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Master of Public Health Research Project

Strategies for Deriving a Single Measure of
the Overall Burden of Antimicrobial Resistance in Hospitals

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Abstract

Background: Antimicrobial-resistant infections result in hospital stays costing between \$18,000 and \$29,000. As of 2009, Centers for Medicare and Medicaid Services no longer upgrade payments for hospital-acquired infections. Hospital epidemiologists monitor and document rates of individual resistant microbes in antibiogram reports. Overall summary measures capturing resistance within a hospital may be useful.

Objectives: We applied four techniques (L1- and L2-principal component analysis (PCA), desirability functions, and simple summary) to create summary measures of resistance and described the four summary measures with respect to reliability, proportion of variance explained, and clinical utility.

Methods: We requested antibiograms from hospitals participating in the University HealthSystem Consortium for the years 2002–2008 (n=40). A clinical team selected organism-drug resistant pairs (as resistant isolates per 1,000 patient days) based on 1) virulence, 2) complicated or toxic therapies, 3) transmissibility, and 4) high incidence with increasing levels of resistance. Four methods were used to create summary scores: 1) L1- and L2-PCA: derived multipliers so that the variance explained is maximized; 2) desirability function: transformed resistance data to be between 0 and 1; 3) simple sum: each resistance rate was added and divided by the square root of the total number of microbes summed. Simple correlation analyses between time and each summary score evaluated reliability. For each year, we calculated the proportion of explained variance by dividing each summary score's variance by the variance in the original data. Clinical utility was checked by comparing the trends for all of the individual microbe's resistance rates to the trends seen in the summary scores for each hospital.

Results: Proportion of variance explained by L1- and L2-PCA and the simple sum was 0.61, 0.62, and 0.29 respectively. Simple sum and L1- and L2-PCA summary scores best followed the trends seen in the individual antimicrobial resistance rates; trends in desirability function scores deviated from those seen in individual trends of antimicrobial resistance. L1- and L2-PCA summary scores were more influenced by MRSA rates, and the simple sum score was less influenced. Pearson correlation coefficients revealed good reliability through time.

Conclusion: Deriving summary measures of antimicrobial resistance can be reliable over time and explain a high proportion of variance. Infection control practitioners and hospital epidemiologists may find the inclusion of a summary score of antimicrobial resistance beneficial in describing the trends of overall resistance in their yearly antibiogram reports.

Key words: antimicrobial resistance, nosocomial, MRSA, L1-PCA, summary measure, overall burden

Introduction

Nosocomial infections are a great burden to US hospitals and their patients, and are major contributors to morbidity and mortality.¹ In the past decades, we have seen an increase in the number and diversity of resistant organisms.^{2, 3, 4, 5} Antimicrobial exposure is a risk factor for colonization and infection with resistant microbes, and places selective pressures on microbes to develop resistance.^{6, 7} US hospitals spend an estimated \$4-7 billion annually to treat patients infected with antimicrobial-resistant organisms, and this cost is partially attributable to infected individuals' extended hospital visits.^{8, 9}

In 2009, the Centers for Medicare and Medicaid Services (CMS) implemented policy such that they will no longer pay the additional costs associated with some hospital-acquired infections (HAIs).¹⁰ With an average cost ranging from \$18,000 to \$29,000 per antimicrobial-resistant infection in a hospital, it is in the best interest of a hospital to fully understand the overall burdens and trends of resistance to appropriately allocate infection control and antimicrobial stewardship resources.¹¹ Hospital infection control practitioners and epidemiologists monitor rates of resistant microbes, and document their findings in reports of susceptibility, also known as antibiograms. Antibiogram reports contain data on single antibiotics paired with single microbes and document the number of susceptible isolates. While these detailed reports can elucidate trends within particular microbes or within particular antibiotics, they fail to provide an overall view of resistance within a hospital.

The Society for Healthcare Epidemiology of America and Infectious Diseases
Society of America Joint Committee on the Prevention of Antimicrobial Resistance

urged hospitals to collect data on antimicrobial use and resistance within specific patient care areas.¹² Yet, having to digest data on multiple microbes and their resistance rates within specific patient areas impedes health practitioners' and consumers' ability to comprehend a hospital's total burden of resistance.

