation, which carries the potential to delay empiric antimicrobial therapy. The need to evaluate this newly implemented clinical decision support tool led to this evaluation of PTD and its effects on promptness of antimicrobial therapy, an important quality indicator for the treatment of patients with severe infections.

Research Question
The objectives of the study were to describe PTD request utilization, examine the effects of PTD requests on the promptness of antimicrobial therapy with vancomycin and aminoglycosides, and test the hypothesis that PTD requests do not significantly prolong medication turn-around times for first antibiotic doses.

Methods
Pharmacist-to-Dose Clinical Decision Support
At our institution, electronic prescribing begins with provider order entry in Sunrise Clinical Manager (SCM; Eclipsys; Atlanta, GA). Providers may request PTD by electronic order entry in SCM. Requests for PTD information can be found in SCM by searching for the request itself, medications that require individualized dosing for special patient populations, and order sets specific for patient care services. Orders for PTD information require provider input of the medication for which dosing support is requested and the indication for its use. Patient height and weight may be included in the entry, and any additional information may be submitted in a free text field. Following electronic request for PTD, a STAT order is transmitted to the unidirectional pharmacy order verification system, WORx (Mediware; Lenexa, KS), and a clinical pharmacist is notified of the pending consultation. The pharmacist performs an assessment and recommends an individualized pharmacotherapy regimen including appropriate laboratory tests and therapeutic drug monitoring, when indicated. The pharmacist conducting the consultation electronically enters medication orders into the CPOE system under “per protocol” authorization of the requesting provider. Transmission of the medication order to WORx occurs for subsequent pharmacist verification and distribution. Figure 1 describes the steps involved in requesting PTD.

Patient Population
This is a retrospective review of medical records for patients who received vancomycin, tobramycin, or gentamicin to treat pneumonia at our institution from April 2005 to March 2007. Expedited institutional review board approval was obtained. The study group included adult patients whose provider requested pharmacist-to-dose via the electronic prescribing system and indicated in the free text instruction field that antibiotics were prescribed to treat pneumonia. An equal number of control patients were randomly identified by query of the University HealthSystem Consortium (Oak Brook, IL) database from the database if they were admitted during the study time period, received vancomycin or an aminoglycoside via routine provider order entry, had a diagnosis of pneumonia, and were not prescribed vancomycin or aminoglycosides through PTD request. Patients in the Children’s Hospital, less than 18 years of age, patients admitted to labor and delivery, and those diagnosed with cystic fibrosis were excluded from both groups. Upon chart review, those patients with incomplete medical records or who received prior antimicrobial therapy with aminoglycosides or vancomycin during hospital admission were also excluded.

Data Collection and Analysis
Descriptive analysis of PTD included review of all requests for PTD from May 2006 to May 2007. The following data
points were measured: mean overall utilization of the PTD service, patient care service usage, and most frequently requested medications. The primary endpoint of this investigation was time to pharmacist order entry, which included the time for pharmacists to assess the patient and make recommendations for dosing and monitoring of vancomycin, tobramycin, or gentamicin (Fig 1). The departmental goal set forth was for clinical assessment and order entry by a pharmacist to be completed within 30 minutes of electronic consultation. Secondary endpoints included medication turn-around times for first doses of aminoglycosides, vancomycin, or other first antibiotic doses.

Additional data points included the incidence of medication errors of incorrect dose, defined as discontinuation of an initial medication order and order re-entry of the same medication for a different dosage and/or interval within 24 hours. Comparison of dose adjustments for renal dysfunction (defined by internal guidelines) was performed, in which a decrease in dose or interval was made due to the presence of renal insufficiency. Time of medication order entry during pharmacy staff work shifts (e.g., 1st shift—0730 to 1530) was also collected.

