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David N. Schwartz
Rush Medical College

R Scott Evans
University of Utah

Bernard C. Camins
Washington University School of Medicine in St. Louis

Yosef M. Khan
Ohio State University - Main Campus

James F. Lloyd
LDS Hospital/Intermountain Healthcare

See next page for additional authors

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Recommended Citation

Schwartz, David N.; Evans, R Scott; Camins, Bernard C.; Khan, Yosef M.; Lloyd, James F.; Shehab, Nadine; Stevenson, Kurt; and Centers for Disease Control and Prevention Epicenter Program, ,"Deriving measures of intensive care unit antimicrobial use from computerized pharmacy data: Methods, validation, and overcoming barriers." Infection Control and Hospital Epidemiology.32,5. 472-480. (2011).
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Authors
David N. Schwartz, R Scott Evans, Bernard C. Camins, Yosef M. Khan, James F. Lloyd, Nadine Shehab, Kurt Stevenson, and Centers for Disease Control and Prevention Epicenter Program

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Author(s): David N. Schwartz, R. Scott Evans, Bernard C. Camins, Yosef M. Khan, James F. Lloyd, Nadine Shehab, Kurt Stevenson
Reviewed work(s):
Source: *Infection Control and Hospital Epidemiology*, Vol. 32, No. 5 (May 2011), pp. 472-480
Published by: The University of Chicago Press on behalf of The Society for Healthcare Epidemiology of America
Stable URL: http://www.jstor.org/stable/10.1086/659760
Accessed: 06/03/2012 22:53

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ORIGINAL ARTICLE

Deriving Measures of Intensive Care Unit Antimicrobial Use from Computerized Pharmacy Data: Methods, Validation, and Overcoming Barriers

David N. Schwartz, MD;[1] R. Scott Evans, MS, PhD;[2,3] Bernard C. Camins, MD, MSCR;[4] Yosef M. Khan, MD, MPH;[5] James F. Lloyd, BS;[2] Nadine Shehab, PharmD, MPH;[6] Kurt Stevenson, MD, MPH;[5] for the Centers for Disease Control and Prevention Epicenter Program

OBJECTIVE. To outline methods for deriving and validating intensive care unit (ICU) antimicrobial utilization (AU) measures from computerized data and to describe programming problems that emerged.

DESIGN. Retrospective evaluation of computerized pharmacy and administrative data.

SETTING. ICUs from 4 academic medical centers over 36 months.

INTERVENTIONS. Investigators separately developed and validated programming code to report AU measures in selected ICUs. Use of antibacterial and antifungal drugs for systemic administration was categorized and expressed as antimicrobial-days (each day that each antimicrobial drug was given to each patient) and patient-days receiving antimicrobials (each day that any antimicrobial drug was given to each patient). Monthly rates were compiled and analyzed centrally, with ICU patient-days as the denominator. Results were validated against data collected from manual review of medical records. Frequent discussion among investigators aided identification and correction of programming problems.

RESULTS. AU data were successfully programmed though a reiterative process of computer code revision. After identifying and resolving major programming errors, comparison of computerized patient-level data with data collected by manual review of medical records revealed discrepancies in antimicrobial-days and patient-days receiving antimicrobials that ranged from less than 1% to 17.7%. The hospital from which numerator data were derived from electronic records of medication administration had the least discrepant results.

CONCLUSIONS. Computerized AU measures can be derived feasibly, but threats to validity must be sought out and corrected. The magnitude of discrepancies between computerized AU data and a gold standard based on manual review of medical records varies, with electronic records of medication administration providing maximal accuracy.

Infect Control Hosp Epidemiol 2011;32(5):472-480

Antimicrobial resistance that renders previously treatable infections unresponsive to most drugs is a significant and growing public health concern.[1,2] This threat was recognized in the most recent national action plan for the prevention of healthcare-associated infections outlined by the Department of Health and Human Services,[3] and calls for a coordinated national effort to monitor resistance and implement prevention and control efforts have been long-standing.[1,4] The Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America recently published guidelines promoting the implementation of antimicrobial stewardship interventions in hospitals.[5] An integral component of evaluating the impact of any of these strategies is the accurate and continuous measurement of antimicrobial utilization over time.

