Antibiotic Stewardship Strategies and Their Association With Antibiotic Overuse After Hospital Discharge: An Analysis of the Reducing Overuse of Antibiotics at Discharge (Road) Home Framework

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Supplementary Data

Supplementary materials are available at Clinical Infectious Diseases online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

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Abstract

Background.—Strategies to optimize antibiotic prescribing at discharge are not well understood.

Methods.—In fall 2019, we surveyed 39 Michigan hospitals on their antibiotic stewardship strategies. The association of reported strategies with discharge antibiotic overuse (unnecessary, excess, suboptimal fluoroquinolones) for community-acquired pneumonia (CAP) and urinary tract infection (UTI) was evaluated in 2 ways: (1) all strategies assumed equal weight and (2) strategies were weighted based on the ROAD (Reducing Overuse of Antibiotics at Discharge) Home Framework (ie, Tier 1—Critical infrastructure, Tier 2—Broad inpatient interventions, Tier 3—Discharge-specific strategies) with Tier 3 strategies receiving the highest weight.

Results.—Between 1 July 2017 and 30 July 2019, 39 hospitals with 20,444 patients (56.5% CAP; 43.5% UTI) were included. Survey response was 100%. Hospitals reported a median (interquartile range [IQR]) 12 (9–14) of 34 possible stewardship strategies. On analyses of individual stewardship strategies, the Tier 3 intervention, review of antibiotics prior to discharge, was the only strategy consistently associated with lower antibiotic overuse at discharge (adjusted incident rate ratio [aIRR] 0.543, 95% confidence interval [CI]: .335–.878). On multivariable analysis, weighting by ROAD Home tier predicted antibiotic overuse at discharge for both CAP and UTI. For diseases combined, having more weighted strategies was associated with lower antibiotic overuse at discharge (aIRR 0.957, 95% CI: .927–.987, per weighted intervention); discharge-specific stewardship strategies were associated with a 12.4% relative decrease in antibiotic overuse days at discharge.

Conclusions.—The more stewardship strategies a hospital reported, the lower its antibiotic overuse at discharge. However, Tier 3, or discharge-specific strategies, appeared to have the largest effect on antibiotic prescribing at discharge.

Keywords

antibiotic stewardship; transitions of care; pneumonia; urinary tract infection; quality of care

Antibiotics are frequently prescribed—and overprescribed—at hospital discharge [1, 2]. Up to half of patients hospitalized for infections are prescribed unnecessary, excessive, or suboptimal antibiotics at discharge [3, 4]. Such antibiotic overuse at discharge may increase antibiotic resistance and antibiotic-associated adverse events without improving outcomes [5].

Across hospitals, antibiotic overuse at discharge varies widely with rates of overuse differing up to 5-fold [4]. One potential cause of this variation relates to a limited understanding of which strategies optimize prescribing at discharge. Compared to inpatient antibiotic stewardship, there are few evidence-based, effective strategies for improving antibiotic prescribing at discharge. One recent systematic review found only 6 published studies demonstrating effective discharge stewardship interventions [6]. Additionally, hospital stewardship programs faced with resource constraints may elect to focus on inpatient prescribing assuming inpatient stewardship “trickles over” to discharge prescribing. The effect of this approach is unclear: although some inpatient stewardship strategies seem to secondarily improve discharge prescribing [2, 7], others may have negative unintended...
consequences at discharge (eg, switching to restricted antimicrobials) [8]. Similarly, many argue that critical stewardship infrastructure alone is insufficient to change prescribing practices. For example, education—although common in stewardship interventions—has not reliably demonstrated improvement in antibiotic prescribing unless paired with more intensive interventions.

Recently, we developed the ROAD (Reducing Overuse of Antibiotics at Discharge) Home Framework that identifies potential strategies for improving antibiotic prescribing at discharge across 3 tiers: Tier 1—Critical infrastructure, Tier 2—Broad inpatient interventions, Tier 3—Discharge-specific strategies [9]. To help antibiotic stewardship programs understand how to apply this framework, we aimed to assess the association of different types of antibiotic stewardship strategies with antibiotic overuse at discharge. We hypothesized that strategies directly targeting antibiotic prescribing at discharge would have a larger effect on antibiotic use at discharge than strategies indirectly targeting antibiotic use at discharge (eg, inpatient strategies).

**METHODS**

**Study Setting and Participants**

This retrospective cohort study includes hospitals in Michigan that participated in the Michigan Hospital Medicine Safety (HMS) Consortium. HMS is a statewide, multi-institutional collaborative quality initiative sponsored by Blue Cross Blue Shield of Michigan and Blue Care Network with a goal of improving quality of care (including antibiotic use) for hospitalized medical patients. Hospital participation in HMS is voluntary and includes half of nongovernment hospitals in Michigan, including rural hospitals, community hospitals, and academic teaching hospitals [10]. Since 2017, HMS has collected detailed medical record data on a sample of hospitalized, non-critically ill medical patients treated for community-acquired pneumonia (CAP) or urinary tract infection (UTI) at each hospital [4, 5, 8, 11]. These data are then fed back to hospitals in the form of hospital benchmarking and pay-for-performance metrics [12]. HMS does not specify which stewardship strategies hospitals should perform; thus, each hospital conducts antibiotic stewardship according to their local or system antibiotic stewardship and/or quality committees.

