

ORIGINAL ARTICLE

The Role of Institutional Epidemiologic Weight in Guiding Infection Surveillance and Control in Community and Hospital Populations

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BACKGROUND. Institutions such as hospitals, prisons, and long-term care facilities have been identified as focal points for the transmission of emerging infections. Cost-effective control of these infections in large populations requires the identification of optimal subpopulations for targeted infection control interventions. Our objective was to quantify and compare the relative impact that individual institutions or subpopulations have on wider population-level outbreaks of emerging pathogens.

DESIGN. We describe a simple mathematical model to compute the epidemiologic weight (EW) of an institution or subpopulation. The EW represents the rate at which newly infectious individuals exit the institution under consideration.

SETTING. A hypothetical academic tertiary-care hospital (700 beds, 5-day length of stay [LOS]) and prison (3098 inmates, 27-day LOS).

PATIENTS. Individuals entering a hospital in-patient prison ward and nonprisoners entering both medical and surgical intensive-care units and those admitted to the general medical and surgical wards.

RESULTS. The recent example of the community-acquired methicillin-resistant *Staphylococcus aureus* epidemic is used to illustrate the EW calculation. Hospitals and prisons, which often have vastly dissimilar populations sizes and LOSs and might have differing transmission rates, can have comparable EWs and thus contribute equally to an epidemic in the community.

CONCLUSIONS. This method highlights the importance of measuring entrance and exit colonization prevalences for the optimal targeting of prevention measures. The EW not only identified superspreader institutions but also ranks them, enabling public health workers to optimize the allocation of resources to places where they are likely to be of most benefit.

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The morbidity, mortality, and costs associated with a number of emerging antimicrobial-resistant infections—including nosocomial vancomycin-resistant enterococci, methicillin-resistant *Staphylococcus aureus* (MRSA), and the newly emergent community-acquired MRSA—are increasing.¹⁻⁴ Ideally, once a problem organism is identified, every effort would be undertaken to control the pathogen's spread at all potential geographic sites of transmission. However, reductions in healthcare budgets have disproportionately affected budgets for hospital infection control and for state health departments.⁵ A key question for public health and infection control professionals is, therefore, how to rapidly identify, in a cost-effective manner, institutions or subpopulations that are prone to the transmission of such pathogens, so that focused control and intervention measures can be taken to curb the perpetuation of spread.

For example, the emerging view is that the transmission of MRSA is dominated by hospitals and long-term care fa-

cilities, but other institutions also contribute to incident colonization in the community via the release of MRSA carriers. An important part of the public health response should be to identify and weigh various MRSA sources so that interventions to control the spread of MRSA can be directed toward optimal points for control.⁶ In the United States, several outbreaks in prisons have been described, which suggests that correctional facilities may be prone to MRSA transmission.⁷⁻⁹ Given this organism's association with skin and soft-tissue infections, a reasonable working hypothesis is that institutions that house large numbers of individuals in small areas support intense MRSA transmission. If such institutions release colonized individuals (ie, carriers) into the community at high rates, they may contribute disproportionately to the MRSA pandemic. Correctional facilities that serve as short-term holding areas for prisoners awaiting arraignment, bail, or removal to a longer-term holding facility may be such institutions.

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TABLE 1. Input Parameter Estimates for the Epidemiologic Weight

Location	D_s^a %	A_s^b %	N	R_s^c in days
Prison	11	NA	3098	27
Hospital	NA	4	700	5

NOTE. NA = Not available.

^a Fraction of patients or prisoners colonized with MRSA when discharged.

^b Fraction of patients or prisoners colonized with MRSA when admitted.

^c Length of stay (LOS) before discharge. The hospital LOS of persons who provided culture samples did not differ from those who did not provide culture samples ($P > .05$). Data were not available to assess whether the prison LOS of persons who provided culture samples differed from those who did not provide culture samples.