Mean and median were used as the central measures of data analysis. Means were used for evenly distributed data and medians for skewed data. The Mann-Whitney U-test was used to measure a difference in median data at an alpha level of significance. The student’s t test was used to identify differences in mean data. Multilevel mixed-effects linear regression was performed using the xtmixed function in Stata, version 9.0, for the dependent variables total time to pharmacist order entry (defined as time to pharmacist order entry and time to order verification in the study group and time to order verification in the control group) and medication turn-around time of the first administered dose of vancomycin or aminoglycoside. The fixed effects included in the models were pharmacist-to-dose request, the sequence in which the antibiotic was ordered if more than one antibiotic was ordered at once, renal adjustment, order re-entry within 24 hours, location (ICU or floor), antibiotic ordered, number of total first doses, and centralized pharmacy distribution. The patient ID was included as a grouping variable whose effect was modeled as random. Dosing analysis was conducted using the variance ratio F test to detect a difference in standard deviation of weight-based doses of vancomycin in each group.

### Results

Over a 1 year time period from May 2006 to May 2007, which differs from the period in which patients were identified for investigation, there were 3,012 electronic requests for PTD, which represents a mean of approximately 8 requests/day. Dosing guidance was most commonly requested for vancomycin, tobramycin, and gentamicin, which represented approximately 70% of all requests (Table 1). The patient care services most commonly using PTD were internal medicine, trauma surgery, neurosciences, pulmonary/critical care medicine, and pediatrics. In addition to requests for assistance with medication dosing, providers also requested PTD for evaluation of home medication regimens, therapeutic drug monitoring, therapeutic interchange to formulary medication, and dosage form conversion.

There were 56 patients who met inclusion criteria in the study group, of whom 8 were excluded (age less than 18 yrs \( n = 2 \), incomplete medical records \( n = 5 \), and vancomycin or aminoglycoside not ordered \( n = 1 \)), leaving 48 patients who received a combined 71 requests for PTD for vancomycin and aminoglycosides. In the control group, 131 patients were identified and 93 were excluded (admission before implementation of CPOE \( n = 33 \), unable to retrieve electronic data \( n = 29 \), incomplete medical records \( n = 22 \), request for pharmacist-to-dose \( n = 4 \), and written medication orders \( n = 5 \)). An additional 22 patients were identified for inclusion from the UHC database who received a study medication for any indication, of which 11 were excluded. This resulted in 49 patients in the control population who received a combined 57 medication orders for vancomycin and aminoglycosides (Table 1). Baseline characteristics of the patients included are listed in Table 2 and the antibiotics they received are listed in Table 3. Patients in the study and control group varied significantly by sex and hospital location (ICU v. floor) at time of order entry, and the 8-hour work shift during which the antibiotic was ordered.

Median time to pharmacist order entry for vancomycin or aminoglycosides was 29 minutes (range = 1–489 min). Median total time to pharmacy verification (Fig 2) was 37 minutes (range = 8–295 min) in the study group compared with 20 minutes (range = 0–241) in the control group (p = 0.028). Median turn-around times for first doses of vancomycin or aminoglycosides were 185 minutes, range = 28–310, in the study group and 138 minutes, range = 33–907, in the control group, p = 0.45. Many patients received additional first antibiotics in combination with vancomycin or an

### Table 1. Pharmacist-To-Dose (PTD) Requests from May 2006 to May 2007, by Medication

<table>
<thead>
<tr>
<th>Medication Requested by PTD*</th>
<th>Number of Requests (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancomycin</td>
<td>1,008 (33)</td>
</tr>
<tr>
<td>Tobramycin</td>
<td>564 (19)</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>539 (18)</td>
</tr>
<tr>
<td>Phenytoin/fosphenytoin</td>
<td>129 (4)</td>
</tr>
<tr>
<td>Enoxaparin</td>
<td>128 (4)</td>
</tr>
<tr>
<td>Piperacillin/tazobactam</td>
<td>81 (3)</td>
</tr>
<tr>
<td>Cefepime</td>
<td>39 (1)</td>
</tr>
<tr>
<td>Therapeutic drug monitoring</td>
<td>39 (1)</td>
</tr>
<tr>
<td>Levofloxacin</td>
<td>35 (1)</td>
</tr>
<tr>
<td>Ampicillin/sulbactam</td>
<td>32 (1)</td>
</tr>
<tr>
<td>Clindamycin</td>
<td>31 (1)</td>
</tr>
</tbody>
</table>

*Including only those requests accounting for medicines ≥ 1% of all PTD requests.