The increasingly computerized processes of health care delivery have made possible the automated acquisition of antimicrobial utilization data. Indeed, most modern hospitals have universal computerization of laboratory, pharmacy, admission-discharge-transfer, and patient demographic and financial data.

However, just as these data sources have been incorporated into fully functional electronic health records for only a small minority of hospitals,[6] the derivation of reliable and accurate reports based on computerized hospital data has generally been difficult to achieve.[7] Because these data are stored at

Affiliations: 1. John H. Stroger, Jr. Hospital of Cook County and Rush Medical College, Chicago, Illinois; 2. LDS Hospital/Intermountain Healthcare, Salt Lake City, Utah; 3. Biomedical Informatics, University of Utah School of Medicine, Salt Lake City, Utah; 4. Barnes-Jewish Hospital and Washington University School of Medicine, St. Louis, Missouri; 5. Ohio State University Medical Center and College of Medicine, Ohio State University, Columbus, Ohio; 6. Division of Healthcare Quality Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia.

Received October 5, 2010; accepted November 18, 2010; electronically published April 7, 2011.

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TABLE 1. Intensive Care Units and Information Technology Resources of Participating Hospitals

Hospital identifier	ICU	Medication ordering system	Medication dispensing system	Medication administration system	Computerized data warehouse	Programming language	Numerator data source	Denominator data source
A[a]	MICU, SICU, CCU	Paper, CPOE	SMS, Cerner	Paper, eMAR	CARP	SQL	Pharmacy dispensing, physician orders	Pharmacy dispensing, ADT
B	MICU, CCU, STRI, RSCU, TICU	Paper	HELP pharmacy	eMAR	HELP 1 and 2 enterprise	Oracle SQL, C++	Medication administration	Medication administration
C	MICU, SICU, CCU	Paper	MCS medication control system	eMAR	Washington University and BJC Healthcare Medical Informatics Database	Sybase SQL	Pharmacy dispensing	Pharmacy dispensing
D	MICU, SICU, BMT	CPOE	Centricity, Siemens, Essentris OSUMC IW	Paper	OSUMC information warehouse	Oracle SQL	Physician orders	Physician orders

NOTE. Medication ordering system describes physician orders; medication dispensing system describes pharmacy order entry. ADT, admission-discharge-transfer; BJC, BJC Healthcare; BMT, bone marrow transplant; CARP, Chicago Antimicrobial Resistance Project; CCU, coronary care unit; CPOE, computerized provider order entry; eMAR, electronic medication administration record; HELP, Health Evaluation through Logical Processing; ICU, intensive care unit; IW, Information Warehouse; MCS, Medication Control System; MICU, medical ICU; OSUMC, Ohio State University Medical Center; RSCU, respiratory special care unit; SICU, surgical ICU; SMS, Shared Medical Systems Corporation; SQL, structured query language; STRI, shock-trauma-respiratory ICU; TICU, thoracic ICU.

[a] A change in the pharmacy system vendor during the study time period necessitated use of 2 data sources in this hospital.

each hospital or health system in disparate information systems, the procedures required for their collection, extraction, cleaning, validation, and computation are often complex and error prone.[8] With regard to antimicrobial use measures specifically, published studies that have used electronic data sources to derive these estimates have almost exclusively relied on proprietary measurement systems, and the methods underlying the acquisition, validation, and consolidation of such data have not been well described.

We describe our efforts to demonstrate the feasibility and validity of obtaining uniform measures of the use of antimicrobials in selected intensive care units (ICUs) in 4 academic medical centers by accessing pharmacy and administrative data contained in computerized data warehouses. Despite the considerable expertise and relevant experience of the healthcare informatics specialists and investigators in this study in accessing such data, we encountered a number of problems that were largely unforeseen and therefore may be informative to the development of a standardized approach to deriving measures of antimicrobial use from electronic data.

METHODS

Four tertiary care, academic medical centers were recruited from institutions participating in the current Prevention Epicenter Program,[9] which is funded by the Centers for Disease Control and Prevention, to participate in this study. The Institutional Review Boards of each hospital approved our study protocols and waived their requirements for patient and physician consent.

