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Korean standardized antimicrobial administration ratio in long-term care hospitals: a benchmark tool

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Abstract

Background Antimicrobial stewardship in long-term care hospitals (LTCHs) is increasingly important; however, standardized benchmarking tools for antimicrobial use in these settings are lacking. The Korean Standardized Antimicrobial Administration Ratio for long-term care hospitals (K-SAAR–LTCHs) was developed to benchmark antimicrobial use in these facilities.

Methods We used 2021 National Health Insurance claims data from 1432 LTCHs (387,211 inpatients, including untreated patients) in Korea. Data were split into training (80%) and test (20%) sets at the hospital level for model validation, with 5-fold hospital-level cross-validation within the training set. The main outcome measure was antimicrobial consumption expressed as days of therapy (DOT) per 1000 patient-days. For the fixed-rate cohort, a two-part Hurdle Gamma model addressed zero-inflation; for fee-for-service (FFS) cohorts (pneumonia, septicemia), a Gamma generalized linear model with log link and length of stay as offset was used. Variable selection used stepwise regression with the Akaike Information Criterion (AIC). Predictive performance was evaluated using mean absolute percentage error (MAPE) and calibration metrics (overall observed-to-expected ratio, intercept, slope). The standardized antimicrobial administration ratio (SAAR) was calculated as observed-to-predicted antimicrobial use for each LTCH. For hospital-level benchmarking, 95% funnel plot control limits were calculated using the Byar approximation.

Results Antimicrobial use under FFS was substantially higher than under the fixed-rate system (1579.3 vs. 108.3 DOT per 1000 patient-days), reflecting that FFS episodes primarily comprised diagnosis-defined infectious conditions. In the FFS pneumonia and septicemia cohorts, delirium, fever, oxygen therapy, and stage 3 pressure ulcer were consistently associated with higher antimicrobial use, although many rate ratios were modest in magnitude. Hospital-level calibration was strongest for the total-antimicrobial FFS models, whereas broad-spectrum models showed greater between-hospital dispersion. Median hospital-level SAAR values were close to 1.0 in the FFS pneumonia and septicemia cohorts. Funnel plot analysis identified hospitals above the upper control limits in 0.8–1.2% for total antimicrobials, while broad-spectrum antimicrobials showed wider variation, with 4.6–5.7% of hospitals falling below the lower control limits. The fixed-rate hurdle model was developed and evaluated separately, but hospital-level benchmarking was less stable because antimicrobial use was sparse and highly right-skewed.

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Conclusions The K-SAAR–LTCH framework provides a risk-adjusted approach for monitoring antimicrobial utilization in Korean LTCHs. Hospital-level benchmarking was primarily demonstrated for diagnosis-specific FFS pneumonia and septicemia cohorts, while fixed-rate reimbursement episodes require further refinement before routine benchmarking use. The framework may inform antimicrobial utilization surveillance and targeted stewardship review, but it should not be interpreted as a direct measure of prescribing appropriateness.

Keywords Long-term care hospitals, Antimicrobial, Days of therapy, Korea

Introduction

Due to the rapidly accelerating pace of population aging, the importance of long-term-care hospitals (LTCHs) is increasing worldwide [1, 2]. LTCHs specialize in managing chronic diseases and providing sustained care for older adults [1, 3, 4]. As of 2025, 20.3% of Korea's population is aged 65 years or older, indicating that the country has reached super-aged status. Approximately 1600 LTCHs are in operation nationwide, out of about 37,500 hospitals and clinics [5]. Under Korean regulation (Medical Service Act), an LTCH is defined as a medical institution equipped with 30 or more long-term care beds for inpatients with chronic illnesses or those who require continuous medical management following surgery or injury. LTCHs are required to maintain a minimum staffing ratio of one physician per 40 inpatients and one nurse per six inpatients, and hospital stays in these institutions commonly exceed 30 days. These institutions provide post-acute and rehabilitative care for predominantly elderly patients with multiple comorbidities and functional impairment, and are clinically and structurally distinct from acute care hospitals.

As the number of older adults requiring long-term care continues to grow, healthcare–associated infections (HAIs) have emerged as a major cause of morbidity and mortality among residents of LTCHs [6]. According to a systematic review of 31 studies, the overall pooled point prevalence of HAIs in LTCFs was 3.5–3.9%, with urinary tract infections (38.9%), respiratory tract infections (33.6%), and skin or soft-tissue infections (23.7%) being the most frequently reported [7]. To manage these infections, antimicrobials are commonly prescribed among LTCH patients [6, 8].

The US Centers for Disease Control and Prevention (CDC) recommend that hospitals implement antibiotic stewardship programs and have introduced the standardized antimicrobial administration ratio (SAAR) as a tool for evaluating and managing antimicrobial use in hospitals [9, 10]. SAAR is a utilization benchmarking metric that compares observed antimicrobial use to predicted use after risk adjustment for facility- and case-mix characteristics, and is intended to identify potential overuse and support stewardship interventions rather than to evaluate guideline concordance, indication validity, or dose and duration appropriateness.

In Korea, several studies have reported that antimicrobial use in LTCHs is higher than in acute care hospitals [11, 12, 13], and that high and inappropriate antibiotic use contributes to the emergence and spread of antimicrobial resistance [14]. Although promoting appropriate antibiotic use in LTCHs is a major challenge for both patient safety and public health [8, 15], broad-spectrum antimicrobials are administered more frequently in some LTCHs than in others, potentially serving as a major driver of antimicrobial resistance [16]. In this context, the Korean Standardized Antimicrobial Administration Ratio (K-SAAR) model has been developed and is currently being implemented in acute care hospitals [17].

