Infection Control & Hospital Epidemiology (2021), **42**, 688–693
doi:10.1017/ice.2020.1285

Original Article

Novel method of calculating adjusted antibiotic use by microbiological burden

Hana R. Winders PharmD[1], Majdi N. Al-Hasan MBBS[2,3], Bruce M. Jones PharmD[4], Darrell T. Childress PharmD[5], Kayla R. Stover PharmD[6], Benjamin B. Britt PharmD[7], Elias B. Chahine PharmD[8], Suetping Lau PharmD[9], Pamela D. Andrews PharmD[9], Shauna Jacobson Junco PharmD[9], Rebekah H. Wrenn PharmD[10], Brad J. Crane PharmD[11], Jordan R. Wong PharmD[12], Megan M. Seddon PharmD[13], Christopher M. Bland PharmD[14], Shawn H. MacVane PharmD[15], Geneen M. Gibson PharmD[4], P. Brandon Bookstaver PharmD[1,3] on behalf of SERGE-45 investigators

[1]University of South Carolina College of Pharmacy, Columbia, South Carolina, [2]University of South Carolina School of Medicine, Columbia, South Carolina, [3]Prisma Health-Midlands, Columbia, South Carolina, [4]St Joseph's/Candler Health System, Savannah, Georgia, [5]East Alabama Medical Center, Opelika, Alabama, [6]University of Mississippi Medical Center and School of Pharmacy, Jackson, Mississippi, [7]Lexington Medical Center, West Columbia, South Carolina, [8]Palm Beach Atlantic University Gregory School of Pharmacy, West Palm Beach, Florida, [9]Orlando Health, Orlando, Florida, [10]Duke University Hospital, Durham, North Carolina, [11]Blount Memorial Hospital, Maryville, Tennessee, [12]Grady Health System, Atlanta, Georgia, [13]Sarasota Memorial Health Care System, Sarasota, Florida, [14]University of Georgia College of Pharmacy, Savannah, Georgia and [15]Medical University of South Carolina, Charleston, South Carolina

Abstract

Objective: To determine the usefulness of adjusting antibiotic use (AU) by prevalence of bacterial isolates as an alternative method for risk adjustment beyond hospital characteristics.

Design: Retrospective, observational, cross-sectional study.

Setting: Hospitals in the southeastern United States.

Methods: AU in days of therapy per 1,000 patient days and microbiologic data from 2015 and 2016 were collected from 26 hospitals. The prevalences of *Pseudomonas aeruginosa,* extended-spectrum β-lactamase (ESBL)–producing bacteria, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant enterococci (VRE) were calculated and compared to the average prevalence of all hospitals in the network. This proportion was used to calculate the adjusted AU (a-AU) for various categories of antimicrobials. For example, a-AU of antipseudomonal β-lactams (APBL) was the AU of APBL divided by (prevalence of *P. aeruginosa* at that hospital divided by the average prevalence of *P. aeruginosa*). Hospitals were categorized by bed size and ranked by AU and a-AU, and the rankings were compared.

Results: Most hospitals in 2015 and 2016, respectively, moved ≥2 positions in the ranking using a-AU of APBL (15 of 24, 63%; 22 of 26, 85%), carbapenems (14 of 23, 61%; 22 of 25; 88%), anti-MRSA agents (13 of 23, 57%; 18 of 26, 69%), and anti-VRE agents (18 of 24, 75%; 15 of 26, 58%). Use of a-AU resulted in a shift in quartile of hospital ranking for 50% of APBL agents, 57% of carbapenems, 35% of anti-MRSA agents, and 75% of anti-VRE agents in 2015 and 50% of APBL agents, 28% of carbapenems, 50% of anti-MRSA agents, and 58% of anti-VRE agents in 2016.

Conclusions: The a-AU considerably changes how hospitals compare among each other within a network. Adjusting AU by microbiological burden allows for a more balanced comparison among hospitals with variable baseline rates of resistant bacteria.