Hospital ICU Types and Information Technology Resources

The characteristics of the participating facilities, respective data warehouses, and medication ordering, dispensing, and administration systems are outlined in Table 1. Descriptions of these data warehouses have been provided elsewhere.[8,10-12] Antimicrobial use data for selected ICUs in each hospital over a 36-month time period (July 2004–June 2007) were acquired, analyzed, and validated separately at each institution before being sent to a single central epicenter (Chicago Epicenter [D.N.S.]) for collation and final analysis.

TABLE 2. Numerators Used in Antimicrobial Utilization Measures and Their Definitions

Measure	Definition	Example
Antimicrobial-days	Sum of the calendar days on which each antimicrobial drug was administered	2 drugs given for 5 days followed by a different drug given for 5 days to 1 patient = 15 antimicrobial-days
Patient-days receiving antimicrobials	Sum of the calendar days on which one or more antimicrobial drugs was administered	2 drugs given for 5 days followed by a different drug given for 5 days to 1 patient = 10 patient-days receiving antimicrobials
Antimicrobial starts	Sum of the calendar days on which each new antimicrobial drug was started, following 3 or more days without exposure to that drug	2 drugs given for 5 days followed by a different drug given for 5 days to 1 patient = 3 antimicrobial starts
Antimicrobial courses	Sum of the calendar days on which any antimicrobial drug was started, following 3 or more days without exposure to any antimicrobial drug	2 drugs given for 5 days followed by a different drug given for 5 days to 1 patient = 1 antimicrobial course
Defined daily doses (DDDs)	World Health Organization–standardized conversion of aggregate drug dosing data into number of doses[26]	200 grams of vancomycin dispensed divided by 2 grams per vancomycin DDD = 100 DDDs of vancomycin

Antimicrobial use numerators (described below) were computed from varying electronic data sources (Table 1). For hospital A, whose pharmacy information system vendor changed during the study period, the numerator data source changed from pharmacy dispensing data to computerized physician order entry (CPOE) data. Hospitals B, C, and D obtained numerator data from electronic medication administration records (eMARs), pharmacy dispensing data, and CPOE data, respectively. Although eMARs were used to document medication administration in 3 of the 4 hospitals, eMAR data were available in a format amenable to analysis only at hospital B, which was able to distinguish antimicrobial doses that were administered from those that were ordered but were not administered for any reason (eg, because of doses held or refused). Denominator data (ICU patient-days) were derived from the same data sources as those from which numerator data were computed in all hospitals, with the exception of Hospital A, where admission-discharge-transfer data sources had to be queried separately after the change in pharmacy information system vendors.

Antimicrobial Use Measures

The primary numerator measure for antimicrobial use was antimicrobial-days, which is defined as calendar days on which patients received each antibacterial or antifungal agent by intravenous (IV) or oral administration. For example, 1 patient given 2 drugs for 5 days accrued 10 antimicrobial-days. Drugs given in injectable, oral, or another systemically administered form were counted only 1 time per day irrespective of route of administration. Secondary numerator measures of antimicrobial use included patient-days receiving antimicrobials, antimicrobial starts, antimicrobial courses, and defined daily doses (Table 2). Our antimicrobial-days have the same meaning as the "days of therapy" reported by Polk and colleagues;[13] however, we avoided this latter term because of its resemblance to patient-days receiving antimicrobials. The programming logic used to compute numerator events from the different data sources is summarized in Table 3. Antimicrobial use measures were summed in each ICU for each calendar month over the study period and for each of the antimicrobial agents and predefined drug classes (Table 4).

Antimicrobial use rates were calculated using ICU patient-days as the denominator. An ICU patient-day was attributed to each patient occupying an ICU bed at midnight of each day, as previously recommended,[14] so that events occurring on the day of ICU admission were counted, while those occurring on the day of ICU discharge were not.

Data Validation

The investigators participated in regular teleconference calls to discuss problems with programming and data collection. This provided a forum for shared learning, as problems encountered at one institution were evaluated in the context of experience at the others. Inspection for face validity of data derived from draft program code sometimes identified the presence of programming errors before more detailed validation efforts were initiated, prompting detailed examination of programming code to pinpoint and correct programming flaws and subsequent validation studies to confirm data validity.

