CONTROLLING METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS: A FEEDBACK APPROACH USING ANNOTATED STATISTICAL PROCESS CONTROL CHARTS

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ABSTRACT

OBJECTIVES: To investigate the benefit of a hospitalwide feedback program regarding methicillin-resistant Staphylococcus aureus (MRSA), using annotated statistical process control charts.

DESIGN: Retrospective and prospective analysis of MRSA rates using statistical process control charts.

PARTICIPANTS: Twenty-four medical, medical specialty, surgical, intensive care, and cardiothoracic care wards and units at four Glasgow Royal Infirmary hospitals.

METHODS: Annotated control charts were applied to prospective and historical monthly data on MRSA cases from each ward and unit during a 46-month period from January 1997 through September 2000. Results were fed back from December 1999 and then on a regular monthly basis to medical staff, ward managers, senior managers, and hotel services.

RESULTS: Monthly reductions in the MRSA acquisition rate started 2 months after the introduction of the feedback program and have continued to the present time. The overall MRSA rate currently is approximately 50% lower than when the program began and has become more consistent and less variable within departments throughout Glasgow Royal Infirmary. The control charts have helped to detect rate changes and manage resources more effectively. Medical and nursing staff and managers also report that they find this the most positive form of MRSA feedback they have received.

CONCLUSIONS: Feedback programs that provide current information to front-line staff and incorporate annotated control charts can be effective in reducing the rate of MRSA (Infect Control Hosp Epidemiol 2002;23:13-18).

Methicillin-resistant Staphylococcus aureus (MRSA) has become endemic in many hospitals in the United Kingdom and abroad despite the best efforts of infection control teams and the introduction of prevention guidelines. There is growing uncertainty about the value of continued current control approaches that have with few exceptions been so universally unsuccessful.1,2

Surveillance with feedback is an accepted approach in the control of other nosocomial infections, but there have been few published reports of this approach's being advocated or used successfully in controlling MRSA.3 The question of whether certain types of feedback would be a useful adjunct to traditionally advocated methods therefore appears to warrant further consideration. In particular, statistical process control charts are a common method of prospective monitoring and quality control in many other industries and recently have experienced growing use in health care.6

Control charts are statistical graphs that provide real-time feedback to practitioners, display data chronologically in an easy-to-interpret manner, and help to detect increases or decreases in the acquisition rate. Once identified, changes in the MRSA rate should be investigated to determine whether they are the result of inconsistently followed infection control practices or are due to changes in case-mix severity or some other reason. Although the use of statistical process control charts has been advocated in infection control,7,8 there has been little published in the literature regarding using them to help control MRSA. The control of MRSA also may be useful as a general marker of the overall infection control practices in a ward or unit.9,10

METHODS

Glasgow Royal Infirmary is a tertiary referral center that provides regional services for cardiac, burn, and bone marrow transplant patients. Glasgow Royal Infirmary consists of one main and three peripheral hospitals with a total of 1,116 beds. As in many other hospitals, the number of isolates of MRSA since 1992 has shown a steady increase, with a general failure to halt its spread (Fig. 1). In 1999, 871 patients with MRSA were identified in our hospitals, many of whom were found to have positive results on an earlier admission or on transfer from another hospital.

Annotated control charts were applied to prospective and historical monthly data on MRSA cases from 24 wards and units at Glasgow Royal Infirmary hospitals during a 46-month period from January 1997 through September 2000. Feedback began on a limited basis in December 1999 and expanded thereafter as more wards were introduced and more experience was gained with the use of control charts.
A total of 24 annotated control charts currently are updated monthly for medical, medical specialty, surgical, intensive care, and cardiothoracic wards and units (Table 1). Indications for obtaining cultures from patients and identifying MRSA in the laboratory are consistent with published guidelines. All new patients colonized or infected with MRSA are referred to infection control nurses who then visit the ward, collect basic epidemiologic data, and offer advice on prevention of cross-infection. This had been customary practice at Glasgow Royal Infirmary for several years before the current study began.

If MRSA is determined to have been acquired during the current admission, then it is accredited to a specific ward. Criteria by which MRSA is classified as not acquired on the current admission include the patient having a positive result on screening on admission, having a known colonization from a previous admission in this or another hospital or facility, or being transferred with an unusual strain of MRSA that is endemic in another unit but new to the receiving unit. If it is not possible to identify an individual ward of origin, then the MRSA is attributed to a specific unit (eg, the surgical unit).