Previously, we published data from 46 HMS hospitals describing antibiotic overuse at discharge for hospitalized patients treated for CAP or UTI from 1 July 2017 to 30 July 2019 [4]. Here we include data on antibiotic overuse at discharge from that same time period for the 39 HMS hospitals surveyed on their antibiotic stewardship strategies during the fall of 2019 (see below).

**Survey Administration**

To better understand stewardship strategies associated with antibiotic overuse at discharge, we surveyed the 39 HMS hospitals participating in HMS during the fall of 2019. The survey included questions on current antibiotic stewardship policies, infrastructure, and interventions and was administered electronically using Qualtrics XM, emailed to all HMS
hospitals on 11/2/2019 (completed by 17 December 2019). The data abstractor (typically a nurse in quality) at each hospital was responsible for working with local individuals (eg, antibiotic stewardship leaders) to ensure survey accuracy and completion.

**Survey Design- Stewardship Characteristics**

We followed the American Association for Public Opinion Research’s “Best Practices for Survey Research” [13]. Survey questions were adapted from the Centers for Disease Control and Prevention’s Core Elements for Antibiotic Stewardship and from the ROAD Home framework [9, 14]. The final survey included questions related to ongoing antibiotic stewardship initiatives from each of the 3 ROAD Home framework tiers. Within each tier, strategies could be focused on one disease (ie, UTI or CAP) or 1 antibiotic class (eg, fluoroquinolone). Similarly, some categories (eg, diagnostic stewardship) include multiple different strategies (eg, remove reflex testing or hiding urine culture results). Tier 1, “Critical Infrastructure,” includes “strategies [that] provide critical infrastructure required for stewardship in general,” such as dedicated stewardship resources and updated disease-specific guidelines [9]. Tier 2, “Broad Interventions,” strategies include “broad interventions aiming to improve inpatient antibiotic prescribing … [that] … do not directly target prescribing at discharge” [9]. Example Tier 2 strategies include syndrome-specific audit and feedback, fluoroquinolone restriction, and antibiotic timeouts. Tier 3, or “Discharge Specific,” interventions are those directly targeting improvement of antibiotic prescribing at discharge and included: discharge intervention de-emphasizing fluoroquinolones, access to institutional data on antibiotic prescribing at discharge, and a process for reviewing of antimicrobial therapy orders prior to discharge. The complete survey can be found in the Appendix. Additionally, we obtained data on general hospital characteristics from publicly available databases (details in Appendix).

**Primary Outcome: Antibiotic Overuse After Discharge**

The primary outcome of interest was the number of days of antibiotic overuse after discharge (per patient treated for CAP or UTI). For analyses of individual stewardship strategies, we also report the proportion of patients treated for CAP or UTI who had antibiotic overuse at discharge.

Definitions used to characterize antibiotic overuse at discharge have been described previously (see Appendix for details) [4]. Briefly, 3 types of antibiotic overuse at discharge were assessed: unnecessary antibiotic use, excess duration, and suboptimal use of fluoroquinolone therapy. Each date could count as a maximum one day of antibiotic overuse (see Supplementary Figure 1 in the Appendix for examples). Unnecessary antibiotic use included any antibiotic use at discharge in patients who had asymptomatic bacteriuria (ASB) or did not meet diagnostic criteria for CAP [11, 15, 16]. Excess duration, determined by disease-specific guidelines, included any antibiotic use at discharge more than 1 day in excess of what was expected [5, 17]. For most patients with CAP the expected duration was 5 days (as long as patients improved clinically within 5 days and did not have an organism requiring longer treatment). For UTI the expected duration varied based on severity of UTI and antibiotic choice (see Appendix for details). Suboptimal fluoroquinolone therapy included use of fluoroquinolones in patients who, based on organism(s), renal function,
sensitivities, allergies, and comorbidities, could have been treated with a safer alternative (eg, uncomplicated cystitis in non-allergic patients with normal renal function and an organism sensitive to nitrofurantoin) [18].

**Data Analysis**

Descriptive statistics were used to characterize self-reported stewardship strategies of participating hospitals. We evaluated the association of stewardship strategies with days of antibiotic overuse at discharge via three methods. First, we evaluated the individual association of each stewardship strategy with antibiotic overuse at discharge with no other strategies in the model. Second, we evaluated the association of number of stewardship strategies with antibiotic overuse at discharge when each stewardship strategy was assumed to have an equal effect on antibiotic overuse at discharge (unweighted). Thus, stewardship strategies were assessed as a count of all reported stewardship strategies. Finally, to test our hypothesis that discharge-specific (Tier 3) interventions have a stronger effect on antibiotic overuse at discharge, we also assessed stewardship strategies weighted by ROAD Home tier. For this analysis, we assumed that Tier 3 (discharge-specific) strategies had 3 times the influence on antibiotic overuse at discharge as Tier 1 (critical infrastructure) strategies and that Tier 2 (broad inpatient) had a medium effect of twice that of Tier 1.

For each model, we evaluated the association of each stewardship strategy with days of antibiotic overuse at discharge using multilevel (patients nested within hospitals) negative binomial regression models controlling for hospital characteristics (bed size, academic status, profit status) and patient characteristics found to be associated with antibiotic overuse at discharge in a previous study [4]: length of stay, condition, presence of severe sepsis on admission, discharge date (by 3-month period), discharge to post-acute care, Charlson comorbidity index, sex, and age. Any strategy associated with more days of antibiotic overuse at discharge on individual strategy models were given a negative value.