To overcome this barrier, methods to summarize the multitudes of data found in hospital antibiogram reports are needed. We posit that the development of summary measures could be used to rate and compare burdens of resistance between hospitals, as well as trends within hospitals.

Objectives

The objectives of this research were twofold. First, we sought to apply four techniques to create summary measures for antibiogram data. Second, we described the properties of each summary measure including the proportion of variance explained, reliability, and clinical utility.

Methods

Data source

We conducted an ecologic study using aggregated hospital-level data from the University HealthSystem Consortium (UHC) database and individual antibiogram reports from hospitals participating in UHC and volunteering such data. UHC is an alliance of 340 academic medical centers and their affiliated hospitals, representing roughly 90% of the nation's non-profit academic medical centers.¹³ Variables recorded

by UHC hospitals include, but are not limited to, bed size, number of patients, International Classification of Disease (ICD-9) diagnostic and procedure codes, severity of illness, age, and number of transplants. Aggregate hospital-level characteristics included were mean patient age, case mix index (CMI), bed size, occupancy rate, average length of stay, total patient days, total discharges, transplant and surgery rates per 1,000 discharges, and the number of major and extreme severity of illness cases per 1,000 discharges.

Antibiogram data

VCU requested antibiograms from 75 medical centers participating in UHC for each year from 2002 to 2008. Each hospital was offered \$100 per year of data shared. At the time of analyses, not all hospitals had submitted six years of antibiogram data, resulting in missing data. We included 51 hospitals in the analysis, with 25 hospitals contributing at least five years of data. Each hospital used their own standards to measure antimicrobial sensitivity and the standards were not reported to the study investigators. A multidisciplinary team including one highly experienced hospital epidemiologist, two infectious disease pharmacists, and two experienced methodologists, reviewed a sample antibiogram to choose organism-drug combinations to be included in the summary score. The organism-drug combinations were selected to represent important pathogens due to 1) virulence (e.g., Methicillin-resistant *Staphylococcus aureus*), 2) require complicated or toxic therapies (e.g., multidrug-resistant *Acinetobacter*), 3) transmissibility in the hospital setting (e.g., Vancomycin-resistant *Enterococcus*), and 4) high incidence with increasing levels of

resistance (e.g., fluoroquinolone-resistant *E. coli*). Aggregate incident sensitivity data was collected on the following resistant microbes: Oxacillin-resistant *Staphylococcus aureus* (MRSA), Vancomycin-resistant *Enterococcus* (VRE) *faecalis* and *faecium*, Imipenem-resistant *Acinetobacter baumannii*, Ceftriaxone-, Ciprofloxacin-, and Levofloxacin-resistant *Escherichia coli*, Ceftriaxone- and Imipenem-resistant *Klebsiella pneumoniae*, and Cefepime-, Ciprofloxacin-, Imipenem-, Levofloxacin- and Piperacillin/Tazobactam-resistant *Pseudomonas aeruginosa*.

For each organism-drug pair, there were several options for summarizing the data: resistance rates (per 1,000 patient days) or proportions. The decision to use rates or proportions depends on the reason for analysis. Resistance rates were chosen over the use of proportions because the comparison of resistance data via proportions has not been shown to be the most accurate indicator of resistance burden.¹⁴ It could be the case that the proportion of resistant microbes for a particular hospital is increasing over time, however the rate of resistant microbes has kept constant.

Approach to estimating summary measures

We implemented four approaches to estimating a summary score for antimicrobial resistance: simple summary score, desirability function, L1 principal component analysis (L1-PCA) and L2-PCA. Each method is described below.

Simple Summary Score

The simple summary score was calculated by summing the individual antibiograms for each hospital for each year. The simple sum methods are linear transformations of the data; each score is a weighted sum of the resistance rates. For the simple sum, the

multiplier for each rate is $1/\sqrt{m}$, where m is the total number of rates being summed.