At the end of each month, the number of cases accredited to each ward or unit is updated by the infection control team on the corresponding statistical process control charts for that ward or unit. These charts are annotated with any important practice or other changes and fed back to ward managers and medical staff on a regular monthly basis and reviewed with senior managers and hotel services staff. Each month the infection control nurse discusses the results with the individual ward manager. Factors that could have contributed to the results are elucidated. Some practice changes are determined by asking staff where they think problems exist with MRSA. Praise is given if progress is made. If not, then possible causes and appropriate actions to reduce the number of new cases the next month are discussed.

For example, if it is believed that junior medical staff are not following basic hand hygiene practices, this information is fed back to them and to the consultants who supervise them. Similarly, if it is believed that cleaning has become inadequate, then the infection control nurse will contact hotel services staff. Adherence to recommendations is verified via general observation and comments from coworkers. It is important that the problem is not seen solely as a nursing problem, but rather as a team or process problem. Review of the control charts enables the infection control team to evaluate the current situation, target resources appropriately, and interpret every new MRSA isolate in the context of past and present acquisitions. If the control chart indicates to the infection control team that the rate in a ward or unit appears to be increasing, then action is taken immediately to rectify the situation (eg, by alerting everyone to the problem and trying to identify causes quickly).

Although different types of control charts are appropriate in different situations, we use Shewhart c charts. The calculations and underlying mathematical theory for these charts are based on a Poisson statistical distribution. These types of charts are appropriate when analyzing rate or “count” data, such as rates of nosocomial infections per time period, bloodstream infections per 100 line-days, or catheter-associated infections per 100 device-days. In our case, the number of new cases of hospital-acquired MRSA is charted monthly on the horizontal x-axis along with three reference lines that aid interpretation of the plotted data. These are called the center line, the upper control limit, and the lower control limit. The center line is equal to the arithmetic mean (or expected value) of the monthly MRSA counts, and the control limits are set by convention at 3 standard deviations above and below the center line.

The control limits define the statistical range in which almost all of the data can be expected to be plotted if the

<table>
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<tr>
<th>TABLE 1</th>
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<tr>
<td><strong>CLINICAL AREAS IN WHICH ANNOTATED CONTROL CHARTS ARE UPDATED AND REVIEWED MONTHLY</strong></td>
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<td>Glasgow Royal Infirmary</td>
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<td>Medical directorate</td>
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<td>Surgical directorate</td>
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<td>Hematology-oncology</td>
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<td>Respiratory intensive treatment unit</td>
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infection or colonization rate remains consistent and stable, with roughly half of the values randomly falling above and half below the center line. Values outside these control thresholds or prolonged runs above or below the center line are referred to as being "out-of-control" or as "unnatural variability" because they indicate changes in the MRSA rate or a lack of adherence to standardized infection control practices. Conversely, values between the control limits are referred to as being "in control" because they exhibit only the "natural variability" that should be expected if standard control processes are being followed consistently. An additional pair of thresholds called warning limits also sometimes are plotted at 2 standard deviations above and below the center line to give practitioners earlier, but less definite, warnings of possible problems. These warning limits will have higher sensitivity, but at the expense of lower specificity.

Further information on the different types of control charts and their use and interpretation in health care can be found in Benneyan and Plsek. For more general information on the technical details of statistical process control, see also Grant and Leavenworth, Duncan, and Montgomery.

RESULTS
Decreased Rate of New Acquisitions

Figure 2 shows the increasing trend in the total number of new MRSA acquisitions before and after our introduction of a monthly feedback program using statistical process control as described above. Since feedback began, only one medical specialty area has shown an out-of-control episode, with all other areas remaining in control. Two months after we began feedback, monthly reductions in the acquisition rate of MRSA occurred and have been sustained (Fig. 2). The rate of new MRSA acquisitions is now approximately 50% of that prior to the use of charts and is in a stable, in-control state throughout Glasgow Royal Infirmary. We are unaware of any other changes in the hospital area that could account for these reductions. The center line and limits in Figure 2 have been recalculated to reflect the increase and later decrease in the MRSA rate.

Faster Response by the Infection Control Team

Because the infection control team updates the charts frequently, they can respond more immediately to an increased rate and interact with the ward in a more timely manner. Because the infection control team is up-to-date with the implications of almost every new acquisition, feedback is given to the ward before the end of the month if the infection control team feels that the MRSA rate may have increased, such as if data already are above the upper control or warning limit. If problems do arise, the data are immediately available for assessment and communication. The hotel services manager now receives annotated charts and is advised in which wards or units to focus monitoring of, and, if necessary, to increase cleaning.