### Table 2. Baseline Patient Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Study (N = 48 Patients)</th>
<th>Control (N = 49 Patients)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean (years)</td>
<td>66 (27)</td>
<td>55.6 (47)</td>
<td>0.46</td>
</tr>
<tr>
<td>Female (%)</td>
<td>13 (27)</td>
<td>23 (47)</td>
<td>0.035</td>
</tr>
<tr>
<td>Weight, median (kg)</td>
<td>86 (73)</td>
<td>73 (73)</td>
<td>0.104</td>
</tr>
<tr>
<td>Serum creatinine, mean (mg/dL)</td>
<td>1.4 (1.8)</td>
<td>1.8 (1.8)</td>
<td>0.15</td>
</tr>
<tr>
<td>ICU (%)</td>
<td>34 (71)</td>
<td>13 (27)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

ICU = intensive care unit.
Table 3 • First Antibiotics Ordered1 (%)  

<table>
<thead>
<tr>
<th></th>
<th>Study</th>
<th>Control</th>
<th>p</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N = 112) Orders</td>
<td>(N = 114) Orders</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vancomycin</td>
<td>38 (33)</td>
<td>41 (36)</td>
<td>0.78</td>
<td></td>
</tr>
<tr>
<td>Aminoglycosides</td>
<td>33 (29)</td>
<td>16 (14)</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>Antipseudomonal β-lactams</td>
<td>33 (29)</td>
<td>21 (18)</td>
<td>0.052</td>
<td></td>
</tr>
<tr>
<td>Levofloxacin</td>
<td>5 (4)</td>
<td>21 (18)</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Other*</td>
<td>3 (3)</td>
<td>15 (13)</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Shift when ordered*:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st, 0731–1,530</td>
<td>42 (59)</td>
<td>14 (29)</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>2nd, 1531–2230</td>
<td>21 (30)</td>
<td>29 (42)</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>3rd, 2,231–0730</td>
<td>8 (11)</td>
<td>14 (29)</td>
<td>0.056</td>
<td></td>
</tr>
</tbody>
</table>

1Study (n = 48) and control (n = 49) patients received first antibiotic orders in addition to vancomycin, tobramycin, or gentamicin.
2Other antibiotics included ampicillin/sulbactam, azithromycin, ceftriaxone, clindamycin, and metronidazole.
*Orders for vancomycin and aminoglycosides only in the study (n = 71) and control (n = 57) groups.

aminoglycoside (Table 3). Turn-around times for first dose of any antibiotic were 134 minutes (range = 3–758) and 118 minutes (range = 25–771) in the study and control groups, respectively, p = 0.42.

A multilevel mixed-effect model was conducted and examined the effect of PTD request on total time to pharmacy verification and time to administration, antibiotic order sequence, location, renal dysfunction, order re-entry within 24 hours, additional first antibiotic orders, method of product distribution, and time of order entry were included in the models as mixed effects; patient ID was included as a random effect. Information on PTD was not significant in predicting either outcome. Renal impairment (p = 0.008) and order re-entry within 24 hours (p = 0.004) were the only variables significant in predicting longer total time to pharmacy verification. The sequence in which antibiotics were ordered (p < 0.0001) and the number of total number of first antibiotic doses ordered simultaneously (p = 0.017) were significant in predicting greater time to antibiotic administration. Antibiotic dispensing from central pharmacy (p = 0.069) and order entry during 1st or 2nd shift (p = 0.066) were not significant predictors of greater time to administration.

Analysis of secondary endpoints demonstrated fewer medication errors of incorrect dosage, fewer omissions of height and weight for dosing calculation in the study group, and more precise weight-based vancomycin dosing in the PTD group (Table 4). However, dosing analysis did not demonstrate a difference between groups for dose adjustments for renal insufficiency.