Korean LTCHs operate under two distinct reimbursement systems. Under the fixed-rate (per diem) system, hospitals receive a predetermined daily payment based on the patient's care level (ranging from mild to most severe medical conditions), regardless of individual services rendered. Under the fee-for-service (FFS) system, specific diagnostic episodes—primarily pneumonia and septicemia—are reimbursed per service, and antimicrobial therapy is routinely expected and clinically indicated in most such cases. Because these systems differ substantially in clinical context, patient severity, and prescribing incentives, separate analytical approaches are warranted.

Applying the SAAR framework to specialized institutions such as LTCHs, however, remains challenging. LTCHs differ substantially from acute care hospitals in patient characteristics, care objectives, and reimbursement structures, necessitating a tailored antimicrobial administration evaluation model that reflects their unique features. This study therefore aimed to develop and validate the K-SAAR–LTCHs framework, incorporating separate risk-adjustment models for fixed-rate and fee-for-service reimbursement types with the latter further stratified by diagnosis (pneumonia and septicemia) to enable benchmarking of antimicrobial use in Korean long-term care hospitals.

Materials and methods

Data source and study population

This study utilized data obtained from the National Health Insurance (NHI) claims data from Health

Insurance Review & Assessment Service (HIRA) for the period spanning January to December 2021. South Korea has a single-payer NHI system, which provides coverage for all citizens (51.8 million). Medical institutions submit claims data to HIRA for reimbursement. The NHI claims database includes patient demographic characteristics, disease diagnosis codes, international non-proprietary names of prescribed medications, daily dosages, and treatment durations [18, 19]. This database also incorporates resource utilization data from LTCHs and long-term care benefit appropriateness evaluation results. Long-term care hospitals in Korea operate under 2 reimbursement systems: fixed-rate (per diem) and fee-for-service (FFS). Because prescribing patterns may differ by payment type, antimicrobial use was analyzed separately for each system.

In 2021, a total of 429,348 patients admitted to 1614 long-term care hospitals were identified. After excluding newly opened or closed institutions ($n = 177$) and excluding patients without fixed-rate or fee-for-service claims (pneumonia, septicemia), the final analysis included 387,211 patients from 1432 hospitals (Fig. 1).

Study antibiotics and measures

In this study, antibiotics were defined as J01 (antibacterials for systemic use) of the Anatomic Therapeutic Chemical (ATC) classification of the World Health Organization Collaborating Center (WHOCC) [20]. Each drug registered in the NHI reimbursement list includes information on the manufacturer, product number, active ingredient code, dose, and formulation. We mapped ATC classification using main active ingredient name and route of administration, and classified the antibiotics into the ATC-3 level, which refers to the pharmacological subgroup.

The outcome measure was antimicrobial consumption expressed as days of therapy (DOT) per 1000 patient-days (DOT/1000 PD). DOT is defined as the number of calendar days during which an antimicrobial agent was administered to a patient, regardless of the dose. Unlike DDD, DOT is not affected by weight-based dosing or formulation differences, making it a more patient-centered measure of antimicrobial exposure [21]. Consistent with standard NHSN-style hospital benchmarking, patients and episodes without antimicrobial prescriptions were retained in the denominator and contributed zero DOT to the numerator, so that the resulting rate reflects facility-level antimicrobial use intensity per patient-day rather than average exposure among treated patients only.

Admission episodes per patient unit were defined to facilitate calculation of the length of hospital stay, based on the benefit type provided by each long-term care hospital. The benefit types of FFS included the most severe medical condition, severe medical