(Received 13 July 2020; accepted 13 October 2020; electronically published 28 January 2021)

Amid global efforts to address the growing issue of antimicrobial resistance, antimicrobial stewardship programs (ASPs) have been promoted to drive appropriate antibiotic use (AU).[1-4] AU is a measure of antibiotic consumption used by ASPs to analyze and report how antibiotics are prescribed at their institution, which can be used to demonstrate the progress and value provided by ASPs.

Historically, the most commonly used AU metrics have been defined daily dose (DDD) or days of therapy (DOT) per patient admissions, per patient days (PD), or per days present.[5,6] Although these metrics may be valuable for intrafacility comparisons, meaningful interfacility comparison may be limited when comparing facilities with differences in hospital epidemiology and patient populations. To facilitate AU standardization, reporting to the National Healthcare Safety Network, and benchmarking between similar facilities, the Centers for Disease Control and Prevention developed a new metric

Author for correspondence: Hana R. Winders, E-mail: hana.winders@prismahealth.org

PREVIOUS PRESENTATION. The preliminary results of this study were presented in part as an oral abstract at the SHEA Annual Spring Meeting on April 19, 2018, in Portland, Oregon.

Cite this article: Winders HR, *et al.* (2021). Novel method of calculating adjusted antibiotic use by microbiological burden. *Infection Control & Hospital Epidemiology*, 42: 688–693, https://doi.org/10.1017/ice.2020.1285

called the standardized antimicrobial administration ratio (SAAR).[7] The SAAR is a ratio of observed to predicted AU. Predictive models are used to estimate the number of predicted DOT for given locations and antimicrobial categories. Various hospital and location-level factors are incorporated into these predictive models including hospital bed size, number of ICU beds, medical school affiliation, and location type. For example, a hospital with a transplant center designation would be expected to have a higher prevalence of opportunistic and nosocomial pathogens (eg, *Pseudomonas aeruginosa*), and more frequent use of broad-spectrum agents (eg, antipseudomonal β-lactams or APBLs) would be expected. Currently, bacterial burden is not directly adjusted for in calculations. Because broad-spectrum antibiotics are used to treat infections due to certain bacterial isolates, and the prevalence of such isolates can vary widely, it would be reasonable to adjust AU calculations for the proportion of such isolates at a particular hospital.[8]

Methods

The AU in DOT per 1,000 PD and microbiologic data from 2015 and 2016 were requested from 32 hospitals in the Southeastern Research Group Endeavor-45 (SERGE-45) research network located in the southeastern United States. Hospitals in the SERGE-45 research network range from small community hospitals to large academic medical centers. Data were collected on characteristics of the hospitals and their ASPs, including formulary agents, protection criteria, and prospective audit and feedback. Protection criteria are defined as prior authorization or preapproved indications.

Antimicrobial use of APBLs included total AU of piperacillin-tazobactam, ceftazidime, cefepime, meropenem, doripenem, and imipenem-cilastatin at each hospital. The AU of carbapenems included total AU of meropenem, doripenem, imipenem-cilastatin, and ertapenem. The AU of anti-methicillin resistant *Staphylococcus aureus* (MRSA) agents included total AU of vancomycin, daptomycin, and linezolid. The AU of anti–vancomycin–resistant enterococci (VRE) agents included the total AU of daptomycin and linezolid. The prevalences of bacterial isolates at each hospital were calculated utilizing antibiogram data as follows: The prevalence of *P. aeruginosa* was the *P. aeruginosa* isolate count divided by the total gram-negative isolate count. The prevalence of extended spectrum β-lactamase (ESBL)–producing bacteria was the ESBL isolate count divided by the total gram-negative isolate count. The prevalence of MRSA was the MRSA isolate count divided by the total gram-positive isolate count. And the prevalence of VRE was the VRE isolate count divided by the total gram-positive isolate count. The denominators were selected to include all possible organisms of concern when choosing to treat with agents that target gram-positive or gram-negative bacteria. Adjusted AU (a-AU) by microbiological burden was calculated as previously proposed by Al-Hasan et al.[8] For example, a-AU APBL is the AU APBL divided by (the prevalence of *P. aeruginosa* at that hospital divided by the average prevalence of *P. aeruginosa* across all hospitals in network). Similar formulas were used to calculate the a-AU of carbapenems, anti-MRSA agents, and anti-VRE agents based on the prevalences of ESBLs, MRSA, and VRE, respectively.[8]