Each hospital used 2 methods to systematically validate their data. First, to measure how accurately medication administration records reflected actual administration of medication to patients, convenience samples of at least 100 intravenous antimicrobial doses that were scheduled for administration in study ICUs were prospectively audited and observed at patient bedsides for timeliness of administration, using the method of Itokazu et al.[15] The subsequent results (timely dose administration or not) were compared with the

TABLE 3. Logic Used in Computing the Numerators Used in Antimicrobial Utilization Measures from Different Computerized Data Sources

Data source	Events measured[a]	Logic applied
Pharmacy dispensing	Antimicrobial doses dispensed from pharmacy	One or more doses of each antimicrobial dispensed during an ICU-day constitutes an antimicrobial-day; 1 or more doses of any antimicrobial dispensed during an ICU-day constitutes a patient-day receiving antimicrobials.
Physician orders (CPOE)	Antimicrobial start and stop orders; days of admission to and discharge from the ICU	ICU-days on which each antimicrobial is ordered for continuous scheduled administration; subsequent ICU-days are counted as antimicrobial-days until either the discontinuation of that drug or discharge from the ICU. ICU-days on which any antimicrobial is ordered and subsequent ICU-days are counted as patient-days receiving antimicrobials until either the discontinuation of all antimicrobials has been ordered or until discharge from the ICU.
Medication administration (eMAR)	Antimicrobial doses administered by a nurse	One or more doses of each antimicrobial administered during an ICU-day constitutes an antimicrobial-day; 1 or more doses of any antimicrobial administered during an ICU-day constitutes a patient-day receiving antimicrobials.

NOTE. CPOE, computerized provider order entry; eMAR, electronic medication administration record; ICU, intensive care unit.

[a] Numerator events are counted only through the calendar day before discharge from the ICU.

disposition of the dose as registered in the medication administration records. Second, retrospective validation studies were conducted by assembling cohorts of randomly selected antimicrobial recipients from each of the ICUs during the study period and comparing counts of numerator events (compiled by applying draft computer queries to these cohorts) with a manual review of the same patients' medication administration records, which is our gold standard. After identifying and correcting programming errors, numerator counts derived via revised program code and manual review of medical records were applied to new cohorts of antimicrobial recipients, and results were compared until no new programming errors could be identified.

RESULTS

Investigators at the 4 participating institutions were able to generate antimicrobial utilization data for each of the selected ICUs over the first 24 months of the 36-month study period, and they reported preliminary intra- and inter-ICU antimi-

TABLE 4. Antimicrobial Classification System

Drug class	Associated antimicrobial agents
Anti-pseudomonal	Piperacillin-tazobactam, imipenem, meropenem, ceftazidime, cefipime, aztreonam, levofloxacin, ciprofloxacin, gentamicin, tobramycin, amikacin
Anti-MRSA	Vancomycin (parenteral only), linezolid, daptomycin, quinopristin-dalfopristin
Anti-MSSA	Oxacillin, nafcillin, dicloxacillin, clindamycin
Other β-lactam drugs	Cefazolin, cephalexin, cefoxitin, ceftriaxone, penicillin, ampicillin, ampicillin-sulbactam, amoxicillin, amoxicillin-clavulanate
Anti–*Clostridium difficile*	Metronidazole (oral only), vancomycin (oral only)
Macrolide	Azithromycin, clarithromycin, erythromycin
Tetracyclines	Doxycycline, minocycline, tetracycline
Other antibacterials	Metronidazole (parenteral only), moxifloxacin, trimethoprim, trimethoprim-sulfamethoxazole
Antifungals	Amphotericin B deoxycholate, liposomal amphotericin B, fluconazole, itraconazole, voriconazole, caspofungin, anidulafungin

NOTE. MRSA, methicillin-resistant *Staphylococcus aureus*; MSSA, methicillin-susceptible *S. aureus*.