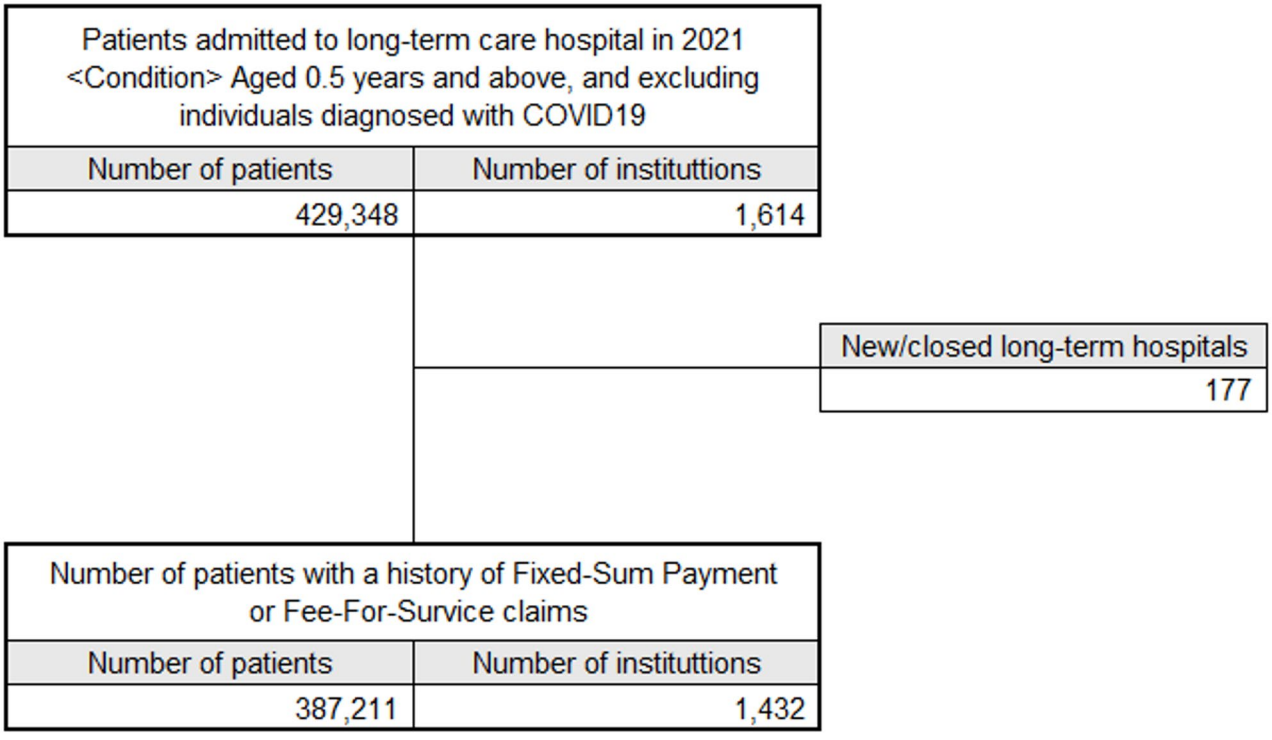

Fig. 1 Schematic diagram of the selection of subjects for analysis

condition, moderate medical condition, mild medical condition, elective admission, pneumonia, septicemia, and isolation ward admission. Supplementary Table 1 summarizes the clinical factors that may influence antimicrobial administration in long-term care hospitals. Variables were excluded if missing values accounted for at least 10% of the data. Multicollinearity was assessed using variance inflation factors (VIF), and variables with VIF > 5 were excluded prior to model selection.

Development of standardized antimicrobial administration model

The standardized antimicrobial administration ratio (SAAR) serves as a metric for comparing predicted versus actual antimicrobial use in long-term care hospitals, while accounting for patient case-mix and non-modifiable structural characteristics. A SAAR value greater than 1 indicates that actual antimicrobial use exceeds the predicted amount, whereas a value less than 1 indicates lower-than-predicted use. SAAR is a utilization benchmarking metric, not a direct measure of prescribing appropriateness; it is intended to identify potential overuse or underuse relative to expected facility- and case-mix-adjusted levels, supporting stewardship interventions and inter-hospital comparisons.

$$\mathrm{SAAR} = \frac{\text{Actual amount administered}}{\text{Predicted amount administered}}$$

Because prescribing patterns differed markedly between the two payment systems, separate modeling strategies were applied for fixed-rate and FFS cohorts.

Fixed-rate model

The fixed-rate cohort exhibited substantial zero-inflation, with a considerable proportion of episodes having no antibiotic prescription, reflecting the clinical heterogeneity of long-term care admissions. To accommodate this structure, a two-part Hurdle Gamma generalized linear model was applied. In the first part, logistic regression estimated the probability of any antibiotic prescription during an episode. In the second part, a Gamma generalized linear model with a log link estimated antibiotic consumption (DOT) among prescribed episodes, using log-transformed length of stay as an offset term to model the rate of antibiotic use per patient-day. Both components of the model were stratified by clinical severity grade to reflect structural differences in prescribing patterns across severity categories.

Fee-for-service model

In the FFS cohort, antimicrobial therapy was nearly universal among infection-specific episodes (pneumonia and septicemia), as antimicrobial therapy is routinely expected and clinically indicated in most such diagnosis-defined infection episodes. Because Gamma generalized linear models require strictly positive outcome values, the small number of episodes with zero DOT were assigned a value of 0.001 DOT prior to model fitting. Accordingly, a single-part Gamma generalized linear model with a log link was fitted separately for each diagnostic cohort, with log-transformed length of stay as an offset term. Models were stratified by clinical severity grade to account for heterogeneity within diagnosis-specific cohorts. Additional models were constructed for broad-spectrum antimicrobials, which are frequently prescribed for hospital-acquired infections.

Variable selection and model validation

For both the fixed-rate and FFS models, candidate covariates included patient-, institutional-, and claim-level factors (Supplementary Table 1). Variable selection was performed using stepwise regression, with the Akaike Information Criterion (AIC) applied to identify the model providing the best balance between goodness of fit and parsimony.

Data were randomly split into training (80%) and test (20%) sets stratified at the hospital level to prevent data leakage. Hospital-level 5-fold cross-validation was conducted within the training set, ensuring that episodes from the same hospital were not present in both training and validation folds. Model performance was evaluated using mean absolute percentage error (MAPE) and calibration metrics, including the overall observed-to-expected (O/E) ratio, calibration intercept, and calibration slope. Calibration was assessed at both the episode and hospital levels, with hospital-level metrics calculated after aggregating observed and predicted DOT values within each hospital. After cross-validation, final models were refitted on the complete dataset using identical specifications and used to generate predicted DOT values for SAAR computation.

For hospital-level benchmarking, 95% funnel plot control limits for SAAR were calculated using the Byar approximation, a standard method for standardized ratio measures, and were used to construct hospital-level funnel plots.

Although models were developed for both fixed-rate and FFS cohorts, the primary hospital-level SAAR benchmarking and funnel plot analyses focused on

diagnosis-specific FFS pneumonia and septicemia cohorts. This decision was made because antimicrobial exposure in the fixed-rate cohort was sparse, zero-inflated, and highly right-skewed, whereas FFS pneumonia and septicemia episodes represented clinically more homogeneous infection-specific cohorts. Fixed-rate model performance was therefore presented as a supplementary exploratory analysis rather than as the primary benchmarking application.

Results

Distribution of antimicrobial use in long-term care hospitals

When the total amount of antimicrobials administered was calculated according to claim type and length of hospital stay, antimicrobial use under the fee-for-service system was substantially higher than that under the fixed-rate system, at 1579.3 DOT per 1000 patient-days and 108.3 DOT per 1000 patient-days, respectively. Among fixed-rate claim types, the highest density of antimicrobial administration per hospital day was observed in cases involving the most severe medical conditions (322.3 DOT per 1000 patient-days), followed by severe medical conditions (184.9 DOT per 1000 patient-days), moderate medical conditions (78.2 DOT per 1000 patient-days), mild medical conditions (59.6 DOT per 1000 patient-days), and elective admissions (52.2 DOT per 1000 patient-days) (Table 1).