For example: If hospital A had three resistant microbes, X, Y, and Z, the simple summary score for 2002 would be:

$$Q = (\text{Rate of X in 2002}/\sqrt{3}) + (\text{Rate of Y in 2002}/\sqrt{3}) + (\text{Rate of Z in 2002}/\sqrt{3})$$

Desirability Function

Desirability functions were estimated using standard procedures.¹⁵ The desirability function method begins by converting each resistance rate y to a desirability d as follows:

$$d = \left\{ \begin{array}{ll} 0 & y < L, \\ \left(\frac{y}{U}\right)^r & L \leq y \leq U, \\ 1 & y > U \end{array} \right\}$$

where U is an upper threshold and L is a lower threshold. For this analysis, we set $r = 1$ for a linear desirability function. For a given hospital, once the desirability scores for each resistance rate were calculated, the overall desirability was calculated by the formula: $D = (d_1 + d_2 + \dots + d_m)^{1/m}$. This formula for D is the geometric mean of the resistance rate desirabilities. The overall desirability is the score for a hospital. Note that as with the other methods, a low score is "desirable". This convention is the opposite of the usual notion of desirability.

Principal Component Analysis (PCA)

The principal component analysis derives multipliers so that the variance explained is maximized.¹⁶ The first principal component describes the direction of maximum variation in the data. The location of a hospital on this line/direction is the score and is

an indication of its goodness or badness with respect to drug-resistant bacteria. A high score indicates high rates of resistance. The function *prcomp()* in the R Environment for Statistical Computing is used for traditional PCA. L1-PCA is a variant of PCA that is based on finding L1-norm best-fit subspaces rather than using the traditional Euclidean or L2 norm. Using the L1 norm provides robustness to outlier observations so that the underlying pattern of most of the data is more likely to be captured. The L1-PCA is implemented in C¹⁷; code for R is available from <http://www.people.vcu.edu/jpbrooks/l1pcastar>.

There are two approaches to deal with correlated data through time. First, we estimated L1-PCA and L2-PCA functions for each year by applying the weights derived for each hospital within that year; this method will be called the comparison method. The comparison method allows comparisons across hospitals within a year, but does not permit a fair evaluation of trends within a hospital across time. Second, we selected the year 2008 to serve as the standard. With this year's data, the L1-PCA and L2-PCA approach was implemented; this method will be called the trend method. For each PCA method, the summary scale was rescaled to range from 0 to 10, where lower scores signify lower resistance rates.

Because L1-/L2-PCA summary scores included negative numbers, they were scaled to be between 0 and 10. For L1-/L2-PCA summary scores derived using the

comparison method, we used the following formula:

$$10 \frac{(x - Min_i)}{(Max_i - Min_i)}$$

Where Min_i = the minimum score for year i , Max_i = the maximum score for year i , and

$x = \text{PCA score. Using the trend method, we used the following formula: } 10 \frac{(x - \text{Min})}{(\text{Max} - \text{Min})}$

Where *Min* = the minimum score over all years, *Max* = the maximum score over all years, and *x* = PCA score.

Analytic approach

First, we calculated descriptive statistics to describe the hospital characteristics and case mix for the UHC hospitals participating in the study. Second, we evaluated the variance explained. For each year, we calculated the proportion of explained variance of each of the three summary measures by dividing their variance by the variance in the original data. Percent variance explained was not calculated for desirability function scores because there was less variance once all data were fit between 0 and 1, and the original scale of measurement was not preserved. The best summary measure would have higher proportion of explained variance. For each method, we included all of the organism-drug pairs listed above to create the summary scores.

We also estimated the construct validity of the summary measures. Currently, there is no gold standard for measuring the overall burden of resistance in a hospital. This precludes us from estimating the sensitivity and specificity of the four summary measures to a previously validated and reliable measure. Therefore, we chose five variables that have been known to be correlated with hospital resistance and that should correlate well with each summary measure. Occupancy rate^{18, 19}, length of stay^{20, 21}, severity of illness^{21, 22}, transplantation rate^{23, 24}, and age²¹ have all been

associated with antimicrobial resistance. A priori, we hypothesized that these variables would correlate with summary measures of antimicrobial resistance. Severity of illness was provided by UHC in five different categories: no class, minimal, moderate, major, and extreme. We collapsed the major and extreme categories because we assumed that the patients most likely to contribute to the burden of resistance are those whose conditions are most severe. We estimated occupancy rates for each hospital by using data on the number of patient days and the bed size. By multiplying the bed size by the number of days in the year, we calculated the number of possible patient days each hospital could accommodate. Dividing the number of patient days by the number of possible patient days estimates the occupancy rate of each hospital. We checked the distributions for outliers and found the following: major and extreme severity of illness cases per 1,000 discharges, transplant rate per 1,000 discharges. As such, we did not include hospitals with major and extreme severity of illness cases per 1,000 discharges above 110, and transplant rates per 1,000 discharges above 15 in the correlational analyses. A correlational analysis was done between each individual correlate of resistance and each summary measure of resistance. If the variables were normally distributed, Pearsons' correlations were estimated.²⁵ For ordinal variables, Spearman rank-order correlations were computed.²⁶ Residual values were checked for homoscedasticity. Lastly, the reliability of the three summary scores was evaluated by examining a hospital's summary score through time. For a summary score to be useful, it should be reliable and somewhat stable from one year to the next. A correlational analysis was conducted between year and summary score for each hospital for the years 2002 to 2008. As a result of our incomplete data set, some hospitals had missing

