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Original Article

Measuring empiric antibiotic spectrum—A journey through space and time

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Abstract

Objectives: The typical 5-day work week affects healthcare outcomes. Structured work hours have also been implicated in antimicrobial prescribing choice. We developed a visualization tool to aid in evaluating breadth of antibiotic use in various time (day of week and hour of day) and space (patient location) combinations.

Methods: We evaluated antibiotic administration data from a tertiary-care academic medical center between July 1, 2018, and July 1, 2020. We calculated a cumulative empiric antibiotic spectrum score by adapting a previously validated antibiotic spectrum index (ASI) and applying that score to empiric antibiotic use. We visualized these data as a heat map based on various day-of-week–time combinations and then compared the distribution of scores between weekday nights, weekend days, and weekend nights to the typical workweek hours (weekday days, weekday days) using the Mann-Whitney *U* nonparametric test with a Bonferroni correction.

Results: The analysis included 76,535 antibiotic starts across 53,900 unique patient admissions over 2 years. The mean cumulative ASI was higher in all 3 night and weekend combinations (weekday nights, 7.3; weekend days, 7.6; weekend nights, 7.5) compared to the weekday daytime hours (weekday days, 7.1) and the distribution of scores was different in all groups compared to the weekday daytime reference. The cumulative ASI was also higher in intensive care units.

Conclusions: Empiric antibiotic prescribing patterns differed across space and time; broader antibiotic choices occurred in the intensive care units and on nights and weekends. Visualization of these patterns aids in antimicrobial prescribing pattern recognition and may assist in finding opportunities for additional antimicrobial stewardship interventions.

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Antibiotic decision making happens at all hours and in all units of the hospital; however, support from antibiotic stewardship personnel may be limited to weekdays. The typical workweek schedule affects several observed healthcare outcomes, including hospital admission and emergency room visit mortality.[1–3] Some prior studies have also suggested a "weekend effect" in antimicrobial prescribing patterns, where less 'appropriate' antimicrobials are prescribed on weekends or broad antimicrobials are disproportionately discontinued on certain days of the week.[4,5] Analytic tools that evaluate both antibiotic use and antibiotic spectrum by hospital location and time of day could better identify where and when antibiotic decisions that involve broad-spectrum antibiotics occur. With this knowledge, antimicrobial stewardship programs (ASPs) might better investigate and develop interventions to support decision makers during times of broader antibiotic use and identify gaps in resources across space and time.

Previous investigators have quantitatively defined antibiotic spectrum, yet spectrum-score metrics have not been widely applied in assessments of hospital antimicrobial prescribing patterns.[6–11] Our primary aim was to create a visualization aid to demonstrate the spectrum of empiric antibiotic prescribing based on time of administration and location in the acute-care hospital setting. We hypothesized that empiric antimicrobial prescribing would be broader on nights and weekends. Our second aim was to compare empiric antibiotic spectrum occurring in off-hours prescribing on nights and weekends to antibiotic spectrum occurring during traditional workweek hours.

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Methods

We retrospectively evaluated antibiotic administration data from a tertiary-care academic medical center (Duke University Hospital) between July 1, 2018, and July 1, 2020. Antibiotic administration data included antibiotic name, route, indication documented during the ordering process, date and time, and unit location of each administration. Antibiotic administrations with an indication of prophylaxis were excluded. We utilized antibiotic admissions for the analysis, defined as hospital admissions where at least a single dose of nonprophylactic antibiotic was received.

For each antibiotic admission, we calculated a cumulative empiric antibiotic spectrum score by adapting the antibiotic spectrum index (ASI) as described by Gerber et al[7] (Supplementary Material online). Empiric antibiotic choice included all unique antibiotics administered within 24 hours of the first nonprophylactic antibiotic dose for that hospital admission. The cumulative empiric spectrum score was then assigned to the time of the first antibiotic administration, which was assumed to be nearest to the point of antibiotic decision making. For example, if a patient received vancomycin (score, 5) at 1:00 P.M., cefepime (score, 6) at 3:00 P.M., and azithromycin (score, 4) at 10:00 P.M., a cumulative empiric spectrum score of 15 for these 3 agents would be assigned to 1:00 P.M.

We analyzed data in aggregate (ie, hospital-wide) and stratified by hospital unit type (ie, medical and surgical wards and critical care units) as defined by the National Healthcare Safety Network (NHSN).[12] Empiric antibiotic choice for unit-based data was defined as the first 24 hours of new antibiotic starts administered after admission or transfer to a specific unit. To capture only new antibiotic starts, admissions were excluded if the patient received antibiotics on the preceding calendar day on a different unit. Duplicate antibiotic courses per hospital admission were also excluded. The cumulative empiric spectrum score was calculated and assigned in the same manner as hospital-wide data. Mean cumulative empiric spectrum scores were then graphed in a heat map by hour of day and day of the week, creating separate heat maps for specific unit types.