Factors influencing antimicrobial use in LTCHs

Table 2 summarizes the determinants of antibiotic utilization in the fee-for-service (FFS) cohorts (pneumonia and septicemia), expressed as rate ratios (RR) with 95% confidence intervals from Gamma generalized linear models with log(length of stay) as offset. In the FFS pneumonia cohort, delirium symptoms (RR, 1.04; 95% CI, 1.03–1.05), stage 3 pressure ulcer (RR, 1.03; 95% CI, 1.02–1.04), receptive communication impairment (RR, 1.01; 95% CI, 1.01–1.02), fever (RR, 1.02; 95% CI, 1.01–1.03), oxygen therapy (RR, 1.02; 95% CI, 1.01–1.03), and cognitive impairment (RR, 1.02; 95% CI, 1.01–1.03) were associated with higher DOT rates, whereas female sex (vs. male) was inversely associated (RR, 0.98; 95% CI, 0.98–0.99). In the FFS septicemia cohort, delirium symptoms (RR, 1.05; 95% CI, 1.04–1.06), oxygen therapy (RR, 1.03; 95% CI, 1.02–1.04), fever (RR, 1.03; 95% CI, 1.02–1.04), cognitive impairment (RR, 1.02; 95% CI, 1.02–1.03), receptive communication impairment (RR, 1.02; 95% CI, 1.02–1.03), and stage 3 pressure ulcer (RR, 1.02; 95% CI, 1.01–1.03) were associated with higher DOT rates; female sex was again inversely associated (RR, 0.98; 95% CI, 0.98–0.99). Modifiable institutional staffing variables (number of pharmacists, nurses, and physicians) were excluded a priori from the risk-adjustment model and are therefore not reported here.

For broad-spectrum antibiotics primarily used for hospital-acquired infections, the determinants showed a broadly similar pattern but with larger magnitudes of effect. In the FFS pneumonia cohort, delirium symptoms (RR, 1.08; 95% CI, 1.05–1.11), oxygen therapy (RR, 1.06; 95% CI, 1.04–1.07), indwelling urinary catheter program (RR, 1.06; 95% CI, 1.04–1.07), Elixhauser Comorbidity Index category 1 (vs. 0; RR, 1.04; 95% CI, 1.02–1.06), stage 3 pressure ulcer (RR, 1.03; 95% CI, 1.01–1.05), and cognitive impairment (RR, 1.03; 95% CI, 1.01–1.05) were associated with higher DOT rates, whereas female sex was inversely associated (RR, 0.95; 95% CI, 0.94–0.96). In the FFS septicemia cohort, similar patterns were observed: oxygen therapy

Table 1 Antimicrobial administration by antimicrobial claim type (denominator: sum of the length of hospital stay for each benefit type)

Category	Type	Number of unique patients or claim episodes	Total length of hospital stays	Number of episodes with antibiotic prescriptions	Days of therapy (DOT)	DOT per 1000 patient-days
Total		387,211	74,914,780	224,063	12,294,038	164.11
Fixed-rate	Total	382,587	72,912,828	199,682	7,899,529	108.34
	Most severe medical conditions	9286	1,070,565	6048	344,987	322.25
	Severe medical conditions	141,343	22,561,536	91,243	4,171,813	184.91
	Moderate medical conditions	171,884	26,470,740	75,611	2,068,812	78.15
	Mild medical conditions	101,712	16,607,783	39,892	990,106	59.62
	Elective admission group	65,544	6,202,204	16,494	323,811	52.21
Fee-for-service	Total	83,496	1,967,081	94,365	3,106,595	1579.29
	Pneumonia	45,946	971,372	45,844	1,597,489	1644.57
	Septicemia	48,657	995,709	48,521	1,509,106	1515.61

DOT, days of therapy; FFS, fee-for-service. Aggregate rows ("Total" for fixed-rate and FFS) represent counts of unique patients, while sub-category rows (severity grades; pneumonia, septicemia) represent admission/claim episodes, as a single patient may contribute episodes to multiple severity grades or diagnostic categories during the study period

(RR, 1.07; 95% CI, 1.05–1.09), fever (RR, 1.07; 95% CI, 1.05–1.09), indwelling urinary catheter program (RR, 1.06; 95% CI, 1.04–1.08), delirium symptoms (RR, 1.05; 95% CI, 1.03–1.08), receptive communication impairment (RR, 1.05; 95% CI, 1.04–1.07), stage 3 pressure ulcer (RR, 1.05; 95% CI, 1.03–1.08), and cognitive impairment (RR, 1.05; 95% CI, 1.03–1.07) were each associated with higher broad-spectrum DOT rates, while female sex and long-term hospitalization were inversely associated (RR, 0.95; 95% CI, 0.94–0.96 and RR, 0.93; 95% CI, 0.91–0.96, respectively).

Comparison of standardized antimicrobial administration ratios in long-term care hospitals

A hurdle model was also developed for the fixed-rate cohort to accommodate the high proportion of episodes without antimicrobial prescriptions. Performance metrics for the fixed-rate model are presented in Supplementary Table 3. The model showed an overall observed-to-expected ratio of 0.90; however, hospital-level SAAR values were more widely dispersed and hospital-level prediction error was higher than in the diagnosis-specific FFS cohorts. This pattern reflects the sparse and highly right-skewed distribution of antimicrobial use under the fixed-rate reimbursement system. Therefore, subsequent hospital-level benchmarking analyses focused on the diagnosis-specific FFS cohorts.