TABLE 5. Errors Encountered during Validation of Antimicrobial Utilization Rates Derived from Computerized Data Sources

Data source	Error	Cause	Solution
Numerator data			
1. Physician orders (CPOE)	Spuriously high rates of cefazolin use in an ICU in hospital A after a change to a new pharmacy computer system.	Unbeknownst to study personnel, an automated testing procedure added 233 cefazolin-days over 7 months to nonexistent patients.	Test entries were removed, which resulted in revised rates of cefazolin use that were more comparable to rates ascertained from data from the older pharmacy system.
2. Physician orders (CPOE)	Spurious increase in antimicrobial utilization rates in hospital A after change to new pharmacy computer system.	Errant programming of ADT data in the new system led to an inappropriate attribution of antimicrobial use following patient transfer from the ICU.	Programming was revised to limit numerator events to ICU patient-days as defined by the ADT tables, and new results were validated.
3. Pharmacy dispensing	Patient-days receiving antimicrobials were calculated incorrectly, with rates exceeding the maximum 1,000 patient-days receiving antimicrobials per 1,000 ICU patient-days in hospital C.	The programmer misunderstood the definition of patient-days receiving antimicrobials.	Rates were corrected and validated after the definition of patient-days receiving antimicrobials was clarified.
Denominator data			
1. Medication administration (eMAR)	Spuriously high antimicrobial utilization rates in an ICU in hospital B.	Communication error led to programming of only antimicrobial recipients in the ICU, rather than all patients in the ICU, in computing denominator data.	Rates were reprogrammed to include all ICU patients, and new results were validated.
2. Pharmacy dispensing	Spuriously low antimicrobial utilization rates in a single ICU in hospital C.	Summed denominator-days from 2 parallel nursing units comprising an ICU were used to calculate antimicrobial use rates for each nursing unit instead of calculating denominator ICU-days from each nursing unit separately.	Rates were recomputed and validated after the programmer was made familiar with physical layout of the ICU.

NOTE. ADT, admission-discharge-transfer; CPOE, computerized provider order entry; eMAR, electronic medication administration record; ICU, intensive care unit.

crobial use rate comparisons.[16] However, preliminary retrospective and prospective validation studies revealed major discrepancies between numerator counts that substantially biased the preliminary results and prompted careful review of the code used in the computer queries for systematic error by programmers and investigators. A summary of these programming errors is provided in Table 5. These errors were detected after findings of an inspection of the resulting reports suggested a lack of face validity or after detection of inconsistencies between computerized reports of patient-level data and recorded medication administration record entries during retrospective validation.

After we identified and corrected all identifiable programming errors, the numerator counts we derived via revised program code and manual review of medical records were applied to new cohorts of antimicrobial recipients, and results were compared until no new programming errors could be identified. The discrepancies between computer-derived and manual counts of antimicrobial-days and patient-days receiving antimicrobials (presented in Table 6) reflect these final comparisons. The retrospective validation studies revealed variable levels of discrepancy by institution via numerator counts derived from the application of final computer queries and a manual review of medication administration records. The overestimation of counts of antimicrobial-days and patient-days receiving antimicrobials that had been generated

by computer code was less than 1% at hospital B, where antimicrobial utilization rates were computed from eMAR data. By contrast, programming of computerized pharmacy dispensing data at hospital C, where delayed delivery of paper medication orders from ICUs to the pharmacy may have led to the dispensing of antimicrobials after orders for drug discontinuation or patient discharge were written,[15] counted 17.7% more antimicrobial-days and 14.5% more patient-days receiving antimicrobials than manual review of medical records did. Use of CPOE data to derive numerator antimicrobial measures at hospitals A and D generated intermediate levels of discrepancy (Table 6).

Prospective bedside observations of the intravenous administration of routinely scheduled antimicrobial doses revealed more than 95% concordance between the observed outcomes of dose administration events and the corresponding dose administration statuses recorded in the MARs in every ICU in this study (data not shown).

DISCUSSION

Our findings show that derivation of standardized patient-level measures of antimicrobial utilization from a sample of hospitals with disparate computerized pharmacy systems is feasible. However, our experience highlights a few important issues related to the use of computerized data sources to derive and report hospital antimicrobial utilization rates.

First, interinstitutional differences in pharmacy computer systems and available data sources (Table 1) necessitated the use of institution-specific computing strategies (Table 3). This contributed to varying levels of fidelity between antimicrobial utilization results obtained by application of computer code and results of manual reviews of patient records (Table 6). Until greater uniformity among hospital data systems is achieved or until valid antimicrobial use measurement programs are included in commercial and governmental hospital pharmacy computer systems, institution-specific strategies for data programming, validation, and interpretation will have to be developed to ensure that accurate and comparable measures of antimicrobial utilization data are derived and reported across hospitals.