Notably, some strategies targeted CAP (N = 5), some targeted UTI (N = 17), and some targeted both CAP and UTI (N = 12; Supplementary Figure 2). Thus, we used separate models to evaluate the effect of strategies on CAP-specific antibiotic overuse at discharge, UTI-specific overuse, and combined CAP and UTI overuse at discharge. Disease-agnostic strategies were included in all models (CAP, UTI, combined CAP and UTI). Model results are reported as adjusted incident rate ratios (aIRRs) per strategy, point, or weighted point and 95% confidence intervals (CIs). For example, an aIRR of 0.900 per weighted point would indicate a Tier 1 strategy is associated with a 10.0% decrease (100%*[1–.900]) in antibiotic overuse days at discharge and a Tier 3 strategy is associated with a 27.1% decrease (100%*[1–.900^3]) in antibiotic overuse days at discharge. Each additional strategy provides diminishing returns; for example, the second Tier 1 strategy would result in a 10% decrease of the remaining antibiotic overuse (90%) or 10% × 90% (ie, 9% of baseline). Figures 2 and 3 visually depict the additive benefit of each additional strategy.

Finally, to better describe how these models represent pathways to improving antibiotic use at discharge, we describe three hospitals with low days of antibiotic overuse at discharge. The 3 hospitals were chosen specifically to represent contrasting pathways to low discharge antibiotic overuse.
All statistical tests were performed at an alpha level of 0.05. Analysis was completed using SAS version 9.4. We followed EQUATOR reporting guidelines (STROBE checklist in the Appendix). As the purpose of HMS is to measure and improve the quality of existing care practices, it received a “not regulated” status by our institutional review board.

RESULTS

Between 1 July 2017 and 30 July 2019, 39 hospitals with 20,444 patients (56.5% [11,554] CAP; 43.5% [8,890] UTI) were included. All hospitals responded to the survey. Hospitals were largely academic (89.7%, 35/39) and nonprofit (92.3%, 36/39) and had a median size of 310 beds (interquartile range [IQR]: 186–443; see Supplementary Table 1 for details).

Table 1 and Supplementary Figure 2 show self-reported stewardship strategies. Hospitals had a median (IQR) 12 (9–14) of 34 possible stewardship strategies, including 3 (3–5) of 6 possible Tier 1 strategies, 8 (5–10) of 25 possible Tier 2 strategies, and 0 (0–0) of 3 possible Tier 3 strategies. Of 17 strategies targeting CAP (12 disease-agnostic, 5 CAP-specific), hospitals had a median (IQR) 6 (5–8) strategies. Of 29 strategies targeting UTI (12 disease-agnostic, 17 UTI-specific), hospitals had a median (IQR) 10 (8–12) strategies. Only 23% (9/39) of hospitals had any Tier 3 interventions (6 hospitals had 1, 3 hospitals had 2). Compared to hospitals without Tier 3 interventions, hospitals with Tier 3 interventions had fewer Tier 1 (3 vs 4 out of 6, \(P = .12\)) and more Tier 2 (9 vs 7 out of 23, \(P = .14\)) interventions. Hospitals reporting Tier 3 interventions are marked by arrows in Figure 1.

When evaluating the association of individual stewardship strategies with days of antibiotic overuse at discharge, few stewardship interventions were associated with CAP-specific, UTI-specific, or combined antibiotic overuse at discharge (Table 2). Only 1 intervention, the Tier 3 intervention “review of out-patient antibiotics before discharge,” was associated with fewer days of antibiotic overuse at discharge for both diseases: 50% fewer for UTI (aIRR 0.496, 95% CI: .300–.820), 46% fewer for CAP (aIRR 0.542, 95% CI: .326–.901), and 46% fewer for CAP and UTI combined (aIRR 0.543, 95% CI: .335–.878). Notably, hospitals that reported having a preset antibiotic duration for CAP (Tier 2) were more likely to have antibiotic overuse at discharge in hospitalized patients treated for CAP (aIRR 1.441, 95% CI: 1.131–1.836).

Association of Number of Stewardship Strategies With Antibiotic Overuse at Discharge

When each stewardship strategy was assessed as having equal weight, having more self-reported stewardship interventions was associated with less antibiotic overuse for both diseases combined (aIRR: 0.922, 95% CI: .862–.986, per intervention; Figure 2A). Thus, the predicted effect of each additional stewardship strategy would be ~8% relative reduction in days of antibiotic overuse at discharge. This association was driven by decreases in antibiotic overuse at discharge for CAP (aIRR 0.933, 95% CI: .880–.990, per intervention), as the association with unweighted strategies on UTI was not statistically significant (aIRR: 0.962, 95% CI: .922–1.003, per intervention).
Association of ROAD Home Tiers With Antibiotic Overuse at Discharge

When weighted by ROAD Home Tier, having more weighted stewardship interventions was associated with fewer days of antibiotic overuse at discharge overall (aIRR 0.957, 95% CI: .927–.987, per weighted intervention; Figure 2B), for CAP (aIRR 0.966, 95% CI: .939–.994, per weighted intervention; Figure 3A) and for UTI (aIRR 0.978, 95% CI: .958–.999, per weighted intervention; Figure 3B). To place these findings in context, a hospital with the most (16) interventions would be predicted to have 45.3% (95% CI: 14.8%–64.9%) fewer antibiotic overuse days at discharge for combined UTI and CAP than a hospital with the least (2) interventions. The predicted effect of a Tier 1 intervention would be a 4.3% (95% CI: 1.3%–7.3%) relative reduction in days of antibiotic overuse at discharge; the predicted relative reduction resulting from a Tier 3 intervention would be 12.4% (95% CI: 3.6%–20.4%).