Only hospitals submitting all necessary data were included in each independent analysis. Hospitals were ranked by AU and a-AU from lowest to highest in each antimicrobial category in 2015 and 2016. The rankings of each hospital were compared using AU and a-AU for various antimicrobial categories in both years. To quantify the magnitude of change in rankings between AU and a-AU, the proportion of hospitals that had ≥2 positions change in ranking was calculated. The proportion of hospitals that underwent a change in quartile of ranking based on AU and a-AU (ie, from the first to second quartiles or vice versa) has also been reported.

To examine the impact of hospital size on change in rankings, the χ^2 test was used to compare differences in rankings between hospitals with ≤200 beds, 201–500 beds, and >500 beds. In this analysis, the rankings of all reported antimicrobial categories in both years of study were evaluated in each hospital (up to 8 categories per hospital). The level of significance for statistical testing was defined as $P < .05$ (2-sided). REDCap version 7.3.4 software was used for data collection and management. Excel 2016 software (Microsoft, Redmond WA) and JMP Pro version 13.0 software (SAS Institute, Cary, NC) were used for statistical analyses.

Results

The AU in DOT per 1,000 PD and microbiologic data were available for analysis for at least 1 year from 26 hospitals. However, 6 hospitals with comparable characteristics were only able to submit DDD data and were excluded. Participating hospitals were assigned to numbers from 1 to 26 to maintain anonymity (Table 1). Hospitals varied in bed capacity: 7 (27%) had ≤200 beds, 10 (38%) had 201–500 beds, and 9 (35%) had >500 beds. Moreover, 21 hospitals (81%) had formal ASPs during the study period. The median full-time equivalent for stewardship pharmacists was 1 and for physician champions was 0.25. All hospitals utilized a certain degree of formulary restrictions, protection criteria, or prospective audit and feedback for antimicrobial agents, most commonly carbapenems.

Hospitals had a median AU of 143 DOT per 1,000 PD for APBL, 32 for carbapenems, 120 for anti-MRSA agents, and 10 for anti-VRE agents. The average prevalences of *P. aeruginosa*, ESBLs, MRSA, and VRE across participating hospitals are shown in Table 2. After adjustment for microbiological burden, the median a-AU was 144 DOT per 1,000 PD for APBL, 25 for carbapenems, 112 for anti-MRSA agents, and 12 for anti-VRE agents.

Most hospitals in 2015 and 2016 moved ≥2 positions in the ranking in either direction using the a-AU of all antibiotic classes studied (Table 3, Figs. 1 and 2, and Supplementary Figs. 1–6 online). The use of a-AU resulted in a shift in quartile of hospital ranking for many hospitals as well (Table 3). For example, 4 hospitals (17%) moved from first (lowest use) to second quartiles or vice versa, 4 (17%) moved between second and third, and 4 (17%) between the third and fourth quartiles for AU of APBL in 2015 after an the adjustment for microbiological burden.

When ranked from lowest to highest AU and a-AU for all antibiotic categories in both years, smaller hospitals were more likely to have an increase in hospital ranking: 31 of 52 (60%) for ≤200 beds versus 26 of 77 (34%) for 201–500 beds versus 24 of 68 (35%) for >500 beds ($P = .007$). Smaller hospitals were also less likely to have a decrease in hospital ranking: 14 of 52 (27%) for ≤200 beds versus 44 of 77 (57%) for 201–500 beds versus 35 of 68 (51%) for >500 beds ($P = .002$). This trend was most prominent for APBLs. Smaller hospitals were more likely to have an increase in hospital ranking based on APBL use compared to others (11 of 13 [85%] for ≤200 beds vs. 4 of 20 [20%] for 201–500 beds vs. 6 of 17 [35%] for >500 beds; $P < 0.001$) and less likely to have a decrease in ranking

https://doi.org/10.1017/ice.2020.1285 Published online by Cambridge University Press