Second, we found that programming antimicrobial utilization measures on the basis of computerized pharmacy and administrative data was complex and error prone. Despite considerable experience in querying and analyzing computerized data from our respective institutions,[8,10-12] we made important errors in our initial attempts to derive these measures of antimicrobial utilization (Table 5). Our need to adopt separate, institution-specific computing strategies (Tables 1, 3), along with the complexities of computerized medical records in general[17] and pharmacy data in particular,[8] likely contributed to these problems. However, many of the mistakes made stemmed from conceptual misunderstandings and inadequacies in communication between clinician-investigators and informaticists, and mitigation of these issues requires careful application of basic tenets of multidisciplinary collaboration and data review and validation (Table 7). The use of complementary methods—that is, assessment of face validity, review of procedures for developing computer code, and retrospective validation procedures—were necessary to fully identify and correct these errors, and this highlights the importance of adopting a careful, systematic approach to collecting and validating data from electronic health records.

Third, after maximally validating the program code in each of our respective institutions, we measured variable levels of overestimation of computed numerator counts against a gold standard based on retrospective review of medical records (Table 6). These discrepancies likely reflect interinstitutional variation in efficiency and coordination of medication ordering, distribution, and administration procedures.[15,18] In particular, in hospital C, which had the most discrepancies, delays to a centralized pharmacy in the transport of paper orders for medication may have contributed to a delayed response by the pharmacy to ordered changes in patient antimicrobial regimens, which then resulted in the pharmacy dispensing to the ICU antimicrobial doses that were not administered and that were therefore omitted from the MAR

TABLE 6. Retrospective Comparisons of Computerized Antimicrobial Numerator Data with Manual Review of Medical Records for Randomly Selected Recipients of Antimicrobials in Intensive Care Units

			No. of antimicrobial-days			No. of patient-days receiving antimicrobials		
Hospital identifier	Numerator data source	No. of patients	Computer	Manual review	Percent computer overestimation	Computer	Manual review	Percent computer overestimation
A[a]	Pharmacy dispensing	100	661	613	7.8	385	408	−5.6
A	Physician orders (CPOE)	90	609	570	6.8	353	345	2.3
B	Medication administration (eMAR)	100	4,551	4,509	<1	2,015	2,018	<1
C	Pharmacy dispensing	100	1,792	1,523	17.7	953	832	14.5
D	Physician orders (CPOE)	100	1,198	1,082	10.7	595	563	5.7

NOTE. CPOE, computerized provider order entry; eMAR, electronic medication administration record.

[a] A change in the pharmacy system vendor during the study time period necessitated the use of 2 data sources in this hospital.

TABLE 7. Potential Sources of Error in Computing Rates of Antimicrobial Use from Computerized Pharmacy Data and Suggestions for Avoiding Them

Potential sources of error	Suggested solutions
Data request/acquisition	
Programmer's understanding of clinical concepts and goals underlying investigator's request for data may be incomplete	Written request for data must clearly outline clinical concepts and goals. Programmer should have frequent access to investigator to clarify conceptual issues.
Programmer's understanding of the physical context and clinical processes and procedures relevant to the request for data may be incomplete	The programmer should tour site(s) of care being studied. The programmer should be oriented to the processes of care relevant to the request for data (eg, hospital processes of medication ordering, distribution, and administration) emphasizing the point(s) at which the computerized data being studied are generated.
Investigator's understanding of data structure and programming procedures may be limited	Programmer should describe proposed approach to request for data, including anticipated shortcomings in data structure or availability, to investigator before writing program code. Programmer should review program code with investigator before executing programming procedures.
Data analysis	
Computerized data may require careful review for outlier entries and may require reformatting (eg, converting free text to categorical tabular entries) before programming is possible	Programmer should involve investigator in review of data tables and obtain investigator's guidance in interpreting outlier entries. Magnitude of data cleaning and conversion efforts must be estimated and the necessary resources—primarily, personnel time—allocated. Investigator must assist in designing data restructuring plan and provide necessary nomenclature and definitions.
Data validation	
Investigator's predisposition to trust integrity of programming processes and data derived thereby ("if it's on a computer screen, it must be right") may be misguided	Reports based on queries of computerized data must be carefully reviewed for face validity: Are all expected data elements (eg, antimicrobial names) represented? Are results comparable to previously validated data, if available? Do the results reflect anticipated variation? Reports based on queries of computerized data require validation, ideally via manual comparison of samples of computerized data with an acceptable gold standard. Systematic sources of error must be vigorously sought to explain recurring or substantial discrepancies in the results of these comparisons.