Three Pathways to Low Antibiotic Overuse at Discharge

At least 3 pathways may exist to low antibiotic overuse at discharge as demonstrated by Hospitals 1, 2, and 3 (marked in Figure 1). As described in Table 3, Hospital 1 has no discharge interventions but plentiful and robust inpatient antibiotic stewardship. Hospital 2 “does it all” and has robust inpatient as well as discharge-specific strategies. In contrast, Hospital 3 has limited inpatient stewardship activities but two Tier 3 (discharge-specific) strategies. All have low antibiotic overuse at discharge compared to other hospitals in the HMS collaborative.

DISCUSSION

In this study of 20 444 patients at 39 hospitals, we found that the more stewardship strategies a hospital reported, the lower its antibiotic overuse at discharge. The ROAD Home Framework—which was developed to characterize stewardship strategies and their relationship to discharge antibiotic use—effectively explained the association of strategies with antibiotic overuse at discharge. Our study suggests that, while Tier 1 (stewardship infrastructure) and Tier 2 (broad inpatient) strategies contribute to appropriate antibiotic use at discharge, Tier 3 (discharge-specific) strategies may have the greatest effect on antibiotic overuse at discharge.

Previously, studies on discharge stewardship interventions have been limited. Successful strategies have included: pharmacist review of antibiotics prior to discharge [19], disease-specific order sets [20], preset antibiotic durations [21], or some combination of interventions. Here we found review of antibiotics prior to discharge was the only intervention consistently associated with less antibiotic overuse at discharge across diseases. This makes conceptual sense, as review of inpatient antibiotics via prospective audit and feedback is the inpatient strategy with the most evidence for improving antibiotic appropriateness [7, 14]. Similar to inpatient prospective audit, discharge antibiotic review has challenges to sustainability due to its resource-intensive nature. All hospitals in HMS that reported conducting discharge antibiotic review engaged clinical pharmacists—either inpatient or transitions of care pharmacists—and ensured antibiotic review fit into existing workflows. Thus, successful discharge antibiotic review may differ depending...
on a hospital’s existing pharmacy resources. One notable barrier often cited to discharge stewardship is prospective identification of discharges. In our study, hospitals identified discharges through a combination of face-to-face (eg, identification during rounds) and automatic notifications when discharge orders were placed.

As described in the hospital examples, our findings suggest there is no single solution to improving antibiotic use at discharge. First, as implied by the Centers for Disease Control and Prevention in their “Core Elements” and by studies of successful stewardship interventions, effective antibiotic stewardship is often multi-faceted [14]. We found that the more strategies a hospital reported, the lower their antibiotic overuse at discharge. One notable exception is that hospitals with a preset duration were more (rather than less) likely to have antibiotic overuse at discharge; potentially indicating that preset durations were set longer than recommended (eg, 7 days additional at discharge), nudging prescribers toward excessive durations. Second, there appear to be multiple pathways to success. Hospitals such as Hospital 1 follow 1 pathway; they have a large number of Tier 1 and Tier 2 strategies that, when evaluated closer, are robustly implemented with discharge in mind (eg, discussion of discharge antibiotics during audit and feedback). Hospitals like Hospital 1 have such robust stewardship infrastructure that they likely have low antibiotic overuse regardless of which metric or disease is evaluated. The second pathway involves “doing it all”—a path not always feasible. Notably, hospitals that reported Tier 3 strategies (such as Hospital 2 above), tended to have more Tier 2 strategies, suggesting they generally had more infrastructure for antibiotic stewardship and thus were more easily able to expand to discharge stewardship despite barriers. Most practically, there is an important third pathway demonstrated by Hospital 3. That hospital had relatively few Tier 1 or Tier 2 interventions yet had lower antibiotic overuse at discharge likely due to focused implementation of Tier 3 interventions.

The implementation implications to our study are threefold. First, infrastructure remains critical but insufficient for antibiotic stewardship. Although theoretically possible, no hospitals had only Tier 3 interventions. Rather, hospitals with a Tier 3 intervention had 2 more Tier 2 interventions than hospitals without discharge stewardship. It appears that having broad inpatient interventions made Tier 3 interventions more feasible and thus more likely. This supports the importance of investing in inpatient stewardship infrastructure. Second, if a hospital truly has limited resources and limited existing stewardship strategies, implementing Tier 3 interventions straightaway may provide the biggest return on investment—particularly if antibiotic overuse at discharge is high as the tradeoff would be fewer resources for new inpatient strategies. Finally, if a hospital already has multiple stewardship interventions and good inpatient infrastructure, adding a discharge stewardship intervention may not result in further (substantial) improvement in antibiotic use at discharge. In summary, discharge stewardship strategies should be tailored to existing resources and needs at individual hospitals.