data points for this analysis. An a priori decision was made to exclude those hospitals with more than two years of missing summary measures.

Results

Table 1 shows the hospital descriptive characteristics. Average bed size was ~538 with 164,534 patient days. The hospitals contributing antibiogram data had an average occupancy rate of 84%. Table 2 provides the descriptive statistics on the four summary measures for antimicrobial resistance. Through PCA analyses, MRSA rates were found to be highly variable between hospitals. Regardless of the approach to develop the summary score, overall antimicrobial resistance was low across all measures. L1-/L2-PCA scores had the highest percent variance explained. For example, the proportion of variance explained by the L1-PCA was 62% compared to 29% for the simple score. L1-/L2-PCA summary scores had similar percent variance explained, and simple summary scores had low percent variance explained.

Simple correlational analyses revealed both L1-/L2-PCA summary scores to have moderate non-significant positive correlations with mean length of stay and transplant rate per 1,000 discharges, and moderate negative correlations with major and extreme severity of illness cases per 1,000 discharges. L1-/L2-PCA were found to poorly correlate with percent occupancy and mean age (Table 3). Desirability function scores were found to have significant negative correlations with mean length of stay and transplant rates per 1,000 discharges, and moderate to low, non-significant positive correlations with severity of illness per 1,000 discharges, occupancy rate, and mean age. The simple sum scores were found to have a significant positive correlation with

transplant rate per 1,000 discharges, and low, non-significant positive correlations with severity of illness rates per 1,000 discharges, occupancy rate, mean length of stay, and mean age.

The reliability of the summary scores of antimicrobial resistance was estimated by looking at the strength of the correlation between the summary scores for each hospital and time. Out of the 61 hospitals that were included in our data set, 25 provided enough antibiogram data to calculate at least five years of summary measures using the trend method (Table 4). L1-PCA Pearson correlation coefficients were very strong. There were minimal differences between L1-/L2-PCA Pearson correlation coefficients. Desirability function correlation coefficients varied from those seen with L1-/L2-PCA; some showed strong negative correlations where L1-/L2-PCA scores showed strong positive correlations. Desirability function scores of zero for some hospitals resulted in the summary score having an opposite or different Pearson correlation coefficient than L1-/L2-PCA. Simple sum score correlations were similar in strength and direction to those seen in L1-/L2-PCA scores, with only a few deviations from similarity.

Figure 1 demonstrates the potential utility of the summary scores by including both the trends in summary scores of antimicrobial resistance, as well as trends in individual antimicrobial resistance for a randomly selected hospital. Overall, this hospital had relatively stable antimicrobial resistance trends, except for fluoroquinolone-resistant E. coli and MRSA. From 2002-2008, fluoroquinolone-resistant E. coli increased more than 400%. From 2002-2003, there were increases in all forms of resistance. For example, from 2003-2004, there were increases in the resistance rates of four microbes, and

decreases in two; L1-/L2-PCA and simple sum scores increased, but desirability scores decreased. Overall, L1-/L2-PCA scores and simple sum scores showed similar trends, however L1-/L2-PCA trends seemed to be more influenced by changes in MRSA antimicrobial resistance rates. Figure 1 shows that from 2006-2007 there was a sharp rise in MRSA; L1-/L2-PCA has a steeper slope than that seen with the simple sum score.