With the aid of a simple mathematical model, we propose a set of measurement parameters that can help to identify institutions (or subpopulations within a larger institution) of interest quickly. A general methodology for the assessment of the relative importance of an institution (eg, a hospital, prison, or long-term care facility) in producing new carriers, compared with other community institutions, is described. The approach is illustrated for the specific case of MRSA in a hospital and a prison, but the method has much broader applicability.

METHODS

To weigh the contribution of various institutions to incident MRSA carriage in a population, we compare 2 institutions: a short-term holding jail and a large tertiary care hospital. For each institution, we let A denote the fraction of patients or prisoners who are colonized with MRSA at admission and D denote the fraction of patients who are colonized when they are discharged. Thus, $D - A$ is the net change in the prevalence of MRSA colonization within each institution during the mean length of stay (LOS). The institutions have LOSs of R before discharge to the community and constant population sizes (N). When $D - A$ is divided by R , the result is the mean rate of MRSA acquisition. Such an institution will then release newly colonized individuals into the community at an average daily rate, $EW = N(D - A)/R$. The quantity EW is an institutional-specific epidemiologic weight, because institutions with higher values of EW contribute more colonized (and potentially infectious) individuals per unit of time, on average, than do institutions with lower values.

Parameter Estimates and Sensitivity Analysis

For each parameter, initial estimates were taken from the best available sources. Demographic data from Baltimore city prisons were gathered from updated published statistics (available at <http://www2.dpscs.state.md.us/dpds/detention.shtml>; accessed May 14, 2004). Estimated hospital LOSs and the prevalence of MRSA in both prison and hospital populations were derived from existing administrative and infection control databases at the University of Maryland Medical Center in

Baltimore.¹⁰ The University of Maryland Medical Center is a 656-bed, tertiary care, academic medical center, and it maintains the only (13-bed) correctional healthcare unit in the state that is dedicated to serving people transferred from correctional facilities.

For the present study, we estimated model parameters on the basis of our facility’s surveillance program for MRSA, for which surveillance cultures are collected at admission from all patients entering the hospital’s in-patient prison ward and medical and surgical intensive care units and from a random selection of patients admitted to the general medical and surgical wards. In addition, discharge cultures are collected from all patients who leave the medical and surgical intensive care units, to determine acquisition rates of MRSA in these units. Compliance rates for providing admission and discharge cultures were 83.7% and 85.3%, respectively, in the combined units. Additional details of the surveillance have been described elsewhere.¹¹ In this study, individuals who had previously tested positive for MRSA or who tested positive at admission were excluded. Only patients who had negative cultures at admission could be considered to have acquired MRSA infection. The University of Maryland School of Medicine Institutional Review Board approved the study.

Given the level of uncertainty concerning parameter estimates, missing data, and the fact that local factors in Baltimore may be very different from those of other locales, we completed several 1- and 2-way sensitivity analyses. These allow for an estimation of confidence in our findings and support generalization of these findings to other prison-hospital-city groups.

RESULTS

Parameter estimates appear in Table 1. Estimates of the prevalence of colonization with MRSA at entrance to the prison (A_p) and discharge from the hospital (D_h) were not available, making it instructive to compute the epidemiologic weight, EW , for a range of possible net acquisition rate, ($D - A$). In Table 2, we compare the resulting epidemiologic weights for a hypothetical hospital ($N = 700$, $R = 5$ days) and prison ($N = 3098$, $R = 27$ days). Depending on the intensity of transmission, we see that, for typical sizes and LOSs, prisons

TABLE 2. Sensitivity of Epidemiologic Weight to Varying Net Acquisition

Sensitivity of $(D - A)$, %	EW_p	EW_h
1	1.1/day	1.4/day
5	5.7/day	7.0/day
10	11.5/day	14.0/day
15	17.2/day	21.0/day
20	22.9/day	28.0/day

NOTE. Estimated epidemiologic weights for a hypothetical hospital (EW_h ; $N = 700$, length of stay [LOS] = 5 days) and prison (EW_p ; $N = 3098$, LOS = 27 days).

can be sources of MRSA-colonized individuals at rates comparable to those of hospitals. These results illustrate that institutions that are vastly dissimilar in size and LOSs can have similar epidemiologic weight and highlight the importance of directly measuring A as well as D .