Our findings should be taken in the context of limitations. Surveys are self-reported from a single moment in time and may not reflect the entire study timeframe. Because responses were derived from a survey, we were unable to evaluate for critical factors that affect stewardship such as prescribing culture or details of strategy implementation. We evaluated only 2 disease states and three types of overuse, although it is possible that the findings...
may apply beyond these narrow groups. Our study is retrospective and therefore does not demonstrate causality. Furthermore, most HMS hospitals self-identified as academic and few were rural hospitals; thus, results may not be generalizable to all hospitals. Study strengths include detailed assessment of stewardship strategies and appropriate antibiotic use and use of an a priori framework based on existing literature [9].

In conclusion, we found that the more stewardship strategies a hospital reported, the lower its antibiotic overuse at discharge. However, different pathways exist to improving discharge antibiotic use. Thus, discharge stewardship strategies should be tailored to existing resources and needs at individual hospitals. Specifically, hospitals with limited existing resources and infrastructure should consider implementing a discharge-specific strategy straightaway, although hospitals with substantial existing infrastructure may benefit the most from incorporating discharge practices into their existing inpatient stewardship strategies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Antibiotic overuse after discharge in patients treated for pneumonia or urinary tract infection, by hospital (N = 39 hospitals). Variation in antibiotic overuse at discharge across hospitals is shown. Each bar represents a single hospital. Antibiotic overuse is divided by 4 types of overuse: (a) unnecessary antibiotics (asymptomatic bacteriuria or patients treated for pneumonia who did not have pneumonia), (b) excess duration, (c) suboptimal use of fluoroquinolones, and (d) suboptimal use of fluoroquinolones and excess duration. Hospitals marked with a star are those reporting at least 1 Tier 3 or discharge-specific stewardship strategy. Hospitals 1, 2, and 3 are those described in detail in Table 3.
Figure 2.

A. Association of stewardship strategies with antibiotic overuse at discharge (stewardship strategies unweighted). Bars shown represent the adjusted (with 95% CI) number of days of antibiotic overuse at discharge in hospitals with the specific number of unweighted strategies (eg, hospitals with 2 unweighted strategies had, on average, 2.7 days of antibiotic overuse at discharge per patient). Yellow line (model) shows the expected number of antibiotic overuse days at discharge based on the number of unweighted antibiotic stewardship strategies. Thus, values represent the adjusted overuse duration for an average patient treated at an average hospital where the number of unweighted antibiotic stewardship strategies varies from 1 to 8. Although 12 disease-agnostic strategies are possible, the maximum reported by included hospitals was 8 and thus data are not reported for values >8.

B. Association of stewardship strategies with antibiotic overuse at discharge (stewardship strategies weight by tier). Bars shown represent the adjusted (red) number of days of antibiotic overuse at discharge based on the number of weighted antibiotic stewardship strategies weight by tier. The yellow line (model) shows the expected number of antibiotic overuse days at discharge based on the number of weighted antibiotic stewardship strategies.
discharge in hospitals with the specified number of weighted strategies (e.g., hospitals with 8 weighted strategies had, on average, 2.4 days of antibiotic overuse at discharge per patient). Yellow line (model) shows the expected number of antibiotic overuse days at discharge based on the number of weighted antibiotic stewardship strategies (with Tier 3 strategies weighted 3 times Tier 1 strategies). Thus, the values represent the adjusted overuse duration for an average patient treated at an average hospital where the number of weighted antibiotic stewardship strategies is then varied from 1 to 16. Although 25 disease-agnostic weighted strategies are possible, the maximum reported by included hospitals was 16, and thus data are not reported for values >16. No hospitals reported 6, 12, or 15 weighted strategies.

Abbreviation: CI, confidence interval.
Figure 3.

A. Association of tiered stewardship strategies with antibiotic overuse at discharge, pneumonia. Bars shown represent the adjusted (red) number of days of antibiotic overuse at discharge for patients with CAP in hospitals with the specified number of weighted strategies (eg, hospitals with 8 weighted strategies had, on average, 1.9 days of antibiotic overuse at discharge per CAP patient). Yellow line (model) shows the expected number of antibiotic overuse days at discharge based on the number of weighted antibiotic stewardship strategies (with Tier 3 strategies weighted 3 times Tier 1 strategies). Thus, values represent the adjusted overuse duration for an average patient treated at an average hospital where the number of weighted antibiotic stewardship strategies is then varied from 1 to 20. Although 33 CAP-related weighted strategies are possible, the maximum reported by included hospitals was 20, and thus data are not reported for values >20. No hospitals reported 6 or 18 weighted strategies. B, Association of tiered stewardship strategies with antibiotic overuse.
at discharge, urinary tract infection. Bars shown represent the adjusted (red) number of days of antibiotic overuse at discharge for patients with a UTI in hospitals with the specified number of weighted strategies (eg, hospitals with 8 weighted strategies had, on average, 2.8 days of antibiotic overuse at discharge per UTI patient). Yellow line (model) shows the expected number of antibiotic overuse days at discharge based on the number of weighted antibiotic stewardship strategies (with Tier 3 strategies weighted 3 times Tier 1 strategies). Thus, values represent the adjusted overuse duration for an average patient treated for a UTI at an average hospital where the number of weighted antibiotic stewardship strategies is then varied from 1 to 32. Although 57 UTI-related weighted strategies are possible, the maximum reported by included hospitals was 32, and thus data are not reported for values >32. No hospitals reported <6, 7, 10, 16, or 27–31 weighted strategies. Abbreviations: CAP, community-acquired pneumonia; UTI, urinary tract infection
Table 1.