Weekday days were Monday through Friday, 7:00 A.M. to 7:00 P.M. and weekend days included Saturday and Sunday from 7:00 A.M. to 7:00 P.M. Weekday nights included Monday through Thursday 7:00 P.M. to 7:00 A.M., and weekend nights included Friday, Saturday, and Sunday evening from 7:00 P.M. to 7:00 A.M. The distribution of scores on weekday nights, weekend days, and weekend nights were compared against the typical workweek hours using the Mann-Whitney *U* nonparametric test with a Bonferroni correction.

Results

The analysis included 76,535 antibiotic starts across 53,900 unique patient admissions over 2 years. The mean cumulative empiric ASI for all new antibiotic admissions was 7.17, and the mean number of antibiotics per admission was 1.4.

The hospital-wide mean ASI score by hour ranged from a low of 5.7 on Sunday, Monday, and Tuesday at 11:00 P.M. to a high of 8.9 on Saturday at 7:00 A.M. (Fig. 1). A pattern of higher scores was seen on weekends or the early morning hours, and the lowest scores appeared in the late evening and mid-morning.

The mean cumulative ASI was higher in all 3 off-hours week–time combinations (weekday nights, 7.3; weekend days, 7.6; weekend nights, 7.5) compared to the weekday daytime hours (weekday days, 7.1). The median ASI for all 3 comparator groups was 6, and the ASI for the typical work-hour timeframe was 5. The distribution of scores was different in weekday evenings, weekend nights, and weekend days compared to weekday daytime hours ($P < .001$ in all comparisons) (Fig. 2).

Medical and surgical floor data showed administration timing patterns similar to the hospital-wide data (Fig. 3). Critical-care units had a higher overall mean cumulative ASIs compared to ward units (8.2 for ICUs vs 6.9 for wards) and timing patterns were unique. Higher cumulative ASIs occurred in the early morning hours in the medical ICU, but no similar pattern was observed in the surgical ICU.

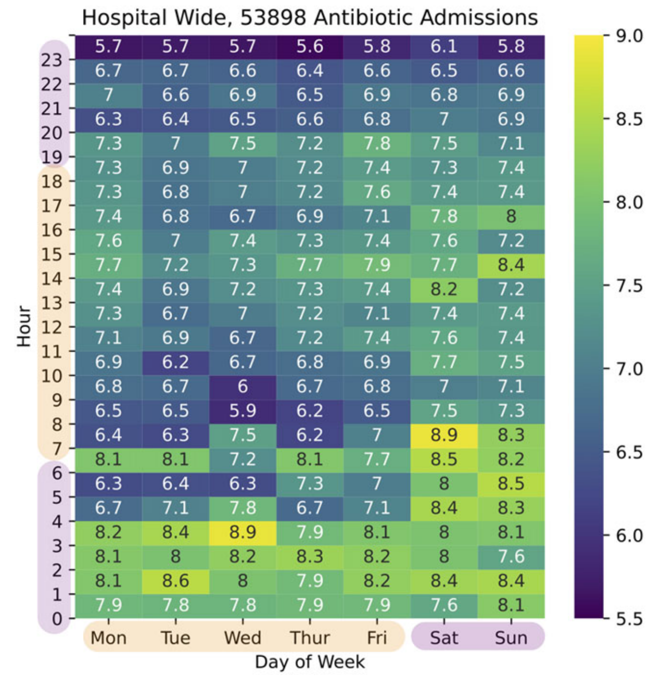

Fig. 1. Antibiotic spectrum index heat map by day and time (mean). Note. Typical work-week periods are highlighted on each axis in orange and off-hours periods are highlighted in purple.