Table 1. Hospital Characteristics

Hospital	Bed Count	Formal ASP[a]	Automated System	Updated CLSI Break Points	Included Antibiotics NOT on Formulary	Included Antibiotics With Protection Criteria	Included Antibiotics With Prospective Audit and Feedback
1	≤200	No	MicroScan	Yes	DOR, IPM	IPM	DAP, ETP, LZD, MEM, TZP
2	≤200	No	Vitek II	No	DAP, DOR, IPM	CAZ, DOR, IPM	
3	≤200	No	Vitek II	No	DAP, DOR, IPM	CAZ, DOR, IPM	
4	≤200	Yes	MicroScan	No	DOR, IPM	DAP, DOR, ETP, IPM, LZD	ATM, CAZ, DAP, DOR, ETP, FEP, IPM, LZD, MEM, TZP
5	≤200	Yes	MicroScan	No	DOR, IPM	DAP, ETP, LZD	ATM, CAZ, DAP, DOR, ETP, FEP, IPM, LZD, MEM, TZP
6	≤200	No	Vitek II	No	DOR, IPM	CAZ, DOR, IPM	
7	≤200	Yes	MicroScan	Yes	DOR, IPM	DAP, ETP, LZD, MEM	ATM, CAZ, DAP, ETP, FEP, LZD, MEM, TZP
8	201–500	Yes	MicroScan	No	DOR, IPM	DAP, ETP, LZD	ATM, CAZ, DAP, DOR, ETP, FEP, IPM, LZD, MEM, TZP
9	201–500	Yes	Vitek II	Yes	DOR	DAP, IPM, LZD, MEM	DAP, ETP, IPM, LZD, MEM
10	201–500	Yes	MicroScan	Yes	DOR, IPM		ATM, CAZ, DAP, ETP, FEP, LZD, MEM, TZP
11	201–500	Yes	Vitek II	No	DOR, IPM	CAZ, DOR, ETP, IPM, MEM	DAP, DOR, ETP, IPM, LZD, MEM
12	201–500	Yes	Vitek II	No	DOR, IPM	ATM, CAZ, DAP, ETP, FEP, LZD, MEM	ATM, CAZ, ETP, FEP, MEM
13	201–500	Yes	Vitek II	Yes	DOR, IPM, CAZ	CAZ, DAP, DOR, ETP, IPM, LZD, MEM	ATM, DAP, DOR, ETP, IPM, LZD, MEM
14	201–500	Yes	Vitek II	Yes	DOR, IPM	DAP, ETP	DAP, ETP, FEP, LZD, MEM, TZP
15	201–500	Yes	Vitek II	Yes	DOR, IPM, CAZ	CAZ, DAP, DOR, ETP, IPM, LZD, MEM	CAZ, DAP, DOR, ETP, IPM, LZD, MEM, TZP
16	201–500	Yes	Vitek II	No	DOR, IPM		MEM
17	201–500	Yes	MicroScan	No	DOR, IPM		DAP, LZD
18	>500	Yes	Vitek II	Yes	DOR, ETP, IPM	DAP, LZD, MEM	DAP, ETP, IPM, LZD, MEM, TZP
19	>500	Yes	Vitek II	Yes	DOR	DAP, IPM, LZD, MEM	DAP, ETP, IPM, LZD, MEM
20	>500	Yes	MicroScan	Yes	CAZ, DOR, IPM	CAZ, DAP, IPM, LZD	ATM, CAZ, DAP, DOR, ETP, FEP, IPM, LZD, MEM, TZP
21	>500	Yes	Vitek II	No	DOR, IPM	CAZ, DAP, DOR, ETP, IPM, LZD, MEM	DAP, LZD
22	>500	Yes	Phoenix	Yes	CAZ, DOR, IPM	DAP, ETP, LZD	ETP
23	>500	Yes	MicroScan	Yes	DOR	ATM, CAZ, DAP, DOR, ETP, IPM, LZD, MEM	FEP, MEM, TZP
24	>500	Yes	MicroScan	Yes	DOR	CAZ, DAP, ETP, IPM, LZD, MEM	ATM, DAP, ETP, FEP, MEM, LZD, TZP
25	>500	Yes	Phoenix	Yes	DOR	ATM, DAP, ETP, IPM, MEM	ATM, DAP, ETP, IPM, LZD, MEM
26	>500	No	Vitek II	No	DOR	ATM, DAP, ETP, LZD	ATM, CAZ, DAP, ETP, FEP, IPM, LZD, MEM, TZP