Figure 2 presents hospital-level calibration plots comparing observed and predicted antimicrobial use for the fee-for-service pneumonia and septicemia cohorts. For total antimicrobial use, the LOESS-smoothed calibration curves closely followed the line of identity across the prediction range in both cohorts, indicating acceptable agreement between observed and predicted antimicrobial use. In contrast, broad-spectrum antimicrobial models showed greater dispersion of hospital-level observations and modest deviation from the line of identity. The overall observed-to-expected ratios remained close to 1.0 (1.021 for pneumonia and 1.024 for septicemia), but these broad-spectrum models should be interpreted as less stable than the total-antimicrobial models for hospital-level benchmarking.

As shown in Table 3, hospital-level SAAR values were calculated by comparing observed and predicted antimicrobial use. Median SAAR values for both total and broad-spectrum antibiotics were close to 1.0 in the

Table 2 Determinants of antibiotic utilization in fee-for-service systems

Class	Factor	RR (95% CI)	*p*-value
FFS (Pneumonia)	*Total antimicrobials*		
	Sex (female vs. male)	0.98 (0.98–0.99)	< 0.0001
	Age	1.00 (1.00–1.00)	0.1966
	Number of hospital beds	1.00 (1.00–1.00)	< 0.0001
	Elixhauser Comorbidity Index category (1 vs. 0)	0.99 (0.98–1.01)	0.3486
	Elixhauser Comorbidity Index category (2 vs. 0)	1.00 (1.00–1.00)	< 0.0001
	Long-term hospitalization (yes vs. no)	1.00 (0.98–1.01)	0.5372
	Cognitive impairment (yes vs. no)	1.02 (1.01–1.03)	0.0002
	Delirium symptoms (yes vs. no)	1.04 (1.03–1.05)	< 0.0001
	Receptive communication impairment (yes vs. no)	1.01 (1.01–1.02)	< 0.0001
	Indwelling urinary catheter program (yes vs. no)	1.00 (0.99–1.01)	0.554
	Fever (yes vs. no)	1.02 (1.01–1.03)	< 0.0001
	Oxygen therapy (yes vs. no)	1.02 (1.01–1.03)	< 0.0001
	Stage 3 pressure ulcer (yes vs. no)	1.03 (1.02–1.04)	< 0.0001
	Broad-spectrum antibiotics		
	Sex (female vs. male)	0.95 (0.94–0.96)	< 0.0001
	Age	1.00 (1.00–1.00)	< 0.0001
	Number of hospital beds	1.00 (1.00–1.00)	< 0.0001
	Elixhauser Comorbidity Index category (1 vs. 0)	1.04 (1.02–1.06)	0.0006
	Elixhauser Comorbidity Index category (2 vs. 0)	1.00 (1.00–1.00)	< 0.0001
	Long-term hospitalization	1.00 (0.98–1.03)	0.898
	Cognitive impairment (yes vs. no)	1.03 (1.01–1.05)	0.002
	Delirium symptoms (yes vs. no)	1.08 (1.05–1.11)	< 0.0001
	Receptive communication impairment (yes vs. no)	1.02 (1.00-1.03)	0.0117
	Indwelling urinary catheter program (yes vs. no)	1.06 (1.04–1.07)	< 0.0001
	Fever (yes vs. no)	1.01 (1.00-1.03)	0.0642
	Oxygen therapy (yes vs. no)	1.06 (1.04–1.07)	< 0.0001
	Stage 3 pressure ulcer (yes vs. no)	1.03 (1.01–1.05)	0.001

Table 2 (continued)

Class	Factor	RR (95% CI)	*p*-value
FFS (Septicemia)	*Total antimicrobials*		
	Sex (female vs. male)	0.98 (0.98–0.99)	< 0.0001
	Age	1.00 (1.00–1.00)	0.8371
	Number of hospital beds	1.00 (1.00–1.00)	< 0.0001
	Elixhauser Comorbidity Index category (1 vs. 0)	0.98 (0.97–0.99)	0.0024
	Elixhauser Comorbidity Index category (2 vs. 0)	1.00 (1.00–1.00)	< 0.0001
	Long-term hospitalization (yes vs. no)	1.01 (1.00-1.02)	0.0554
	Cognitive impairment (yes vs. no)	1.02 (1.02–1.03)	< 0.0001
	Delirium symptoms (yes vs. no)	1.05 (1.04–1.06)	< 0.0001
	Receptive communication impairment (yes vs. no)	1.02 (1.02–1.03)	< 0.0001
	Indwelling urinary catheter program (yes vs. no)	1.00 (0.99–1.01)	0.839
	Fever (yes vs. no)	1.03 (1.02–1.04)	< 0.0001
	Oxygen therapy (yes vs. no)	1.03 (1.02–1.04)	< 0.0001
	Stage 3 pressure ulcer (yes vs. no)	1.02 (1.01–1.03)	0.0002
	Broad-spectrum antibiotics		
	Sex (female vs. male)	0.95 (0.94–0.96)	< 0.0001
	Age	1.00 (1.00–1.00)	< 0.0001
	Number of hospital beds	1.00 (1.00–1.00)	< 0.0001
	Elixhauser Comorbidity Index category (1 vs. 0)	1.01 (0.99–1.04)	0.2963
	Elixhauser Comorbidity Index category (2 vs. 0)	1.00 (1.00–1.00)	< 0.0001
	Long-term hospitalization (yes vs. no)	0.93 (0.91–0.96)	< 0.0001
	Cognitive impairment (yes vs. no)	1.05 (1.03–1.07)	< 0.0001
	Delirium symptoms (yes vs. no)	1.05 (1.03–1.08)	< 0.0001
	Receptive communication impairment (yes vs. no)	1.05 (1.04–1.07)	< 0.0001
	Indwelling urinary catheter program (yes vs. no)	1.06 (1.04–1.08)	< 0.0001
	Fever (yes vs. no)	1.07 (1.05–1.09)	< 0.0001
	Oxygen therapy (yes vs. no)	1.07 (1.05–1.09)	< 0.0001
	Stage 3 pressure ulcer (yes vs. no)	1.05 (1.03–1.08)	< 0.0001

RR, rate ratio; CI, confidence interval; FFS, fee-for-service; ECI, Elixhauser Comorbidity Index. Models were Gamma generalized linear models with log link and log(length of stay) as offset. Modifiable institutional staffing variables (number of pharmacists, nurses, and physicians) were excluded a priori from the risk-adjustment model

pneumonia and septicemia cohorts, indicating that observed antimicrobial use was generally consistent with model-predicted use after risk adjustment.