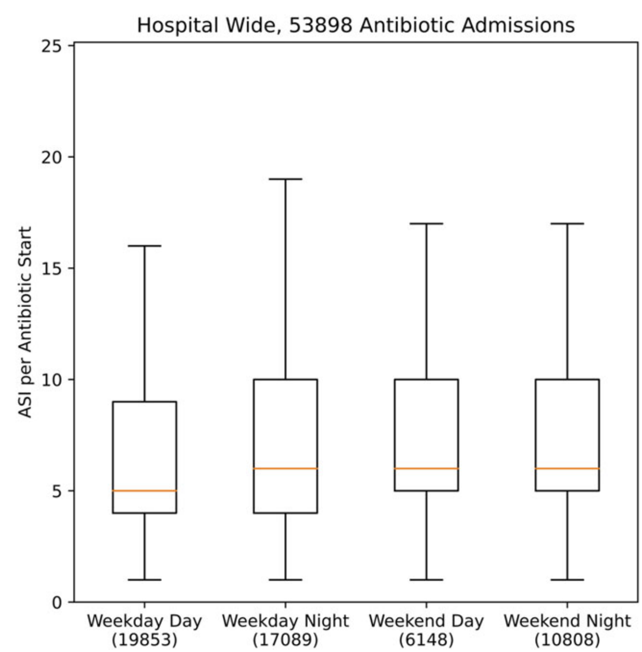

Fig. 2. Box-plot demonstration of ASI distribution by day-and-time groupings. Numbers in parenthesis indicate the number of antibiotic admissions used for each day-and-time group estimate. Note. ASI, Antibiotic spectrum index; *Comparison performed using the Mann-Whitney *U* test with Bonferroni correction. Box plots represent the interquartile ranges and median values.