Self-Reported Stewardship Characteristics and Interventions, N = 39 Hospitals

| Tier 1: Critical infrastructure | Hospitals Responding “Yes” |
|---------------------------------|---------------------------|
| Has an antibiotic stewardship team | 39 (100%) |
| Stewardship resources increased since the joint commission standard | 12 (31%) |
| Hospital policy requiring documentation of intended antibiotic duration | 6 (15%) |

| Tier 1: UTI-specific critical infrastructure | Hospitals Responding “Yes” |
|---------------------------------------------|---------------------------|
| Institutional treatment guideline for UTI | 27 (69%) |
| Institutional treatment guideline for UTI, updated within the last year | 20 (51%) |
| Indications of obtaining urine culture | 18/20 (90%) |
| Recommendations for not treating ASB | 17/20 (85%) |
| Antibiotic regimens that are concordant with national guidelines | 20/20 (100%) |
| Recommend against fluoroquinolone as first line agent for cystitis | 19/20 (95%) |
| Clinicians educated on UTI and ASB | 34 (87%) |

| Tier 1: Pneumonia-specific critical infrastructure | Hospitals Responding “Yes” |
|--------------------------------------------------|---------------------------|
| Institutional treatment guideline for pneumonia | 36 (92%) |
| Institutional treatment guideline for pneumonia, updated within the last year | 21 (59%) |
| Antibiotic regimens consistent with national guidelines | 23/23 (100%) |
| Recommends 5-day antibiotic treatment for most pneumonia | 21/23 (91%) |
| Recommends fluoroquinolone as first line agent for CAP w/o penicillin allergy | 2/23 (9%) |
| PNA guideline oral step-down recommendations | 21/23 (91%) |
| Provides recommendation for de-escalation | 20/23 (87%) |
| Clinicians educated on pneumonia | 37 (95%) |

| Tier 2: Broad interventions (inpatient focused) | Hospitals Responding “Yes” |
|-----------------------------------------------|---------------------------|
| Antibiotic timeout at 48–72 hours | 12 (31%) |
| All fluoroquinolones restricted | 12 (31%) |
| Had a fluoroquinolone-directed intervention in last year | 39 (100%) |
| Median number of interventions (5 potential) | 3 (2–4) |
| Tracked fluoroquinolone prescribing rates | 31 (80%) |
| Included fluoroquinolones in antibiotic timeout | 14 (36%) |
## Tier 2: UTI-specific broad interventions

| Intervention                                                                 | Hospitals Responding “Yes” |
|----------------------------------------------------------------------------|-----------------------------|
| Provided clinician-level feedback on fluoroquinolone prescribing           | 11 (28%)                   |
| Educated clinicians on alternatives to fluoroquinolones                    | 32 (82%)                   |
| Incorporated alternatives to fluoroquinolones in local guidelines          | 30 (77%)                   |

## Tier 2: Pneumonia-specific broad interventions

| Intervention                                                                 | Hospitals Responding “Yes” |
|----------------------------------------------------------------------------|-----------------------------|
| Preset duration of antibiotics (in CPOE) for patients with pneumonia       | 22 (56%)                   |
| Audit and feedback for pneumonia                                          | 31 (80%)                   |
| CPOE for pneumonia                                                         | 39 (100%)                  |

## Tier 3: Discharge-specific interventions

| Intervention                                                                 | Hospitals Responding “Yes” |
|----------------------------------------------------------------------------|-----------------------------|
| Intervention de-emphasizing fluoroquinolones at discharge                   | 6 (15%)                    |
| Have data on institutional antibiotic use at discharge                      | 3 (8%)                     |
| Outpatient antibiotics are reviewed prior to discharge                      | 3 (8%)                     |
| Clinical pharmacist reviews                                                 | 3/3 (100%)                 |
| Pharmacists notified about discharges via face-to-face rounds              | 1/3 (33%)                  |
| Pharmacists notified about discharges via automatic page and face-to-face rounds | 2/3 (67%)                  |
Abbreviations: ASB, asymptomatic bacteriuria; CAP, community-acquired pneumonia; CPOE, computerized provider order entry; ED, emergency department; ID, infectious disease; UTI, urinary tract infection.
Table 2.
Association of Reported Stewardship Strategies With Antibiotic Overuse at Discharge, N = 39 hospitals, 20,444 patients