Assigning Responsibility

Giving the charts to ward staff and managers helps place the responsibility for MRSA acquisition on those directly involved in the patient care and environmental decontamination practices that determine whether cross-infection occurs. In some instances, ward managers and the infection control team have successfully used the charts to support arguments to receive additional cleaning services. The infection control team has received an enthusiastic response to the use of these charts from managers and nursing staff, who think that they are the most meaningful form of MRSA feedback that they have ever received.

Informing Decisions to Close Wards

The ease of interpretation and chronologic presentation of control charts has assisted in decisions to close one unit (plastic surgery) and to keep one ward (vascular) open. In the first case, Figure 3 was prepared using retrospective data during a developing outbreak in the plastic surgery unit and clearly showed that MRSA acquisition in this unit was out-of-control in November and December 1999. As a result, investigations were conducted that resulted in the unit's being closed to major surgery for 1 week, coupled with a thorough environmental cleaning. If the
chart had been prepared before the outbreak, however, the increasing trend would have been spotted sooner and earlier intervention may have reduced the size of, or even prevented, the outbreak.

In the second case (Fig. 4), the vascular ward was kept open. Although there was concern over the number of new patients with MRSA in November 1999, data on the control chart remained "within control limits," indicating that these did not correspond to a significantly increased acquisition rate in this ward, but rather to the admission of patients who were previously known to have MRSA from other areas.

**DISCUSSION**

The almost universal failure to control MRSA in hospitals and the increased burden this has placed on infection control teams draws into question whether attempts to control MRSA are worthwhile and should continue. Moreover, viable solutions need to be statistically valid, inexpensive, easy to implement, and not time-consuming. This study illustrates a feedback-based methodology that achieves all of these objectives. Results of this surveillance feedback approach have been positive and have led to several benefits.

Control charts are used initially to establish a consistent process and an in-control infection or colonization rate (i.e., to eliminate unnatural variability) and then to further reduce the MRSA rate (i.e., to remove natural variability). Examples of eliminating unnatural (out-of-control) variation include standardization in the infection control environment (e.g., improving decontamination or cleaning practices) and infection control practices (e.g., hand hygiene). Examples of reducing natural (in-control) variation include changing standard practices or the standard environment (e.g., increasing the number of washbasins or implementing new cleaning policies and handwashing guidelines).

In trying to define an MRSA outbreak, Wenzel et al. suggested that a monthly rise of 25% against a background level measured during 1 year probably represents an outbreak.21 The control chart approach offers a more exact, yet simple, method for detecting an increase in the acquisition rate. These charts also are useful for delineating endemic rates, with the purpose of reducing them by altering practices. The reduction of new acquisitions of MRSA seen throughout Glasgow Royal Infirmary hospitals appears to be a direct result of the introduction of this feedback program. In industry, simply starting a quality control program can often result in improvements. Haley et al. suggest that this phenomenon also occurs in surveillance with feedback of hospital-acquired infection.22 Our program will continue to determine whether these results can be sustained. Although the type of feedback given is based on the infection control team's interpretation of the control charts, some improvements might be achieved with feedback without the use of control charts. Comparisons with other hospitals using feedback alone therefore have been proposed to study this.

Feedback also has been used with success to control MRSA, albeit with limited application and not employing control charts. Nettleman et al. argued that feedback assigns responsibility and therefore makes healthcare workers aware of the consequences of their actions.3 Sheriden et al. used clinician feedback successfully to control MRSA in a pediatric burn unit.4 In a review, Martin also advocated feedback of data to medical personnel.5 Our feedback is much broader and includes nursing, medical, managerial, and hotel services personnel. In a consensus statement, Goldmann et al. stated that feedback was seen as essential to the control of MRSA, but a particular methodology was not specified.23 Recent reports from the United Kingdom also advocate feedback.24,36

Statistical process control is an accepted approach used in industry to monitor manufacturing processes and to identify increases in defect rates or other types of unnatural variation. In a similar manner, we are monitoring the pan-infection–control processes that include staff numbers, care delivery procedures, and environmental contamination. Cleaning standards are an issue in the United Kingdom. Although control charts can help detect when the MRSA rate has increased or decreased, they typically will not identify the specific cause of the change. Once a change is detected, the infection control team must use its skills to assess the situation, identify possible causes, and promote improvement in practices (Table 2). Microbiologists also visit every ward daily and advise on the prescribing, stopping, and vacations of antibiotics. The ward staff also are hoping to use control charts to help identify when they are understaffed or have excess need of agency staff.