Discussion

In the world of infectious diseases and hospital epidemiology, there is no single measure used to describe and illustrate the overall burden of antimicrobial resistance in a hospital. The use of a summary measure of resistance should not be thought of as a replacement for individual antimicrobial resistance trend analysis. Rather, our aim was to create a measure that could be used to describe the overall patient and hospital burden of antimicrobial-resistant infections. Our data suggest that the use of a summary measure may be a viable option for understanding a hospital's overall burden of antimicrobial resistance. While the approaches to developing the summary measures have advantages and disadvantages (Table 5) that must be thoughtfully considered before selecting the appropriate approach given the intended use of the data, our analyses do not support the use of the desirability function.

Our construct validity analyses did demonstrate that transplant rate had a fairly strong correlation with all summary measures. The fact that transplant rates were fairly correlated with our summary scores suggests that the scores follow known relationships and have a valid construct. The lack of significant correlations in the

construct validity analyses may be attributed to several factors. First, our data set consisted of aggregate hospital-level data and as a result is likely to have masked associations. Second, we could only evaluate one year of data (2008) in these analyses due to the complexity of how the PCA and desirability summary scores were created. This may also have restricted our ability to detect correlations. Indeed, when we conducted the correlational analyses using data from all years with the simple sum score, we did observe significant correlations with percent occupancy, mean length of stay, and transplant rate. Although these findings held for the simple sum score, we do not have evidence that the same would be true for the PCA and desirability function scores.

For a summary score of antimicrobial resistance to be clinically useful, it must be reliable over time. Through reliability analyses, our data showed strong correlations between the summary measures and time for each hospital having at least five years of summary measure data. It may well be that trends in some hospital summary scores of resistance may be non-linear and more variable over time. The clinical utility of a summary score of resistance that varies widely over time is minimal. Indeed, regardless of the approach to developing a summary measure of resistance, the reliability of the score through time appears adequate.

Ideally, a summary measure should not be heavily influenced by the resistance rate trends of one microbe. Our analysis demonstrated that while L1-/L2-PCA summary scores were not extremely influenced by large changes in MRSA, the simple sum scores provided a more robust and less easily influenced measure of overall burden of resistance. Our analyses do not support the use of a desirability function approach to

building summary scores of antimicrobial resistance. There were several years when a majority of the individual microbes had increased in rates of resistance, but the desirability function scores decreased. Logically, these findings are incompatible with characteristics sought in a summary measure of the overall burden of antimicrobial resistance. Although the desirability function summary score of antimicrobial resistance showed promise vis-a-vis construct validity and reliability, it failed to visually and logically follow overall trends of antimicrobial resistance.

For tracking trends within a given hospital, the simple sum summary score may be useful. Trends seen in the simple sum scores logically followed the overall trends seen in the individual antimicrobial resistance rates. Having high reliability, strong construct validity, and being able to logically provide a great measure of overall antimicrobial resistance translates into a very useful tool for clinicians and healthcare consumers. Lastly, the summary measure is straightforward to calculate and does not require specialized software, other hospitals' data, or a statistician.

The applicability of this study must be considered with the following issue in mind. The ability to apply techniques to measure antimicrobial resistance rates depends on available surveillance data. To our knowledge, there is only one other voluntary surveillance system that currently exists in the US (aside from UHC): The National Healthcare Safety Network (NHSN). The NHSN is a voluntary, internet-based system that links all participating hospitals to one another and with other agencies (e.g., public health departments or quality improvement organizations).²⁷ Mandatory reporting and surveillance systems to monitor true nationwide prevalence in resistance has been considered and even implemented in some countries, but not in the US. The

performance of any of the methodological approaches to creating summary measures will rely on valid data streams.

Ultimately, summary measures of antibiotic resistance in hospitals may be of interest to healthcare consumers. In a qualitative evaluation of healthcare consumers' perceptions of healthcare report cards,²⁸ 54% of focus group participants identified hospital-acquired infection rates as being an important indicator for choosing a healthcare facility. Currently, CMS provides a useful online tool that compares hospitals based on process-of-care measures, outcome-of-care measures, and survey of patients' hospital experiences, but no information on nosocomial infections.²⁹ UCompareHealthCare, an About.com health service,³⁰ provides information regarding infection prevention practices including information about the hospital's use of antibiotics under various scenarios (e.g., percent of patients whose preventative antibiotic(s) are stopped within 24 hours after surgery) but information on antimicrobial resistance is nonexistent. Summary measures as explored in the current study are a first step in allowing comparisons across hospitals. Further work on risk adjustment strategies to permit fair comparisons is warranted.