Discussion
Pharmacist-to-dose is a novel method to provide clinical decision support via pharmacist-managed drug therapy within CPOE systems. This service has been well received at our institution. During 2007, there were over 3,000 electronic requests for pharmacists to assist with medication management, for which pharmacists have documented an estimated 1,500 hours providing clinical pharmacy consultations. Most requests were for vancomycin and aminoglycosides, which are the focus of this investigation. Pharmacists completed requests for initial dosing of vancomycin and aminoglycosides for treatment of suspected pneumonia within a median of 29 minutes, meeting the predetermined departmental goal. There was however significant variability in the time pharmacists needed to complete the consultations, indicating a need for better understanding of the established urgency for this type of consultation, which is expected from any in-house consultant.9 This time required for providing drug protocol management for a single patient is similar to a previous report.10

Of greater significance was the finding that total time to pharmacy verification was longer for medication orders for vancomycin and aminoglycosides in the study group (37 vs. 20 min, p = 0.028). This difference was somewhat expected given the differing steps in medication turn-around beginning with initial prescribing when the request for pharmacist-to-dose is submitted and ending with medication administration. On the other hand, in the control group, we were unable to measure each step of medication turn-around because it is difficult to account for the time taken for a provider to determine and order patient-specific dosing and subsequent therapeutic drug monitoring, when indicated. We have labeled this step, time to provider order entry. Without this unmeasured step, the fair comparison of total time to pharmacy verification between groups is not possible. Therefore, the time to pharmacist order entry was selected as the primary endpoint in order to assess time taken for a clinical pharmacist to provide a consultation. Future studies examining time to provider order entry for medications with narrow therapeutic windows and effects on medication safety are warranted.

Delays in the administration of vancomycin and aminoglycosides approaching three hours to treat patients with pneumonia were noted in both the study and control groups. The difference found in the control group of shorter
overall medication turn-around time of 47 minutes was not statistically significant but may be clinically significant in certain cases. To assess the clinical impact of pharmacist-to-dose, the study also examined medication turn-around time for any first antibiotic dose, or time to first antibiotic dose (TFAD), which is an important quality indicator. Frequently, the patients studied also received broad-spectrum antibiotic therapy (e.g., an antipseudomonal β-lactam) in addition to vancomycin and an aminoglycoside. These were often administered before the study medication and may have contributed to delays in the administration of the study antibiotics, although it was not shown to be a predictor of delayed turn-around time in the multivariate analysis. Data for TFAD were similar in both groups, with most patients receiving a first antibiotic dose within approximately two hours.

There are limitations to TFAD measurement and utilization. Data for TFAD have not been clearly defined regarding time to which first antibiotic dose is most important (e.g., which class of antimicrobial should be preferentially administered). However, the importance of prompt and appropriate antibiotic administration in the treatment of serious infections is well documented. For patients infected with multidrug resistant organisms (MDROs), such as methicillin-resistant Staphylococcus aureus (MRSA) or Pseudomonas aeruginosa, prompt administration of vancomycin or an aminoglycoside, respectively, is critical and highlights the importance of minimizing delays in medication turn-around time for first antibiotic doses of these agents. The observed delay of 47 minutes for turn-around times of vancomycin and aminoglycosides would likely be clinically significant in the case of infection with MRSA and multidrug resistant Pseudomonas aeruginosa. The TFAD occurred within about two hours in this study but its interpretation is limited by the absence of microbiological data to determine when the first dose of the most appropriate antimicrobial was administered.

Thus, TFAD, must be better defined. Time to first appropriate antibiotic doses (TFAAD), in the cases of serious nosocomial infections, may be a better measure where appropriateness is defined based on likely pathogens, institutional susceptibility profiles, and the selected antimicrobial agents and doses. Further, for empiric antimicrobial therapy, by definition, the causative pathogen is unknown at the time when antibiotic therapy is initiated. Computerized decision support may be used to accurately predict an infecting pathogen. However, until this or other methods are adopted, it remains difficult to predict a pathogen and it is therefore crucial to promptly administer first doses of all antibiotics. We reported wide ranges of delays in medication turn-around times with first antibiotic orders and in the multivariate analysis, both the number of first antibiotic orders and the sequence in which they were ordered predicted turn-around time. In some cases patients did not receive a first dose of an ordered antibiotic until greater than 12 hours after electronic order entry! In response to these findings, the institutional Pharmacy & Therapeutics Committee mandated that every order entered via pharmacist-to-dose request be a STAT order, to appropriately alert medical, pharmacy, and nursing staff of the urgency needed when involved in medication ordering, distribution, and administration of first antibiotic orders for empiric therapy. Additionally, institutional-wide education and computerized order sets and protocols may be useful to decrease time to first antibiotic doses and improve appropriateness of antimicrobial regimens.