The most appropriate type of chart to use and the most appropriate level of data aggregation depend, in part, on how easy it is to determine where the MRSA was acquired. If the control chart includes too many wards, then staff may feel the responsibility lies elsewhere and they may not be inclined to use the feedback to alter their practices. Further, if the chart contains information from too many departments or units, it sometimes can mask local problems or out-of-control data. For example, providing separate charts for the vascular, general, and urology wards resulted in the identification of an out-of-control
TABLE 2
EVALUATION AND ACTION TAKEN BY THE INFECTION CONTROL NURSE IF METHICILLIN-RESISTANT STAPHYLOCOCCUS AUREUS (MRSA) ACQUISITIONS INCREASE IN A WARD

<table>
<thead>
<tr>
<th>Review of Possible Causes of MRSA Cross-Infection</th>
<th>Examples of Possible Action If Problems Are Identified</th>
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<tbody>
<tr>
<td>Care delivery procedures</td>
<td>Poorly performed procedures (e.g., hand hygiene or isolation procedures)</td>
</tr>
<tr>
<td>Administrative procedures</td>
<td>Not identifying known patients with positive results; not looking for marked notes; not informing other staff or departments if patients have MRSA</td>
</tr>
<tr>
<td>Environment</td>
<td>Inadequate hand hygiene facilities or overcrowding; visible dust in the patient areas</td>
</tr>
<tr>
<td>Healthcare workers</td>
<td>Staff unable to perform hand hygiene adequately because of excess jewelry, wrist watches, or false nails</td>
</tr>
<tr>
<td>Equipment</td>
<td>Difficult to clean equipment in use</td>
</tr>
<tr>
<td>Patients</td>
<td>Unrecognized patients with positive results not isolated</td>
</tr>
<tr>
<td>Policies</td>
<td>Staff are unaware of the policy or its contents or the policy itself is unclear</td>
</tr>
</tbody>
</table>

episode for each ward at different points in time. However, the chart for the entire surgical unit showed no out-of-control episodes in 3 years by the customary recommendation of 3 standard deviations. This underscores the importance of using feedback and statistical process control charts down to the most appropriate local level.

For simplicity and ease of use, the charts presented here have no “denominators” in the sense of adjusting the number of new MRSA cases for hospital census (which does not fluctuate widely on a monthly basis in our facilities). On other occasions, we did adjust the data for occupancy and patient-days in two settings (intensive treatment units and burns wards) and found no significant differences in the resulting control charts. This supports conventional statistical process control advice that if the monthly census does not vary substantially, then total counts by themselves can be sufficient. However, if the monthly census does change substantially (e.g., for the rate of new MRSA cases each month per 100 patient-days), then \( u \) rate charts should be used instead of \( c \) count charts. Additionally, changes in ward configuration (e.g., the ward is relocated or reduced in size) may require a recalculation of the mean and control limits and therefore always should be annotated on the chart. Out-of-control data due to changes in such things as patient mix, rather than infection control practices, also should be annotated on the chart.

**Advantages of This Approach**

Based on our experiences, several advantages of this statistical process control feedback approach are clear. Control charts provide almost real-time feedback for healthcare workers and managers responsible for infection control. As a result, more responsibility for good infection control practices is adopted by these personnel, which reduces the onus for control on the infection control team. In addition, ward managers are given positive, and occasionally negative, feedback on MRSA to relay back to their own staff. A new MRSA case can be assessed appropriately in the context of other recent acquisitions, providing infection control teams with an early warning system to help detect rate changes. Once the initial chart has been constructed, maintaining and updating it in a spreadsheet is simple and not time-consuming. The charts also can assist (in conjunction with other considerations) in judging whether a ward should be closed to further admissions and transfers.

**Disadvantages of This Approach**

The few disadvantages of this approach primarily concern implementation. The ability to assign a new MRSA case to a specific ward rarely can be completely accurate. We attempt to minimize this imprecision by encouraging the input of ward staff in any discussions or debates as to where a patient acquired the MRSA. Our control charts do not include nosocomial MRSA cases that manifest only after discharge (unless a swab is taken in the local area and sent to our laboratory or we are informed by another infection control team when the patient has been transferred). An additional implicit assumption is that sampling is fairly consistent among the staff in terms of the frequency or rationale for sending specimens to the laboratory. Monitoring a large
experience and research is required to determine whether these results are sustainable and whether this approach can be successfully applied to other areas (e.g., the reduction of medical errors in general).

REFERENCES
2. Piment D, Waldvogel FA. To control or not to control colonisation with MRSA, that is the question. Q.J Med 1997;90:239-241.