The analyses must be considered in light of several limitations. First, antibiogram reporting standards for each hospital included in our study were not provided by participating hospitals. If patients contribute duplicate isolates to antibiogram data, resistant rates can be overinflated.³¹ Because we were analyzing different methods of creating a summary score of overall resistance, the possible overestimation of individual resistance rates does not threaten our conclusions. Second, all participating hospitals may not have reported a full 12 months of antibiogram data. Data are

accepted on a rolling basis at UHC, and are updated on a daily bases as more data are submitted by hospitals. Because identifying hospital information was not provided, we could not contact the hospitals to verify the completeness of the data provided to UHC. Third, we estimated the hospital occupancy rate based on the reported number of patient days and the number of beds. This may have been inaccurate. Fourth, only a small number of hospitals participated and we only had aggregate hospital-level data. The extent to which these findings are generalizable to all hospitals is unknown. Lastly, it was not possible to conduct statistical tests to determine which summary score best represented the overall burden of antimicrobial resistance. In the absence of a gold standard, this approach was not feasible. Rather, we used a crude visual and logical check to ensure that the trends in the summary scores reflected those seen in the individual resistance rates.

Conclusions

When Charles Darwin published *On the Origin of Species by Means of Natural Selection* in November, 24, 1859, he introduced the concepts of evolution, selective pressures and survival of the fittest. The same attributes that allowed humans to evolve from primitive beings to one of the supreme species on the planet, allow common microbes such as Staphylococcus and Enterococci to evolve into single and multi-drug resistant bacteria. Surveillance of antimicrobial resistance in hospitals is paramount to ensuring the safety of a hospital's patients and its quality of healthcare. Through the use of antimicrobial resistance summary scores, hospital personnel can hold a better understanding of their hospitals overall burden of antimicrobial resistance and use the

information to better inform their use of pharmacotherapies. Furthermore, infection control practitioners may find the inclusion of a summary score of antimicrobial resistance, in conjunction with individual microbe rates of resistance, beneficial in describing the trends of overall resistance in their yearly reports. Our work posits that a summary measure of antimicrobial resistance can be reliable over time, associated with known correlates of antimicrobial resistance, and clinically relevant. Desirability functions do not perform well with antimicrobial resistance rate data. PCA is a viable approach, but may not warrant the complexity for tracking individual trends within hospitals. Such measures depend on the availability of comprehensive resistance surveillance systems which are not currently mandated in the US. While healthcare consumers may desire publicly reported antimicrobial resistance rate information for hospitals, methodological work on how to appropriately risk adjust summary measures to allow for appropriate comparisons is needed.

Tables

Table 1. Descriptive statistics for UHC hospitals contributing antibiogram data in 2008 (n=61). Comparison method.

Variable	Mean	Median	SD	Range
Mean Age	45.1	45.0	6.59	28 - 65
CMI	1.6	1.6	0.17	1.02 - 1.89
Bed Size	538	504	191.30	185 - 1156
Percent Occupancy	84.2	84.2	16.88	25.07 - 151.14
Average Length of Stay (Days)	5.7	5.7	0.54	4.34 - 7.31
Total Patient Days	164,534	167,466	60,859	31,035 - 294,216
Total Discharges	29,242	28,927	10,897.35	6,944 - 57,179
Transplant Rate per 1,000 Discharges	4.8	4.3	3.72	0 - 18.41
Surgery Rate per 1,000 Discharges	352.1	355.2	58.48	206.31 - 511.61
Major and Extreme Severity of Illness Cases per 1,000 Discharges	59.66	56.77	18.67	32.00 - 183.65

Table 2. Center and spread data on summary measures for n=40 hospitals in 2008. Comparison method.

Variable	L1-PCA	L2-PCA	Desirability Function	Simple Sum
Mean	2.86	2.90	0.35	13.88
Median	2.79	2.84	0.22	11.96
Standard Deviation	1.50	1.52	0.32	7.31
Range	0.18 - 6.70	0.19 - 6.79	0.05 - 1.00	2.98 - 34.55
Variance Explained	62%	61%	n/a*	29%

*Percent variance explained was not calculated for desirability function scores because the data were transformed to be between 0 and 1 and the original scale of measurement was not preserved.

Table 3. Correlation coefficients between summary measures and correlates of resistance for 2008 in n=40 hospitals. Comparison Method.