For pneumonia, the median hospital-level observed antimicrobial use was 1605.3 DOT per 1000 patient-days (IQR, 1304.1–1891.8), compared with a median predicted value of 1,631.1 DOT per 1000 patient-days (IQR, 1621.5–1640.2). The median SAAR was 1.0 (IQR, 0.8–1.2). A total of 16 hospitals (1.5%) fell outside the funnel plot control limits, including 9 hospitals (0.8%) above the upper limit. For broad-spectrum antibiotics primarily used for hospital-acquired infections, the median observed and predicted values were 852.2 and 883.1 DOT per 1000 patient-days, respectively, with a median SAAR of 1.0 (IQR, 0.7–1.1). A total of 58 hospitals (5.7%) fell below the lower control limits.

For septicemia, the median hospital-level observed antimicrobial use was 1,508.3 DOT per 1000 patient-days (IQR, 1269.1–1830.7), compared with a median predicted value of 1519.6 DOT per 1000 patient-days (IQR, 1504.4–1533.4). The median SAAR was 1.0 (IQR, 0.8–1.2). Sixteen hospitals (1.6%) fell outside the control limits, including 12 hospitals (1.2%) above the upper limit. For broad-spectrum antibiotics, the median observed and predicted values were 773.0 and 774.4 DOT per 1000 patient-days, respectively, with a median SAAR of 1.0 (IQR, 0.7–1.2). A total of 44 hospitals (4.6%) fell below the lower control limits. Hospital-level variation in SAAR values and the distribution of hospitals relative to the funnel plot control limits are shown in Supplementary Fig. 2.

Discussion

This study developed and validated risk-adjusted K-SAAR–LTCH models tailored to different reimbursement systems in Korean long-term care hospitals. Using nationwide claims data, we identified patient case-mix, non-modifiable structural, and claim-level determinants of antimicrobial use, compared observed and predicted consumption across antimicrobial categories, and demonstrated the feasibility of benchmarking antimicrobial use in LTCHs through a risk-adjusted model.