In general, different institutions may have very different entering populations, with correspondingly discordant prevalence levels. This has been noted, for example, in populations of injection drug users, who might have a higher prevalence of MRSA colonization and might be expected to account for a large part of the prison population but less of the general tertiary care–facility population.¹² To illustrate how sensitive the epidemiologic weight is to variation in these unmeasured entrance and exit prevalences, in the Figure we have plotted the results of a 2-way sensitivity analysis. For the values of A_h and D_p listed in Table 1 (with A_p varying from 2% to 9% and D_h varying from 4.5% to 7.5%), the Figure depicts a surface plot of the ratio of EW_p to EW_h (color represents surface height). The Figure shows that, on the one hand, in settings of low A_p and low D_h , prisons can actually have a larger weighting factor than hospitals (EW_p is greater than EW_h). On the other hand, when both A_p and D_h are high, hospitals have a larger weighting factor than prisons (EW_p is less than EW_h).

DISCUSSION

From the viewpoint of public health and infection control, it is vital to identify institutions or specific healthcare areas in an institution that may contribute significantly to outbreaks—in this case, the epidemiological engines that drive the unfolding MRSA epidemic. With such knowledge, it may be possible to focus intervention efforts, thereby maximizing scarce public health and hospital resources. Intervention strategies exist; in an effort to reduce the nosocomial transmission of these organisms, the Centers for Disease Control and Prevention and the Society for Healthcare Epidemiology of America, for example, have recommended culturing samples from patients at high risk of colonization by MRSA or vancomycin-resistant enterococci.¹³ This methodology would allow the rapid determination of subpopulations at the highest risk, so that they may be subject to efficient, targeted active surveillance strategies.

We have described the epidemiologic weight, which allows an estimation of the relative contribution that individual subpopulations make to a specific epidemic. The epidemiologic weight is the subpopulation size, N , multiplied by the net acquisition ($D - A$) in that subpopulation, divided by the average LOS, R . Thus, as the subpopulation size grows, the net acquisition increases, or the LOS decreases, the epidemiologic weight of the subpopulation and, thus, its relative importance to the overall epidemic increase.

Although observations in the literature have demonstrated a high incidence of MRSA colonization and infection in prison and hospital settings, we know of no methodology

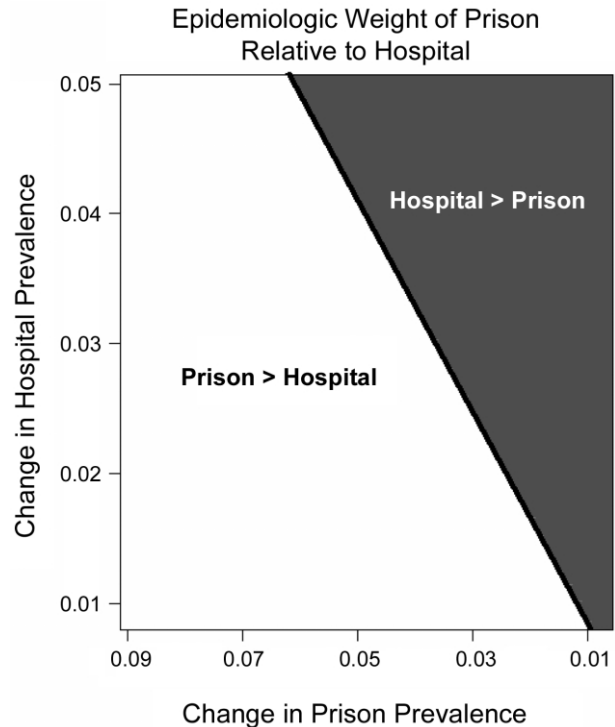


FIGURE. Two-way sensitivity analysis of the relative epidemiologic weight (EW_p/EW_h) for different values of change in hospital prevalence ($D_h - A_h$) and change in prison prevalence ($D_p - A_p$). Dark shade represents the region in which prisons have larger weighting factors than hospitals, and the lightest shade represents the opposite case.