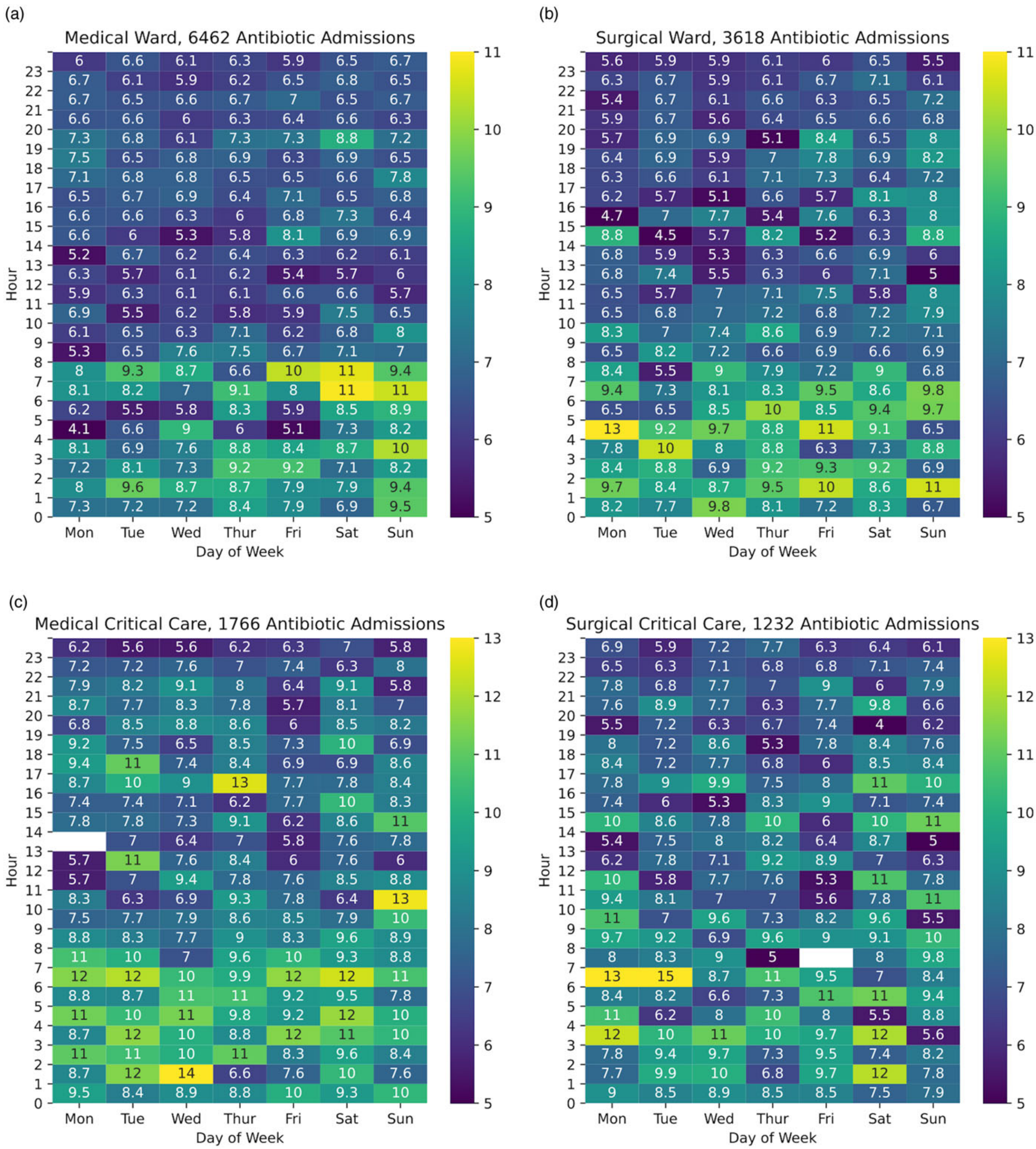

Fig. 3. Academic medical center: unit-based spectrum index heat maps (mean). Note. The heat-map scale varies by unit type to better visualize the differences between day–hour combinations.

Discussion

We developed a tool to visualize empiric antibiotic spectrum across time and space to identify where and when broad-spectrum empiric antibiotic decisions were being made in the hospital. These data were intended primarily for hypothesis generation. Antimicrobials prescribed on nights and weekends were broader than those initiated during the typical workweek hours. This observation was apparent in the overall hospital as well as the general medical and surgical wards. More heterogeneity was seen in critical care units. Direct visualization of such antimicrobial use patterns facilitates an understanding of practice habits that are not captured in traditional antimicrobial consumption metrics and identifies opportunities for stewardship investigation or intervention.

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Prior studies have evaluated the impact of the work week in antibiotic prescribing; however, these studies evaluated antibiotic prescribing rates or appropriateness of antibiotic prescriptions in the ambulatory or emergency setting.[4,13] Two prior studies evaluated the effect of weekdays on broad-spectrum antibiotic discontinuation in inpatient settings.[5,14] Similar to our data, one of these studies also identified increased rates of broad-spectrum initiations on weekends. Our study encompassed a larger number of admissions and was the first, to our knowledge, to utilize an antibiotic spectrum index to provide more granular detail on breadth of empiric antibiotic prescribing across time of day and hospital unit.

Healthcare organizational features are recognized as important contributing factors in antibiotic prescribing.[15] The work-week pattern of empiric inpatient antibiotic choice may be related to staffing patterns throughout the hospital; differences in other healthcare outcomes have been attributed to hospital staffing changes during weekends.[16] Antibiotic choices may vary based on availability of ancillary resources and personnel available during the antibiotic decision-making process (ie, stewardship pharmacists). Clinicians that cover night or weekend shifts may have different decision-making heuristics. In addition, changes in medication availability and antimicrobial approval processes in our institution occur in the evenings.[17] Finally, a difference in patient admission type (ie, acute vs scheduled admissions) may contribute to the patterns observed.[18] These effects may be dampened in intensive care units due to the severity of illness, the usual practice of broader choice of antimicrobials, and the potential for resource availability on nights and weekends.

An integral pillar of antimicrobial stewardship is to limit unnecessarily broad antibiotic exposures for patients. Several prior investigators have proposed metrics to measure the breadth of coverage based on pathogens.[19] We chose to use the antibiotic spectrum index by Gerber et al[7] due to its ability to summarize across multiple agents and provide a cohesive, single value for combination antibiotic regimens. The single value then allowed us to compare between antibiotic admissions. The optimal methods to compare spectrum indices are still unknown, and further epidemiological studies investigating the patterns associated with antibiotic spectrum indices are needed to understand how to utilize these metrics.

We recognize the limitations of an electronic definition of an empiric antibiotic regimen. First, initial therapy may not always be empiric and instead targeted to a specific pathogen. Second, bed transfer data make ward-specific antibiotic attribution imprecise because a regimen may receive a first dose in one ward prior to transfer and receipt of a second dose in a new ward. Third, this analysis identified statistical differences in empiric antibiotic regimens, but the novelty and limited prior experiences with interpretation of antibiotic-spectrum indices limited our ability to infer clinically meaningful difference. Thus, these observations should be viewed as a first step in using these data for meaningful investigations. Finally, we conclude that antibiotic choices were broader on nights and weekends. We cannot, however, comment on the appropriateness of such therapy. The differences outlined above, in addition to other factors, such as the availability of diagnostic procedures, may be rationales for broader therapy on evenings and weekends when less information is available. Future studies may evaluate syndrome-specific antibiotic regimens (eg, sepsis, or community-acquired pneumonia).

In conclusion, spectrum scoring indices provide additional dimensions to traditional antimicrobial consumption metrics. Using such a tool to visualize antibiotic use across space and time in a readily digestible format increased our understanding of our institutional antimicrobial prescribing patterns.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2022.151

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