(Tables 1, 3, 5). By contrast, the use of bedside recording of eMAR data in hospital B for both computer-derived and manually collected numerator data doubtlessly accounted for the high affinity between the data obtained through these different sources. Our results suggest that eMAR is the most accurate source of pharmacy numerator data in the hospitals in which it is in use; however, this finding requires confirmation from other institutions. Measures based on pharmacy dispensing or physician orders, which are further removed from the antimicrobial administration event, are more likely to overestimate actual utilization.

The optimal metric for reporting hospital antimicrobial utilization is unclear.[19-23] We chose antimicrobial-days and patient-days receiving antimicrobials (Table 2) as the primary numerator measures because they provide complementary information on the intensity and breadth of antimicrobial use

in the ICU,[23] they are minimally affected by variation in antimicrobial dosing regimens, and they should be readily extractable given the current widespread availability of detailed, patient-specific computerized pharmacy data within hospitals in the United States. Previous studies have used "days of therapy,"[13] which is analogous to our antimicrobial-days, to rank and assess secular trends in antimicrobial utilization in an alliance of 22 academic health centers and 130 hospitals in the United States.[24,25] However, those analyses were based on charge and billing data, rather than the pharmacy dispensing, physician order, or eMAR data that we employed. Also, the specific methods—proprietary in one instance—were not detailed and validation efforts were limited.[24,25]

Older surveys of antimicrobial utilization from the United States and Europe that were performed where detailed, patient-specific data may not have been available have used conversion factors such as the defined daily dose (DDD) and the recommended daily dose[26,27] to estimate patient-level antimicrobial use from aggregate antimicrobial use and census data to make interinstitutional or international comparisons,[27-29] analyze secular trends,[29,30] and correlate antimicrobial use with antimicrobial resistance.[31-33] However, pharmacy reports of aggregate antimicrobial utilization may substantially overestimate actual use in hospitals because of poorly coordinated mechanisms of medication ordering, distribution, and administration.[15] Moreover, DDDs underestimate patient-level exposure to drugs that require renal dose adjustment,[34] overestimate the use of antimicrobials for which the conversion factor is lower than the doses that are commonly prescribed,[13,35,36] and do not apply to most pediatric patients.[13]

Adaptation of programming approaches to the disparate information systems and data sources available in each institution will be a formidable challenge that will require understanding and the avoidance of potential errors that can impede the valid and efficient measurement of antimicrobial use. The Centers for Disease Control and Prevention is currently revising the data submission requirements for the Antimicrobial Utilization component of the National Healthcare Safety Network to receive standardized summary measures directly from eMAR systems. This may represent the most effective approach to achieving accurate centralized collection, analysis, and reporting of antimicrobial utilization measures from multiple institutions.[37] Application of methods similar to ours by these and other surveillance efforts will be instrumental in achieving the widespread availability of valid and efficient measurements of antimicrobial utilization.

ACKNOWLEDGMENTS

We thank Rick Carlson, PharmD, for his assistance in the manual validation of data at LDS Hospital/Intermountain Healthcare, Salt Lake City, Utah.

Financial support. This work was supported by the Centers for Disease Control and Prevention cooperative agreement 1 U01 CI000327, 1 U01 CI000328, 1 U01 CI000333-01, and 1 U01 CI000334-0. B.C.C. received salary support through National Institutes of Health/National Center for Research Resources grant TL1RR024995.

Potential conflicts of interest. All authors report no conflicts of interest relevant to this article.

Address correspondence to David N. Schwartz, MD, Division of Infectious Diseases, John H. Stroger, Jr. Hospital of Cook County, 1901 West Harrison Street, Chicago, IL 60612 (david.schwartz@hektoen.org).

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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