Note. CLSI, Clinical and Laboratory Standards Institute; ATM, aztreonam; CAZ, ceftazidime; DAP, daptomycin; DOR, doripenem; ETP, ertapenem; FEP, cefepime; IPM, imipenem-cilastatin; LZD, linezolid; MEM, meropenem; TZP, piperacillin-tazobactam.
[a]For most of 2015–2016.

in this antimicrobial category (2 of 13 [15%] for ≤200 beds vs. 14 of 20 [70%] for 201–500 beds vs. 11 of 17 [65%] for >500 beds; $P = 0.005$).

Discussion

Adjusting AU by microbiological burden greatly changed how hospitals compared to each other with respect to use of broad-spectrum antimicrobial agents. Most hospitals in this study moved ≥2 positions in the ranking of AU for broad-spectrum antimicrobial agents and nearly one-half shifted in the quartile of hospital ranking. The greatest relative change in a-AU was observed for anti-VRE agents, likely due to relatively lower use of these agents. We propose that adjusting for the microbiological burden of certain bacterial isolates allows for a more balanced comparison of AU among hospitals at the national level or within a regional network. This comparison may be a more fair and may show individual hospitals where they have undiscovered problems.

Smaller hospitals (≤200 beds) were more likely to see an increase in position in the ranking than larger hospitals. This

https://doi.org/10.1017/ice.2020.1285 Published online by Cambridge University Press

Table 2. Prevalence of Pertinent Bacteria Across Participating Hospitals in 2015 and 2016

Organism	Mean ± SD prevalence in 2015, %	Median (IQR) prevalence in 2015, %	Mean ± SD prevalence in 2016, %	Median (IQR) prevalence in 2016, %
Pseudomonas aeruginosa	11.1 ± 2.6	10.9 (9.4–13.5)	11.0 ± 2.9	11.3 (8.3–13.0)
ESBL-producing bacteria	4.8 ± 2.4	4.7 (2.9–6.2)	5.7 ± 3.1	5.5 (3.3–7.5)
MRSA	22.6 ± 7.7	21.0 (17.0–26.1)	25.0 ± 11.2	25.5 (16.6–28.5)
VRE	2.8 ± 2.3	2.3 (1.1–4.0)	3.1 ± 2.3	2.9 (1.7–3.7)

Note. ESBL, extended-spectrum β-lactamase; MRSA, methicillin-resistant *Staphylococcus aureus*; VRE, vancomycin-resistant enterococci.

Table 3. Comparison of Antibiotic Use and Adjusted Antibiotic Use by Microbiological Burden

	Comparison of Rankings, Fraction of Hospitals (%)			
	2015		2016	
Variable	Moved ≥2 Positions In Ranking	Moved Quartiles	Moved ≥2 Positions in Ranking	Moved Quartiles
APBL	15/24 (63)	12/24 (50)	22/26 (85)	13/26 (50)
Carbapenems	14/23 (61)	13/23 (57)	22/25 (88)	7/25 (28)
Anti-MRSA agents	13/23 (57)	8/23 (35)	18/26 (69)	13/26 (50)
Anti-VRE agents	18/24 (75)	18/24 (75)	15/26 (58)	15/26 (58)
	Median Change in AU			
	2015		2016	
Variable	Median Relative Change, %[a]	Median Absolute Change, DOT/1,000 PD[b]	Median Relative Change, %[a]	Median Absolute Change, DOT/1,000 PD[b]
APBL	17	17	23	35
Carbapenems	38	8	29	6
Anti-MRSA agents	22	24	30	25
Anti-VRE agents	47	6	35	6

Note. APBL, antipseudomonal β-lactams; AU, antibiotic use; DOT, days of therapy; MRSA, methicillin resistant *Staphylococcus aureus*; PD, patient days; VRE, vancomycin-resistant enterococci.
[a]Relative change in AU = (a-AU − AU)/AU × 100.
[b]Absolute change in AU = a-AU − AU.