| Strategy Description                                      | Urinary Tract Infection N = 8890 patients | Pneumonia N = 11,554 patients | Combined N = 20,444 Patients |
|-----------------------------------------------------------|------------------------------------------|-------------------------------|------------------------------|
| **Unadjusted Proportions of Patients With Antibiotic Overuse at Discharge** | **IRR (95% Cl)** | P-value | **Unadjusted Proportions of Patients With Antibiotic Overuse at Discharge** | **aIRR (95% Cl)** | P-value | **Unadjusted Proportions of Patients With Antibiotic Overuse at Discharge** | **aIRR (95% Cl)** | P-value |
| “Yes” (%) | “No” (%) | | “Yes” (%) | “No” (%) | | “Yes” (%) | “No” (%) | |
| Tier 1: Critical infrastructure                          |                                          |                              |                              |                                          |                              |                                          |                              |
| Stewardship resources increased since the Joint Commission standard | 119/3206 (37.1%) | 2204/5684 (38.8%) | 1.057 (.784–1.424) | .72 | 1962/3462 (56.7%) | 4557/8092 (56.3%) | 1.169 (.886–1.543) | .27 | 3153/6668 (47.3%) | 6761/13 776 (49.1%) | 1.075 (.820–1.409) | .60 |
| Hospital policy requiring documentation of intended antibiotic duration | 658/1498 (43.9%) | 2737/7392 (37.0%) | 1.171 (.819–1.673) | .39 | 1307/2277 (57.4%) | 5212/9277 (56.2%) | 0.988 (.697–1.400) | .94 | 1965/3775 (52.1%) | 7949/16 669 (477%) | 1.047 (.749–1.465) | .79 |
| Tier 1: UTI-specific or pneumonia-specific critical infrastructure |                                          |                              |                              |                                          |                              |                                          |                              |
| Institutional treatment guideline for UTI (or Pneumonia), updated within the last year | 1785/4799 (37.2%) | 1610/4091 (39.4%) | 0.875 (.666–1.151) | .34 | 3973/7271 (54.6%) | 25464283 (59.4%) | 0.833 (.641–1.083) | .17 | NA | NA | NA | NA |
| Clinicians educated on UTI and ASB (or Pneumonia) | 2795/7443 (37.6%) | 600/1447 (41.5%) | 0.820 (.559–1.202) | .31 | 6160/10942 (56.3%) | 359/612 (58.7%) | 0.952 (.534–1.697) | .87 | NA | NA | NA | NA |
| Tier 2: Broad interventions (inpatient focused)           |                                          |                              |                              |                                          |                              |                                          |                              |
| Antibiotic timeout at 48–72 hours | 8644250 (38.4%) | 2531/6640 (38.1%) | 0.884 (.644–1.214) | .45 | 1960/3307 (59.3%) | 4559/8247 (55.3%) | 1.038 (.767–1.407) | .81 | 2824/5557 (50.8%) | 887 (476%) | 0.975 (.728–1.360) | .87 |
| All fluoroquinolones restricted | 903/2777 (32.5%) | 2492/6113 (40.8%) | 0.715 (.544–9.404) | .02 | 1880/3574 (52.6%) | 4639/7980 (58.1%) | 0.802 (.614–1.048) | .11 | 2783/6351 (43.8%) | 7131/14 093 (50.6%) | 0.804 (.622–1.038) | .09 |
| No. of fluoroquinolone-directed interventions (5 potential) | 463902 (51.3%) | 16451639 (39.4%) | 21212/3289 (36.9%) | 3961/2719 | 0.871 (.775–9.79) per intervention | 0.742/1319 (65.1%) | 11233/2066 (59.7%) | 2.32324140 (56.2%) | 31990/3731 | 0.917 (8.16–1.032) per intervention | 0.1205/2041 (59.0%) | 11878/3705 (50.7%) | 2.3539/429 (47.6%) | 3.2951/6450 | 0.904 (8.10–1.008) | .07 |
## Unadjusted Proportions of Patients With Antibiotic Overuse at Discharge

| Tier 2: UTI-specific or pneumonia-specific broad interventions | Urinary Tract Infection N = 8890 patients | Pneumonia N = 11,554 patients | Combined N = 20,444 Patients |
|---------------------------------------------------------------|------------------------------------------|--------------------------------|----------------------------|
| No. of diagnostic-stewardship interventions (11 potential)    | “Yes” (%) | “No” (%) | IRR (95% CI)** | P-value | “Yes” (%) | “No” (%) | aIRR (95% CI)** | P-value | “Yes” (%) | “No” (%) | aIRR (95% CI)** | P-value |
| 0:1131/3017 (37.5%)                                           | 35.3% | 4:114/341 (33.4%) | 4:114/341 (33.4%) | 1.011 (929–1.100) | .81 | NA | NA |
| 1:1352/3531 (38.3%)                                           | 4:227/734 (37.1%) | 4:227/734 (37.1%) | 5:106/299 (40.9%) | 1.145/310 (46.8%) | 1.14 | NA | NA |
| 2:149/403 (37.0%)                                             | 1.078 (734–1.144) | 1.078 (734–1.144) | 1.078 (734–1.144) | .88 | 5124/9063 (56.5%) | 1395/2491 (56.0%) | 1.272 (921–1.738) | .14 | NA | NA |
| 3:240/606 (37.7%)                                             | 1.093 (734–1.144) | 1.093 (734–1.144) | 1.093 (734–1.144) | .88 | 2617/4903 (53.4%) | 2617/4903 (53.4%) | 1.441 (1.131–1.836) | .03 | NA | NA |
| 4:272/734 (37.1%)                                             | 1.106 (734–1.144) | 1.106 (734–1.144) | 1.106 (734–1.144) | .88 | 3902/6651 (58.7%) | 2617/4903 (53.4%) | 1.441 (1.131–1.836) | .03 | NA | NA |
| 5:106/299 (40.9%)                                             | 1.145/310 (46.8%) | 1.145/310 (46.8%) | 1.145/310 (46.8%) | .88 | 7145/310 (46.8%) | 7145/310 (46.8%) | 1.272 (921–1.738) | .14 | NA | NA |
| 7:145/310 (46.8%)                                             | 1.145/310 (46.8%) | 1.145/310 (46.8%) | 1.145/310 (46.8%) | .88 | 1352/3531 (38.3%) | 1352/3531 (38.3%) | 1.441 (1.131–1.836) | .03 | NA | NA |