Careful consideration must be given by providers to address the balance needed for empiric antimicrobial therapy that is prompt, adequately dosed, and safe. When the need for promptness is paramount, consultation could be deferred to providing recommendations for subsequent doses and monitoring. Standardized first doses of antimicrobials could be ordered for initial doses as part of an order set or bundle along with a pharmacist-to-dose request to assist with doses to follow and therapeutic drug monitoring as indicated. Additionally, using automated medication dispensing machines may facilitate expedited medication turn-around. Standardized dosing of empiric antimicrobial therapy may be an option but further studies are needed to assess its safety, efficacy, and effects on medication turn-around time. Another drawback of TFAD is lack of a standardized initial time point. Previous studies measuring TFAD used different initial time points for community-acquired infections (e.g., measured time from emergency department arrival to administration) and hospital-acquired infections (e.g., time from clinical evidence of infection to administration). The absence of an initial time of onset of clinical evidence of nosocomial pneumonia is a limitation of our study. Without this time point, the time taken for pharmacist review and time elapsed for patients to receive first doses of vancomycin, aminoglycoside, or other antibiotics is difficult to assess although the reported delays remain clinically important.

Multivariate analyses were performed to identify significant predictors for total time to pharmacy verification and turn-around times for vancomycin or aminoglycosides. The presence of renal dysfunction was found to be a predictor of

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**Table 4** Secondary Data (%)

<table>
<thead>
<tr>
<th></th>
<th>Study (N = 71 Orders)</th>
<th>Control (N = 57 Orders)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medication errors of incorrect dose</td>
<td>5 (7)</td>
<td>18 (32)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Height and weight electronic entry (%)</td>
<td>68 (96)</td>
<td>36 (63)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean ± standard deviation, weight-based vancomycin dosing (mg/kg)</td>
<td>14.9 ± 1.5</td>
<td>13.9 ± 3.1</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Dose adjustment for renal insufficiency†</td>
<td>22 (69)</td>
<td>10 (56)</td>
<td>0.45</td>
</tr>
</tbody>
</table>

1Analysis of medication orders for vancomycin and aminoglycosides.
2Variance F test used to detect a difference between standard deviations.
3Renal insufficiency defined as creatinine clearance less than 40 milliliters/minute/1.73 m² (n = 32 for study, n = 18 for control) and adjustment made for total daily dose of aminoglycoside or vancomycin.
greater total time to pharmacy verification but not for greater turn-around time. Ideally, the clinical pharmacist responsible for the care of a patient (e.g., rounding with the patient care service) with more complicated medication needs (e.g., renal dysfunction) would provide this consultation. However, after business hours, clinical pharmacists may be unavailable and in these situations, the on-call pharmacy resident is frequently consulted, in a similar fashion as the house officer cross-cover model. This is yet another added step in the process, which may explain the delay in pharmacist order entry noted for patients with renal dysfunction. However, PTD is a means to ensure medication safety (Table 4) in this patient population who is at risk for adverse effects of aminoglycosides and vancomycin. Attention must be given by the consulting pharmacist to balance a patient’s needs for prompt therapy with necessary dosage adjustments of initial doses to prevent adverse events.

Despite noted delays, the finding of 29 minutes for pharmacists to provide vancomycin and aminoglycoside protocol management consultations is on par with national averages.

The time of day (e.g., office hours v. overnight) antibiotics are ordered also may affect TFAD. Specifically, antibiotics ordered during night-time hours may reach patients more quickly. However, this finding was not supported in the analysis of orders for vancomycin and aminoglycosides. We observed fewer new medication orders for antibiotics overnight; order entry during 3rd shift accounted for 17% of antibiotics ordered. Fewer orders for antibiotics and other medications may allow for faster time to antibiotic administration. Increased awareness of daytime delays may lead to quality improvements focused on antibiotic administration during this time interval. Additionally, the use of automated medication dispensing machines, although not significant in this study, may expedite medication administration. Using this mode of decentralized, nursing unit-based medication delivery has demonstrated reductions in medication turn-around, medication errors, and cost savings, and should be further explored in the setting of severe nosocomial infections.