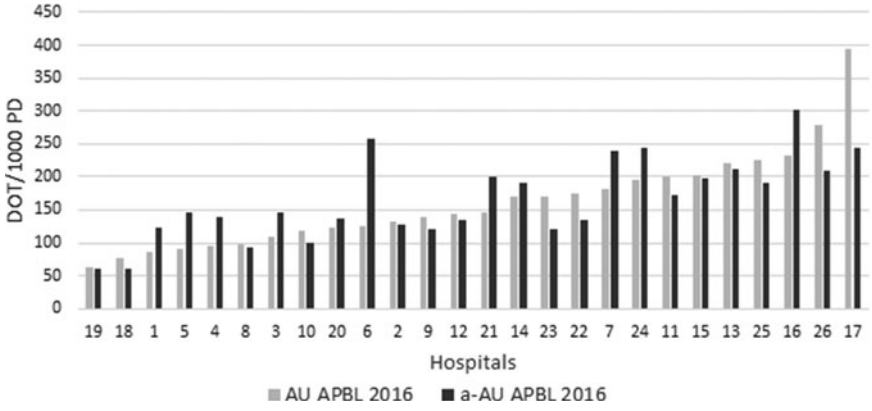

Fig. 1. Actual antibiotic use versus adjusted antibiotic use of antipseudomonal β-lactams in 2016 ranked by actual antibiotic use. Note. a-AU, adjusted antibiotic use; APBL, antipseudomonal β-lactams; AU, antibiotic use; DOT, days of therapy; PD, patient days.

finding was more profound when APBL use was evaluated. This was conceivable given the relatively lower prevalence of resistant bacteria at these hospitals. Previous studies have demonstrated lower prevalence of *P. aeruginosa* among bloodstream and other clinical isolates in small community-hospitals than larger referral tertiary care medical centers.[9,10] After adjustment for microbiological burden, there is even less justification for high use of APBLs in small hospitals compared to larger ones. Similar differences were not seen among hospitals with prospective audit and feedback or protection criteria for at least 1 agent of each class of APBL (ie, cephalosporin, carbapenem, penicillin) and other hospitals without such restrictions (results not shown).

https://doi.org/10.1017/ice.2020.1285 Published online by Cambridge University Press

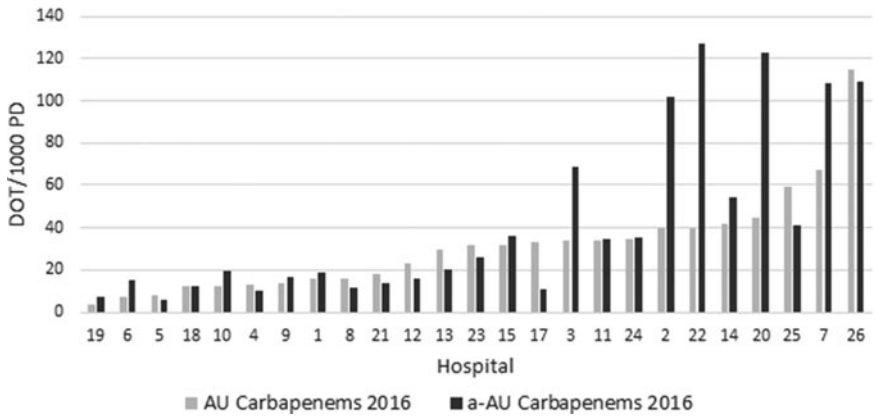

Fig. 2. Actual antibiotic use versus adjusted antibiotic use of carbapenems in 2016 ranked by actual antibiotic use. Note. a-AU, adjusted antibiotic use; AU, antibiotic use; DOT, days of therapy; PD, patient days.

