Patterns in nursing home medication errors: disproportionality analysis as a novel method to identify quality improvement opportunities

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SUMMARY

Purpose To explore the use of disproportionality analysis of medication error data as a novel method to identify relationships that might not be obvious through traditional analyses. This approach can supplement descriptive data and target quality improvement efforts.

Methods Data came from the Medication Error Quality Initiative (MEQI) individual event reporting system. Participants were North Carolina nursing homes who submitted incident reports to the Web-based MEQI data repository during the 2006 and 2007 reporting years. Data from 206 nursing homes were summarized descriptively and then disproportionality analysis was applied. Associations between medication type and possible causes at the state level were explored. A single nursing home was selected to illustrate how the method might inform quality improvement at the facility level. Disproportionality analysis of drug errors in this home was compared with benchmarking.

Results Statewide, 59 drug-cause pairs met the disproportionality signal and 11 occurred in 10 or more reports. Among these, warfarin was co-reported with communication errors; esomeprazole, risperidone, and nitrofurantoin were disproportionately associated with transcription error; and oxycodone and morphine were disproportionally reported with name confusion. Facility-level analyses illustrate how descriptive frequencies and disproportionality analysis are complementary, but also identify different safety targets.

Conclusions Exploratory analysis tools can help identify medication error types that occur at disproportionate rates. Candidate associations might be used to target patient safety work, although further evaluation is needed to determine the value of this information. Copyright © 2010 John Wiley & Sons, Ltd.

INTRODUCTION

In nursing homes, roughly 19% of all administered medication doses are associated with medication error.1 Preventable adverse drug events occur at a rate of approximately 1 per 100 resident-months, with more than 60% of these events considered to be fatal, life-threatening, or serious.2 For every $1 spent on drugs in nursing facilities, an additional $1.33 are spent on treatment of drug-related morbidity and mortality.3 Studying causes of error and methods to reduce risk is an important step toward improving patient safety in nursing homes.

North Carolina is the first state to mandate comprehensive medication error reporting in nursing homes through its Medication Error Quality Initiative (MEQI). Since 2004, nearly 70,000 medication errors have been reported to this Web-based error reporting system by the roughly 400 North Carolina nursing...

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homes subject to reporting requirements. These data provide valuable information for focusing patient safety efforts.

In general, medication error reporting systems can improve patient safety in the following ways: creating signals for early warning systems; developing error reduction strategies through identification of error-prone trends; change in packaging, labeling, and nomenclature; organizational change; and change in practice standards. The most successful voluntary programs for reporting errors provide timely analysis of error trends and signals. A comprehensive framework is necessary for timely analysis and interpretation of error reports. Descriptive frequency counts are the most common approach to communicate lessons learned from medication error reports. However, incomplete reporting, reporting biases, and missing data are common problems among nearly all reporting systems and hinder identification of safety concerns.

Disproportionality analysis is a hypothesis-generating method that provides an alternative to raw frequency counts for identifying safety signals with error reporting programs. While we are not aware of this method previously being applied to medication error data, statistical data mining algorithms using disproportionality analysis have become increasingly popular supplementary tools for drug safety. For example, disproportionality analysis is the basis for drug safety work using the US Food and Drug Administration's Adverse Event Reporting System. The underlying principle of this approach is to identify drug-event combinations that are reported more frequently than might be expected if the drug and event were truly independent. We believe this method can also help overcome some limitations of voluntary error reporting and target efforts to reduce medication errors.

The objective of this paper is to explore the use of disproportionality analysis as a novel method to identify specific relationships among error characteristics that might not be obvious through traditional analyses. This approach can supplement descriptive data and help target quality improvement efforts.

METHODS

We conducted a retrospective analysis of nursing home medication error reports submitted to the North Carolina MEQI during the 2006 through 2007 reporting years. Data analyzed for this study included individual reports of incidents, near misses, and circumstances of unsafe conditions submitted during this time. The study was reviewed and approved by the University of North Carolina at Chapel Hill Institutional Review Board.

Participants and setting

All licensed nursing homes in North Carolina are required to participate in medication error reporting (N = 393). At the time of this study, homes could choose to submit errors through an Annual Report (AR) system or using an Individual Error (IE) system. We focus on data submitted by the early adopters of the IE system: 23 nursing homes in the pilot year (2006) and 206 nursing homes in the second year (2007). Table 1 shows that these homes are generally representative of nursing homes in the State of North Carolina, with an average size of 119 beds and the majority of homes located in metropolitan areas, operated for profit, and part of a chain. In 2007, the study nursing homes reported an average of 23.9 errors per year per 100 beds.