Medications that have the greatest potential to be incorrectly dosed should be the target of advanced efforts to provide medication-related clinical decision support. This investigation documented provider utilization of a computerized request for clinical pharmacist consultation to dose medications. Providers most frequently requested assistance dosing medications that may cause adverse events in the absence of therapeutic drug monitoring. The most frequently requested medicines for PTD consultation were tobramycin, gentamicin, vancomycin, phenytoin and fosphenytoin, and enoxaparin. In effect, medications at higher risk for causing adverse events were identified by provider utilization of pharmacist-assisted dosing guidance. Implementation of advanced clinical decision support for dosing guidance with high-risk medicines may lead to realization of improvements in medication safety and reduction in medication-related costs.

Indeed, fewer medication errors for vancomycin and aminoglycoside orders were reported in the study group, although this investigation was not designed to detect a difference in medication safety. Errors were identified by providers when they discontinued an initial order for vancomycin or aminoglycosides and re-entered the order for a different dosage or interval. Since determining the initial dose of vancomycin or aminoglycosides may require more consideration and the calculation of weight-based dosing, it is not surprising that multivariate analysis identified order re-entry as a predictor of greater time for verification of medication orders. We did not, however, measure clinical outcomes to assess the quality of consultations provided via pharmacist-managed drug therapy. Previous studies have noted reductions in hearing loss, renal dysfunction, drug costs, hospital length of stay, and mortality associated with institutional use of vancomycin and aminoglycoside pharmacist-provided drug protocol management. Individualized initial dosing of vancomycin and aminoglycosides and subsequent therapeutic drug monitoring are likely the root of observed benefits for collaborative services. The PTD was designed to provide patient-specific dosing. It appears pharmacists provided more individualized dosing than their provider counterparts reflected by more precise weight-based vancomycin dosing and more frequent height and weight entry in the study group, which are necessary for accurate calculation of vancomycin and aminoglycoside dosing (Table 4).

Clinical decision support for computerized request for pharmacist assistance with medication dosing may be most appropriately used in academic medical centers. The presence of continuously offered clinical pharmacy services is essential to implementing dosing decision support such as PTD, which is heavily dependent on readily available clinical pharmacists to assist providers. Other dosing support tools targeting high-risk medications and vulnerable patient populations that are less dependent on accessible personnel have been described and may be more practical for some CPOE systems. Institutions seeking to implement services similar to PTD should be advised to consider the economics and ergonomics associated with advanced dosing guidance support services. Additionally, basic medication-related CDS should be implemented before advanced methods to ensure support for clinical workflow.

The role of the clinical pharmacist in the health care team involved in using CPOE systems has not been well established. Pharmacist participation in patient care rounds has demonstrated reductions in adverse events, medication errors, hospital length of stay, and medication-related costs. An editorial in the Journal has suggested that computer-aided pharmacist order entry (CphOE) may offer an opportunity for expansion of pharmacists’ responsibilities beyond traditional distributional roles. Pharmacists may be best suited to perform computerized order entries for medications to provide an additional step for pharmacist review and to allow providers to focus more on patient care responsibilities. This investigation further supports CphOE by documenting the timely provision of medication-related clinical decision support by implementing computerized requests for pharmacist-managed drug therapy.

Conclusions
A computerized pharmacist-to-dose request was implemented to provide medication-related clinical decision support. Clinical pharmacists provided clinical assessments for vancomycin and aminoglycoside pharmacotherapy regimens within 30 minutes, a reasonable time needed to
provide an individualized, evidence-based, collaborative medication management service. Medication turn-around times were longer for vancomycin and aminoglycosides when ordered by PTD, which may be clinically significant for the treatment of patients with serious nosocomial infections. When patients received multiple antibiotics, administration of the first antibiotic dose was not delayed. Additionally, PTD decreased medication errors. Electronic consultation of clinical pharmacists is an option for medication-related clinical decision support for medications with narrow therapeutic windows. However, when selecting initial antibiotic doses, providers should consider the need to provide promptly administered, safe, and effective empiric antibiotic doses, providers should consider the need to provide promptly administered, safe, and effective empiric antimicrobial therapy for the treatment of patients with serious hospital-acquired infections.

References