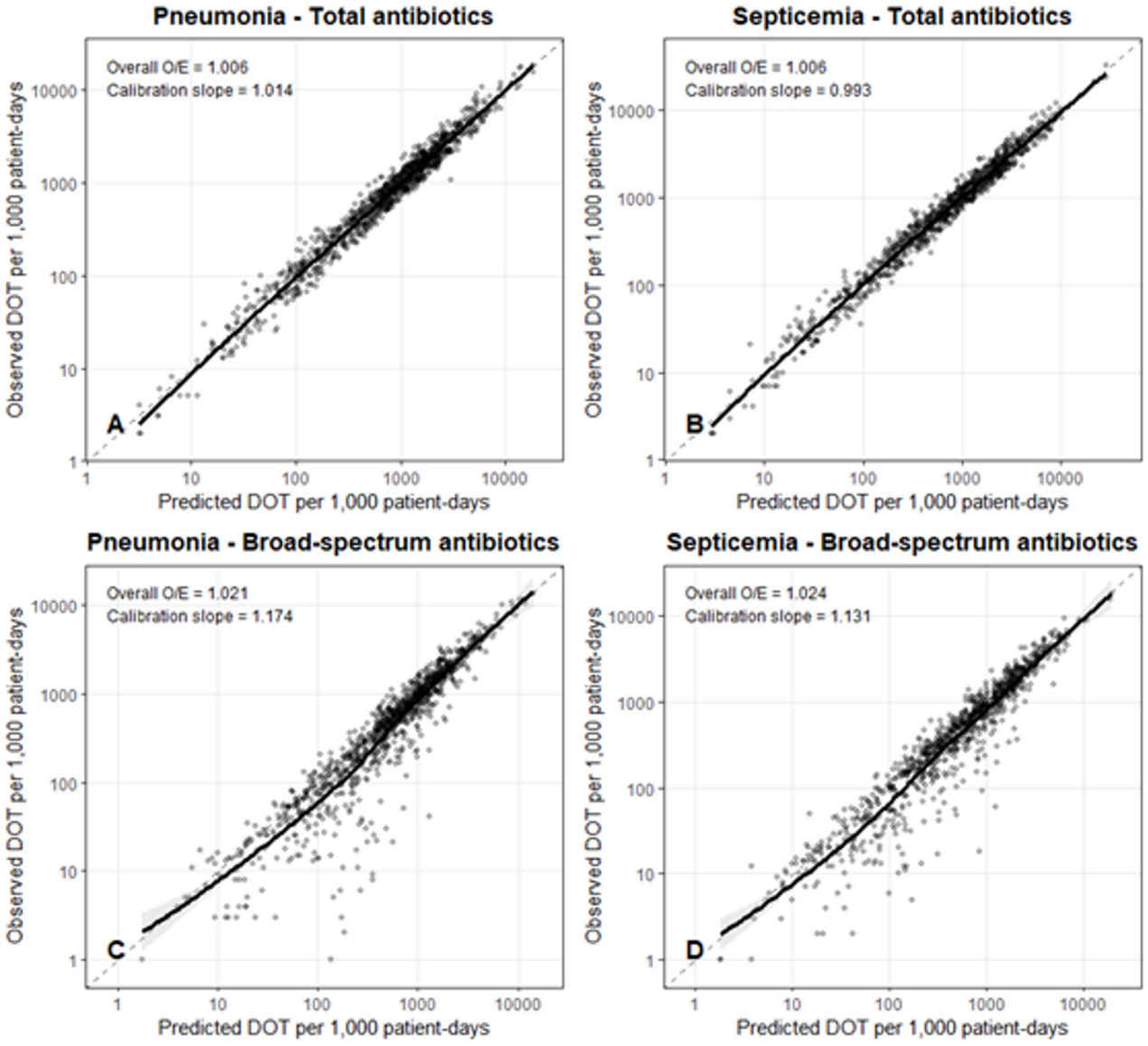

Fig. 2 Hospital-level calibration plots for predicted and observed antimicrobial use. Each point represents one hospital. The dashed line indicates perfect calibration (observed = predicted), and the solid line represents the LOESS-smoothed calibration curve. Both axes are displayed on logarithmic scales. Panels A and B show total antimicrobial use, whereas Panels C and D show broad-spectrum antimicrobials primarily used for hospital-acquired infections

In this large-scale analysis including 387,211 inpatients across 1432 Korean LTCHs, key determinants of antimicrobial use were identified. Within FFS pneumonia and septicemia cohorts, delirium symptoms, fever, oxygen therapy, and stage 3 pressure ulcer were consistently associated with higher antibiotic use, whereas older age and female sex were inversely associated. These findings reflect clinical severity and underlying patient complexity rather than modifiable institutional characteristics, consistent with risk-adjustment principles in which only non-modifiable factors are appropriate for inclusion in the predictive model. Although many associations were statistically significant, several rate ratios were close to unity, reflecting the large sample size of the study. Therefore, these findings should be interpreted primarily in terms of their contribution to risk adjustment and benchmarking performance rather than as indicators of large clinical effects. By design, modifiable staffing variables (e.g., number of pharmacists, nurses, and physicians) were excluded from the risk-adjustment model to avoid penalizing hospitals that invest in stewardship resources.

Median hospital-level SAAR values were close to 1.0 for both pneumonia and septicemia, indicating that observed antimicrobial use was generally consistent with predicted use after risk adjustment. Hospital-level calibration was strongest for the total-antimicrobial models, whereas the broad-spectrum antimicrobial models

Table 3 Comparison of hospital-level SAAR and funnel plot benchmarking results in pneumonia and septicemia

	Amount of antimicrobials administered			Hospitals outside control limits		
	Observed DOT/1000 PD (IQR)	Predicted DOT/1000 PD (IQR)	SAAR (IQR)	Total	Lower limit	Upper limit
FFS (Pneumonia)						
Total antimicrobials	1605.3 (1304.1, 1891.8)	1631.1 (1621.5, 1,640.2)	1.0 (0.8, 1.2)	16 (1.5%)	7 (0.6%)	9 (0.8%)
Broad-spectrum antimicrobials primarily used for hospital-acquired infections	852.2 (605.5, 1002.4)	883.1 (865.8, 901)	1.0 (0.7, 1.1)	58 (5.7%)	58 (5.7%)	0 (0.0%)
FFS (Septicemia)						
Total antimicrobials	1508.3 (1269.1, 1830.7)	1519.6 (1504.4, 1533.4)	1.0 (0.8, 1.2)	16 (1.6%)	4 (0.4%)	12 (1.2%)
Broad-spectrum antimicrobials primarily used for hospital-acquired infections	773 (511.6, 927.2)	774.4 (760.6, 790.7)	1.0 (0.7, 1.2)	44 (4.6%)	44 (4.6%)	0 (0.0%)

SAAR, standardized antimicrobial administration ratio; FFS, fee-for-service

Hospital-level observed DOT, predicted DOT, and SAAR are summarized as median (interquartile range). These values represent between-hospital variation

Observed and predicted DOT are expressed per 1,000 patient-days

SAAR was calculated for each hospital as observed DOT divided by predicted DOT

Hospitals outside control limits indicate institutions falling below the lower or above the upper model-based funnel plot control limits

showed greater dispersion and modest deviations from the ideal calibration line. Funnel plot analysis identified only a small proportion of hospitals above the upper control limits for total antimicrobials (0.8–1.2%), whereas a larger proportion of hospitals fell below the lower control limits for broad-spectrum antimicrobials (4.6–5.7%). These findings indicate that broad-spectrum antimicrobial use varies more substantially across institutions than overall antimicrobial use and may help identify hospitals with distinct prescribing patterns for targeted stewardship review, while recognizing that broad-spectrum benchmarking was less stable than total-antimicrobial benchmarking.

The fixed-rate model should be interpreted more cautiously. Although the hurdle model accommodated the large proportion of zero-antibiotic episodes, hospital-level SAAR values were more dispersed and hospital-level prediction error was higher than in the diagnosis-specific FFS cohorts. This reflects the clinical heterogeneity of fixed-rate LTCH admissions, in which antimicrobial use is not routinely expected for all episodes. Therefore, the current study demonstrates the feasibility of modeling fixed-rate antimicrobial use, but routine hospital-level benchmarking based on this cohort will require further refinement, such as alternative modeling strategies, subgroup-specific benchmarking, or longer observation windows.

The U.S. Centers for Disease Control and Prevention (CDC) introduced the SAAR metric for acute-care hospitals within the National Healthcare Safety Network (NHSN) [9, 10]. The K-SAAR–LTCHs expands this framework to a fundamentally different care environment. Unlike the U.S. SAAR, which focuses on short-stay acute-care facilities, the K-SAAR–LTCHs incorporates long-term admissions, fixed-rate reimbursement structures, and patient populations characterized by chronic conditions and functional dependency.