### Tier 3: Discharge specific interventions

| Intervention de-emphasizing fluoroquinolones at discharge | Urinary Tract Infection N = 8890 patients | Pneumonia N = 11,554 patients | Combined N = 20,444 Patients |
|----------------------------------------------------------|------------------------------------------|--------------------------------|----------------------------|
| 449/1521 (29.5%)                                          | 2946/7369 (40.0%) | 2946/7369 (40.0%) | 2946/7369 (40.0%) | 0.681 (479–967) | .03 | 906/1851 (48.9%) | 5613/9703 (57.8%) | 0.735 (518–1.044) | .09 | 1355/3372 (40.2%) | 8559/17072 (50.1%) | 0.742 (53–21.035) | .08 |
| 2946/7369 (40.0%)                                          | 3089/8007 (38.6%) | 3089/8007 (38.6%) | 3089/8007 (38.6%) | 0.925 (566–1.512) | .76 | 463/747 (62.0%) | 6056/10807 (56.0%) | 1.121 (688–1.826) | .08 | 769/1630 (47.2%) | 9145/18814 (48.6%) | 0.942 (594–1.494) | .08 |
| 3089/8007 (38.6%)                                          | 3175/8052 (39.4%) | 3175/8052 (39.4%) | 3175/8052 (39.4%) | 0.496 (.300–.820) | .006 | 358/863 (41.5%) | 6161/10691 (57.6%) | 0.542 (.326–.901) | .02 | 578/1701 (34.0%) | 9336/17743 (49.8%) | 0.543 (.335–.878) | .01 |
| 3175/8052 (39.4%)                                          | 3175/8052 (39.4%) | 3175/8052 (39.4%) | 3175/8052 (39.4%) | 0.496 (.300–.820) | .006 | 358/863 (41.5%) | 6161/10691 (57.6%) | 0.542 (.326–.901) | .02 | 578/1701 (34.0%) | 9336/17743 (49.8%) | 0.543 (.335–.878) | .01 |
|                              | Urinary Tract Infection N = 8890 patients | Pneumonia N = 11 554 patients | Combined N = 20 444 Patients |
|------------------------------|-------------------------------------------|-------------------------------|-----------------------------|
| Unadjusted Proportions of Patients With Antibiotic Overuse at Discharge | IRR (95% Cl)** | P-value | IRR (95% Cl)** | P-value | IRR (95% Cl)** | P-value |
| “Yes” (%)                  | “No” (%)                                  | “Yes” (%)                  | “No” (%)                  | “Yes” (%)                  | “No” (%)                  | “Yes” (%)                  | “No” (%)                  | “Yes” (%)                  | “No” (%)                  | “Yes” (%)                  | “No” (%)                  |

Association of each stewardship strategy with antibiotic overuse at discharge for UTI, pneumonia, or both are shown as relevant for each strategy. Strategies are shown by ROAD Home Tier.

aIRRs were obtained from multilevel (patients nested within hospitals) negative binomial regression models controlling for teaching hospital, hospital profit status, bed size, length of stay, condition, presence of severe sepsis on admission, discharge date (by quarter), discharge to post-acute care, Charlson comorbidity index, sex, and age. Adjusted IRRs relate to days of antibiotic overuse at discharge. For example, an aIRR of 1.4 indicates that an intervention is associated with a 40% relative increase in antibiotic overuse days at discharge.

Abbreviations: aIRR, adjusted incidence rate ratio; ASB, asymptomatic bacteriuria; CPOE, computer-prescriber order entry; NA, not applicable; ROAD (Reducing Overuse of Antibiotics at Discharge); UTI, urinary tract infection.
Table 3.
Example Pathways to Low Antibiotic Overuse at Discharge

| Hospital Description* | Tier 1 (of 6 Possible) | Tier 2 (of 24 Possible) | Tier 3 (of 3 Possible) | Antibiotic Stewardship Description |
|-----------------------|------------------------|-------------------------|------------------------|-----------------------------------|
| Hospital 1: Strong inpatient stewardship infrastructure | Small, community | 5 | 12 | 0 | No discharge interventions; robust inpatient stewardship including prospective audit and feedback, CPOE, 4 fluoroquinolone-specific interventions (e.g., provider feedback), and 3 diagnostic stewardship interventions (e.g., removal of urine cultures for order sets). |
| Hospital 2: Do it all | Medium, community | 4 | 9 | 2 | Robust inpatient and discharge stewardship activities. Have dedicated transition of care pharmacists who also review antibiotics at discharge for some patients. Conduct inpatient audit and feedback across all diseases with provider peer-comparison and disease-specific guidelines that include oral step-down and duration recommendations. |
| Hospital 3: Discharge-focused | Large, urban | 2 | 6 | 2 | Limited inpatient antibiotic stewardship activities but robust discharge antibiotic stewardship including a discharge intervention de-emphasizing fluoroquinolones and prospective review of antibiotics by a clinical pharmacist prior to discharge. |
| All hospitals; median (IQR) | Largely academic (89.7%), nonprofit (92.3%); Median (IQR) bed size 310 (186–443) | 3 (3–5) | 8 (5–10) | 0 (0–0) | Average hospital has guidelines and some stewardship infrastructure, variable inpatient antibiotic stewardship activities, and no discharge-specific interventions. |

Abbreviations: CPOE, computerized physician order entry; IQR, interquartile range.

* Hospital descriptions vague so as to not reveal the identity of participating hospitals.