Correlate of Resistance	L1-PCA			L2-PCA			Desirability Function			Simple Sum		
	Corr	p	df	Corr	p	df	Corr	p	df	Corr	p	df
Severity of Illness per 1,000 Discharges*† (Major + Extreme)	-0.17	0.31	37	-0.17	0.30	37	-0.06	0.70	37	-0.08	0.62	37
Percent Occupancy	0.02	0.91	38	0.02	0.91	38	0.09	0.59	38	0.03	0.86	38
Mean Length of Stay	0.23	0.14	38	0.23	0.15	38	0.23	0.15	38	0.38	0.02	38
Transplant Rate per 1,000 Discharges*	0.18	0.29	37	0.17	0.29	37	0.20	0.22	37	0.32	0.05	37
Mean Age	-0.03	0.87	38	-0.02	0.88	38	0.01	0.97	38	-0.02	0.89	38

* Outlying observations were excluded

† Spearman correlation coefficients shown

Corr=correlation coefficient, p=p-value, df=degrees of freedom

Table 4. Stability of hospital antimicrobial resistance index values from 2002-2008.

Hospital ID	L1-PCA		L2-PCA		Desirability Function		Simple Sum	
	Corr	# Obs	Corr	# Obs	Corr	# Obs	Corr	# Obs
1	0.89	7	0.90	7	0.88	7	0.80	7
2	0.95	6	0.95	6	-0.68	6	0.40	7
4	0.96	7	0.96	7	0.87	7	0.96	7
5	0.44	6	0.44	6	0.51	6	0.79	7
6	0.89	6	0.89	6	0.45	6	0.34	7
7	0.52	7	0.53	7	0.23	7	0.51	7
9	0.71	6	0.72	6	0.65	6	0.31	7
10	0.81	7	0.82	7	0.17	7	0.74	7
11	0.61	7	0.62	7	0.49	7	0.58	7
13	0.69	7	0.70	7	-0.85	7	0.60	7
14	-0.67	7	-0.66	7	-0.74	7	-0.77	7
15	0.83	7	0.84	7	0.23	7	0.90	7
16	-0.03	7	0.03	7	-0.63	7	-0.75	7
19	-0.86	6	-0.86	6	-0.96	6	0.72	7
23	0.19	5	0.27	5	0.59	5	-0.72	7
24	0.31	7	0.34	7	-0.20	7	-0.10	7
25	0.55	6	0.57	6	0.90	6	0.80	7
28	0.81	6	0.82	6	0.87	6	0.62	7
29	-0.83	6	-0.83	6	-0.70	6	-0.13	7
31	-0.01	6	0.01	6	-0.41	6	0.04	7
33	0.85	7	0.86	7	-0.17	7	0.64	7
34	0.89	6	0.90	6	0.60	6	0.93	7
39	0.74	5	0.75	5	0.75	5	0.94	7
41	-0.05	5	-0.05	5	-0.30	5	0.71	7
43	-0.37	5	-0.35	5	-0.61	5	0.70	7