This model also differs from the previously developed Korean SAAR for acute-care hospitals [17]. The acute-care K-SAAR used data primarily from general and tertiary hospitals under fee-for-service reimbursement, emphasizing infection type and case-mix adjustment. In contrast, the K-SAAR–LTCHs integrates contextual factors unique to long-term care, such as prolonged hospitalization, fixed-rate (per diem) payment mechanisms, and patient cognitive and functional status. These features improve model fit and interpretability for the LTCH setting and demonstrate that the SAAR framework can be effectively adapted to diverse care environments. We intentionally excluded modifiable staffing variables (e.g., number of pharmacists, nurses, and physicians) from the risk-adjustment model to avoid adjusting away potentially meaningful stewardship-related differences across hospitals; such workforce factors are therefore preserved as candidate explanations for between-hospital variation in observed SAAR rather than being incorporated into the predicted (expected) values.

Our findings align with prior Korean studies reporting high and heterogeneous antimicrobial use in LTCHs [16, 17, 22] and complement international evidence

underscoring institutional culture, physician practice patterns, and resource allocation as major drivers of prescribing behavior [23, 24]. These converging findings suggest that antimicrobial stewardship in LTCHs must address not only clinical complexity but also organizational and behavioral determinants of prescribing. The K-SAAR–LTCHs distribution observed in this study parallels results from U.S. SAAR analyses, where outlier hospitals with excessive antimicrobial use were similarly identified [9, 10], supporting the generalizability of SAAR-based approaches to long-term care settings.

The K-SAAR–LTCH framework may provide a scalable, data-driven basis for antimicrobial utilization surveillance and targeted stewardship review within Korea's long-term care sector. By enabling risk-adjusted comparisons across institutions, it can identify facilities with higher-than-expected antimicrobial use and support targeted feedback, education, and monitoring. These insights may inform national initiatives led by the HIRA and the Ministry of Health and Welfare to strengthen antimicrobial utilization monitoring in LTCHs. Incorporating SAAR-based indicators into regular institutional evaluations could further support review of prescribing patterns, particularly in settings with limited infectious disease specialists.

Strengths and limitations

The strengths of this study include its use of a comprehensive, nationwide dataset encompassing nearly all Korean LTCHs and its integration of patient case-mix, non-modifiable structural, and system-level factors into a unified benchmarking model. This is the first study to adapt and validate the SAAR framework for long-term care institutions, which differ markedly from acute care hospitals in patient profiles, care objectives, and reimbursement structures. The revised model addresses limitations of the original SAAR, which was designed primarily for acute care settings. A standardized antimicrobial utilization benchmarking tool tailored to LTCHs may support inter-hospital comparison, identify outlier facilities for targeted review, and inform antimicrobial utilization surveillance and quality-improvement planning in these facilities.

Although the SAAR model serves as a valuable benchmarking tool for monitoring antimicrobial utilization, this study has several limitations. First, SAAR measures observed-to-predicted antimicrobial use after risk adjustment and is intended to identify potential overuse for further review; it does not directly assess guideline concordance, indication validity, or dose and duration appropriateness, which require clinical chart review. Second, this analysis relied on claims-based data lacking microbiological results, infection severity scores, and clinical decision-making context. Third, diagnostic coding variability may have led to misclassification of infection categories. Fourth, residual confounding due to unmeasured institutional factors such as stewardship culture or laboratory capacity cannot be excluded. Fifth, downstream outcomes—such as infection resolution, readmission, or mortality—were not examined. Sixth, although fixed-rate antimicrobial use was modeled, hospital-level benchmarking for this reimbursement category was exploratory because antimicrobial use was sparse, zero-inflated, and highly right-skewed. Finally, findings are specific to the Korean LTCH system and may not directly generalize to other health systems.

Conclusions

Despite these limitations, this study developed a national risk-adjusted K-SAAR–LTCH framework for monitoring antimicrobial utilization in Korean long-term care hospitals. The primary hospital-level benchmarking demonstration was strongest for diagnosis-specific FFS pneumonia and septicemia cohorts. In contrast, the fixed-rate model should be interpreted as an exploratory extension because antimicrobial use in this reimbursement category was sparse, zero-inflated, and highly right-skewed. The K-SAAR–LTCH framework provides standardized benchmarking information on antimicrobial utilization and identifies institutional variation that may inform national surveillance, targeted stewardship review, and quality-improvement planning in Korea.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13756-026-01795-8.

Supplementary Material 1

Author contributions

J.S. and D.-S.K. conceived and designed the study. J.S. and J.C. curated the National Health Insurance claims data and performed the antimicrobial classification using the ATC system. J.S. developed the statistical models (Hurdle Gamma and Gamma generalized linear models), conducted the formal analyses, and prepared all tables and figures. B.K. provided clinical expertise on antimicrobial stewardship and infectious disease and contributed to the clinical interpretation of the results. J.S. wrote the main manuscript text. J.C., B.K., and D.-S.K. reviewed and edited the manuscript. D.-S.K. supervised the project and acted as the corresponding author. All authors (J.S., J.C., B.K., and D.-S.K.) reviewed and approved the final manuscript.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. De-identified participant-level data that support the findings of this study can be made available upon reasonable request and subject to approval by the institutional ethics committee and data-sharing agreements, where required.

Declarations

Ethics approval and consent to participate

This study received approval from the Institutional Review Board (IRB) of the Health Insurance Review and Assessment Service (HIRA), under IRB No. 2024-

015-001. The IRB waived the requirement for written informed consent, as all datasets utilized were anonymous and had been de-identified.

Competing interests
The authors declare no competing interests.

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