Adjustment for institutional characteristics such as bed size, ICUs, and complexity of patient population has been implemented for several stewardship metrics, including incidence of hospital-onset *Clostridioides difficile* infection. Although it is convenient to use the same formula for AU as suggested in the SAAR, an association between the need for broad-spectrum antibiotics and hospital characteristics remains to be determined. In fact, a few studies looking at incorporating additional patient-specific factors into predictive models for AU have been suggested.[11,12] From an antimicrobial stewardship standpoint, antibiotics are used to treat infections caused by specific bacteria. Adjustment of AU by microbiological burden emphasizes this concept and encourages targeted antimicrobial therapy based on actual or predicted microbiologic etiology of infections rather than broad-spectrum empiricism solely based on clinical indications. To encourage this method of prescribing, patient-specific risk factors for resistant pathogens can be added into treatment guidelines, and education on AU and a-AU could be provided to front-line prescribers. Calculation of the prevalence of bacterial isolates is readily available using institutional antibiograms. This makes adjustment of AU based on bacterial burden relatively simple and convenient. In addition, it may be more up to date than adjustments based solely on hospital characteristics because antibiograms are updated annually. Although a recent study has also shown that MRSA prevalence has an effect on hospital-level anti-MRSA agent use, validation of this novel method of adjusting AU and comparison with other formulas for adjustment would be valuable in future studies.[13]

Contrary to most traditional stewardship metrics, this novel metric may encourage healthcare providers to obtain appropriate cultures. Obtaining blood cultures with subsequent growth of *P. aeruginosa*, for example, justifies the use of APBLs in patients with sepsis. Empirical antimicrobial therapy for "culture-negative" infections due to lack of effort to obtain cultures or obtaining low-yield cultures increases use of broad-spectrum agents without documentation of microbiological burden. On the other hand, the incidence of central-line–associated bloodstream infections and hospital-onset *C. difficile* infections would increase with more blood cultures and *C. difficile* tests obtained. This may discourage clinicians from obtaining appropriate cultures to avoid a heavy burden of hospital-acquired infections or the financial repercussions of publicly reported metrics.

This study implemented a novel method to adjust AU based on microbiological burden. The inclusion of 26 hospitals in 8 states adds strength to this work. However, this study has several limitations. All hospitals were from the southeastern United States, and these results may not be generalizable to hospitals in other areas with very high rates of multidrug-resistant organisms. In addition, microbiologic data were collected from antibiograms, which may be affected by culture frequency, susceptibility testing, and selective reporting of microorganisms. However, if a hospital regularly sends more cultures than others, the percentage of the organism would likely remain the same since both numerator and denominator are increased. The ability of microbiology labs to designate isolates as ESBL producing may also differ between hospitals. In addition, antibiograms do not take into account cultures taken at outside hospitals. Finally, not all bacteria in antibiograms are clinically relevant. Many urinary and respiratory isolates may represent colonization. It would be useful to compare microbiological burden based on overall and sterile antibiograms in future investigations. A limitation of the definitions is the overlap between carbapenems and APBLs and between anti-MRSA and anti-VRE agents. Hospitals would want to look at their rankings in all categories to better understand their use. In addition, similar to other metrics, a-AU does not measure appropriateness of therapy, although it may be a step in the right direction.

In conclusion, adjusting AU by microbiological burden allows for a more balanced comparison among hospitals that have different rates of organisms and antimicrobial resistance patterns. As shown, the a-AU considerably changes how hospitals compare among each other.

Acknowledgments. We thank all participating hospitals that submitted data: Blount Memorial Hospital, Candler Hospital, Duke University Hospital, East Alabama Medical Center, Grady Health System, Lexington Medical Center, McLeod Regional Medical Center and affiliated hospitals, Mt. Pleasant Hospital, Medical University of South Carolina, Nash UNC Health Care, Orlando Health and affiliated hospitals, Prisma Health Midlands hospitals, Providence Health, Roper Hospital, St Francis Hospital, St Joseph's Hospital, St Mary's Hospital, University of Arkansas for Medical Sciences Medical Center, University of Mississippi Medical Center, University of Tennessee Medical Center, Vanderbilt University Medical Center, Vidant Medical Center, Wake Forest Baptist Medical Center, Wellington Regional Medical Center, and Wilson Medical Center.