that has been proposed previously to estimate the relative importance of one institution versus another from a community public health viewpoint. We have proposed a conceptual model and measurement to help guide thinking about the dynamics of community transmission as a function of the presence of multiple institutions. This conceptual model focuses on the carriage of MRSA from institution to community only by patients and inmates. Of course, there may be carriage and spread to the community at large by healthcare or prison workers, but few estimates of the significance of this mode exist.¹⁴ Our model suggests a somewhat counterintuitive result: institutions with characteristics similar to prisons (large at-risk populations with long LOSs) can be as important as hospitals (relatively small at-risk populations with shorter mean LOSs) when no interventions are in place to prevent spread. In this sense, prisons may have an impact similar to that of long-term care facilities in the emergence of antimicrobial-resistant pathogens.¹⁵ The conceptual model can also be used to assess carriage from one institution (or one particular area within an institution) to another.

It is true that prisoners have a high documented prevalence of community-associated MRSA.^{8,9} One limitation of this study is that our parameter estimate of MRSA colonization

in prisons was derived from a population of prisoners who were admitted to our hospital. It is likely that these prisoners are different from the prison population as a whole. However, in this study, we have assumed that community-acquired MRSA is not preferentially associated with the conditions under which inmates present to our prison ward. Furthermore, the prevalence of colonization in the correctional facilities of interest was not available. This lack of a precise estimate of an important parameter of interest points to the utility of the epidemiologic weight, in that it directs researchers to data that should be measured to determine optimal targeting of infection control interventions.

Institutions with higher epidemiologic weights are likely more "important" in the epidemic, in the sense that they release more individuals per time, relative to institutions with lower epidemiologic weights. Thus, the epidemiologic weight not only identifies superspreader institutions but also ranks them, which enables public health workers to allocate scarce funds in an optimal way by administering control programs in places where they may do the most good. The fact that the epidemiologic weight can be calculated using relatively few measurable parameters could make it a useful statistic for deciding which populations to target in interventions to control population-level epidemics. With the aid of this metric, we suggest that prison holding facilities, relative to hospitals, may contribute comparable numbers of MRSA-colonized individuals per day to a catchment community. Thus, efforts to control community-acquired MRSA in settings such as Baltimore should likely target prison populations as well as hospitals.

Although we are not suggesting that MRSA is endemic at high levels in all prisons, our results illustrate that institutions with high acquisition and turnover rates contribute substantially to the transmission of MRSA and should represent a key focus for prevention and control efforts. Anecdotal reports of prisons in the literature suggest that they may be key players in the community epidemic.^{8,9} There are no accepted guidelines regarding the control of the transmission of community-acquired MRSA, but candidate strategies do exist: hand hygiene, surveillance, and isolation are long-accepted measures for the control of *S. aureus* infection.¹³

The method that we describe is applicable to many types of institutions and highlights important data to collect for the optimal targeting of prevention measures.¹⁶ Because there is significant transfer of patients between healthcare facilities, determining each facility's epidemiologic weight may be a valuable tool in determining which populations are at high risk of colonization with resistant organisms. Patients who spend time in a facility with a high epidemiologic weight could be targeted for active surveillance. Similarly, epidemiologic weights can be calculated for specific areas of patient care within an institution. Patients who have spent time in an area with a high epidemiologic weight could be screened when they transfer to another area of the hospital, so that

precautions could be implemented to halt further transmission of this organism.

In conclusion, the epidemiologic weight allows the quantification and comparison of the relative impact that individual institutions or subpopulations have on wider, population-level outbreaks of emerging pathogens. The epidemiologic weight provides a quantitative method for assessing the need for control and intervention measures, and the simplicity of these calculations makes them easy to use. Facilities will need to continue to monitor their epidemiologic weights as a measure of the effectiveness of their prevention measures, which would require ongoing, active entrance and exit culturing for surveillance.

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