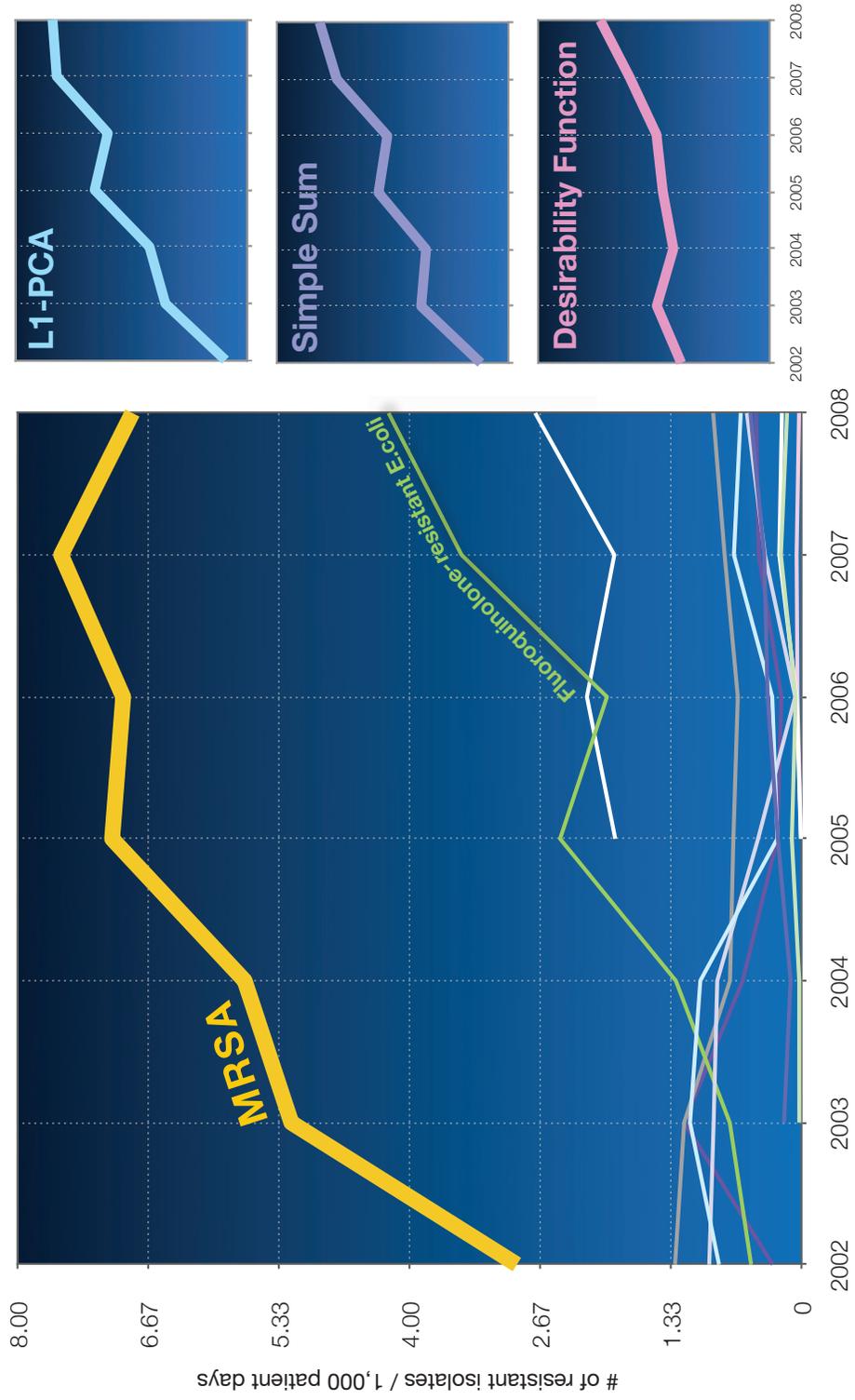
Corr=correlation coefficient; Pearson correlation coefficients shown using trend method.

Table 5. Advantages and disadvantages to different approaches to create resistance summary measures.

Summary Measure	Advantages	Disadvantages
L1-PCA	<ul style="list-style-type: none"> • Resistant to outliers • Principal components indicate importance of variables • Can calculate the proportion of variance explained • Can detect emerging resistance in a single drug, even when all resistance rates are combined • Unbounded 	<ul style="list-style-type: none"> • Method is uncommon and is not widely known or tested • Is influenced by highly variable antimicrobial resistance rates
L2-PCA	<ul style="list-style-type: none"> • Finds direction of maximum variance • Principal components indicate importance of variables • Can calculate the proportion of variance explained • Can detect emerging resistance in a single drug, even when all resistance rates are combined • Unbounded 	<ul style="list-style-type: none"> • Not resistant to outliers • Is influenced by highly variable antimicrobial resistance rates
Desirability Function	<ul style="list-style-type: none"> • Simple to calculate 	<ul style="list-style-type: none"> • Poor measure of overall antimicrobial resistance • Cannot calculate the proportion of variance explained • Does not preserve the original scale of the data • Scores are bound between 0 and 1 • Requires choice of parameter r
Simple Sum	<ul style="list-style-type: none"> • Easiest measure to calculate • Good measure of overall antimicrobial resistance • Can calculate the proportion of variance explained • Unbounded • Can compare hospitals across time <i>and</i> to each other 	<ul style="list-style-type: none"> • Proportion of variance explained is lowest

Figure

Figure 1. Examining the clinical utility of the different summary measures of antimicrobial resistance for hospital #4.



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