Financial support. No financial support was provided relevant to this article.

Conflicts of interest. P.B.B. reports that he is on the speakers bureau for bioMerieux, that he is a content developer and speaker for T.R.C. Healthcare, and that he is a content developer and speaker for FreeCE.com. B.M.J. reports that he is on the speakers bureaus for Allergan, Tetraphase, and Paratek. E.B.C. reports being on the speakers bureau for Merck and Paratek. C.M.B. reports receiving honoraria and grant funding from Merck, grant funding from ALK Abello, and

https://doi.org/10.1017/ice.2020.1285 Published online by Cambridge University Press

honoraria from Paratek Pharmaceuticals, bioMerieux, and La Jolla Pharmaceutical Company. G.M.G. reports having consulted for ASHP Consulting. MMS reports being on the speakers bureau for Accelerate Diagnostics. H.R.W. reports being on the speakers bureau for bioMerieux. S.H.M. is currently an employee of Accelerate Diagnostics. All other authors report no conflicts of interest relevant to this article.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2020.1285

References

1. Core elements of hospital antibiotic stewardship programs. Centers for Disease Control and Prevention website. www.cdc.gov/getsmart/healthcare/implementation/core-elements.html. Published 2014. Accessed October 2020.
2. The core elements of antibiotic stewardship for nursing homes. Centers for Disease Control and Prevention website. www.cdc.gov/longtermcare/index.html. Published 2015. Accessed October 2020.
3. Sanchez GV, Fleming-Dura KE, Roberts RM, Hicks LA. Core elements of outpatient antibiotic stewardship. *MMWR Recomm Rep* 2016;65:1–12.
4. New antimicrobial stewardship standard. The Joint Commission website. https://www.jointcommission.org/-/media/enterprise/tjc/imported-resource-assets/documents/new_antimicrobial_stewardship_standardpdf.pdf?db=web&hash=69307456CCE435B134854392C7FA7D76#:~:text=The%20Joint%20Commission%20recently%20announced,becomes%20effective%20January%201%2C%202017. Published July 2016. Accessed February 21, 2019.
5. Polk RE, Fox C, Mahoney A, Letcavage J, MacDougall C. Measurement of adult antibacterial drug use in 130 US hospitals: comparison of defined daily dose and days of therapy. *Clin Infect Dis* 2007;44:664–670.
6. Morris AM. Antimicrobial stewardship programs: appropriate measures and metrics to study their impact. *Curr Treat Options Infect Dis* 2014;6:101–112.
7. van Santen KL, Edwards JR, Webb AK, *et al.* The standardized antimicrobial administration ratio: a new metric for measuring and comparing antibiotic use. *Clin Infect Dis* 2018;67:179–185.
8. Al-Hasan MN, Winders HR, Bookstaver PB, Justo JA. Direct measurement of performance: a new era in antimicrobial stewardship. *Antibiotics (Basel)* 2019;8:127.
9. Al-Hasan MN, Eckel-Passow JE, Baddour LM. Influence of referral bias on the clinical characteristics of patients with gram-negative bloodstream infection. *Epidemiol Infect* 2011;139:1750–1756.
10. Baddour LM, Hicks DV, Tayidi MM, *et al.* Risk factor assessment for the acquisition of fluoroquinolone-resistant isolates of *Pseudomonas aeruginosa* in a community-based hospital. *Microb Drug Resist* 1995;1:219–222.
11. Yu KC, Moisan E, Tartof SY, *et al.* Benchmarking inpatient antimicrobial use: a comparison of risk-adjusted observed-to-expected ratios. *Clin Infect Dis* 2018;67:1677–1685.
12. Goodman KE, Pineles L, Magder LS, *et al.* Electronically available patient claims data improve models for comparing antibiotic use across hospitals: results from 576 US facilities. *Clin Infect Dis* 2020. doi: 10.1093/cid/ciaa1127.
13. Livorsi DJ, Nair R, Lund BC, *et al.* MRSA prevalence and hospital-level antibiotic use: a retrospective study across 122 acute-care hospitals. *Infect Control Hosp Epidemiol* 2020:1–3.