Measures

Errors are entered into a Web-based form that collects the following information: date error occurred, time of event, patient age at time of event, cognitive status of patient, type of error, medications involved, possible causes, phase in medication process, personnel involved, type of effects, and patient outcomes. Error definitions are based on the National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) Index for Categorizing Medication Errors. Pierson et al. previously have described the technical specifications of the system.

In brief, the system was designed so that almost any user can log in and it guides the user step by step to enter the correct information needed to complete the report, with built in mechanisms to prevent inappropriate responses or missing data. For example, to report an error in which a patient was given the wrong medication several days in a row, the user begins by starting a new error report and indicating the severity of the outcome using nine categories specific to the nursing home environment. The user then enters patient characteristics (age, gender, etc.) and the date and time the error occurred or was first noted. If the error occurred repeatedly (e.g., the wrong medication was administered several days in a row before someone caught the error), the user enters the number of repeat incidents. For the purpose of this analysis, a repeat error is counted as a single event. Then based on error type, the system prompts the user for specific
error information: if the error type is wrong medication, then the system prompts for both the intended and actual medications administered; if the error type is overdose, the system prompts for both intended and actual dose. A drug identification tool allows the user to search a comprehensive drug database by typing all or part of the drug name and select the exact medication involved in error, including drug strength, route, and dosage form. One feature of the search algorithm is to provide alternative spellings based on a phonetic algorithm so that the user can select the appropriate drug despite spelling mistakes.

Possible causes consist of a pick menu containing the following main categories: product issues, prescription record issues, dispensing issues, facility issues, personnel issues, and other. Within each category, check boxes note specific types of possible causes. For example, product issues include check boxes for medication name confusion, packaging design, and product labeling. Prescription record issues include checkboxes for illegible handwriting, inadequate information, use of abbreviations, and transcription error; multiple causes may be indicated on a single error report. For feedback to reporters, a user can create on-demand summary reports of errors entered to date, categorized by time period, patient impact, type of error, and other relevant variables.

Statistical analysis

The proportional reporting ratio (PRR) is a disproportionality analysis method originally proposed by Evans et al.24 The method has been applied to adverse event reporting systems to explore disproportionate co-reporting of drugs and adverse events in a spontaneous reporting system. These and other disproportionality analysis methods have been developed and applied.

Table 1. Descriptive Statistics on Facilities and Errors

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>All homes</th>
<th>2007</th>
<th>All homes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEQI-IE</td>
<td></td>
<td>MEQI-IE</td>
<td></td>
</tr>
<tr>
<td>Nursing Homes</td>
<td>N = 23</td>
<td>N = 390</td>
<td>N = 206</td>
<td>N = 393</td>
</tr>
<tr>
<td>Beds per home, mean</td>
<td>118.8</td>
<td>120.4</td>
<td>118.9</td>
<td>120.4</td>
</tr>
<tr>
<td>For-profit status, n (%)</td>
<td>16 (70)</td>
<td>301 (79)</td>
<td>157 (76)</td>
<td>310 (78)</td>
</tr>
<tr>
<td>Chain ownership, n (%)</td>
<td>17 (74)</td>
<td>286 (73)</td>
<td>146 (71)</td>
<td>288 (73)</td>
</tr>
<tr>
<td>Metro area, n (%)</td>
<td>13 (57)</td>
<td>205 (53)</td>
<td>108 (52)</td>
<td>205 (52)</td>
</tr>
<tr>
<td>Errors per 100 beds, mean per home</td>
<td>22.8</td>
<td>31.2</td>
<td>23.9</td>
<td>28.3</td>
</tr>
<tr>
<td>Total error reports</td>
<td>n = 636</td>
<td>n = 15 781</td>
<td>n = 5823</td>
<td>n = 13 572</td>
</tr>
<tr>
<td>Most frequent errors by drug, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warfarin</td>
<td>25 (3.9)</td>
<td>646 (4.1)</td>
<td>312 (5.4)</td>
<td>623 (4.6)</td>
</tr>
<tr>
<td>Lorazepam</td>
<td>40 (6.3)</td>
<td>868 (5.5)</td>
<td>293 (5.0)</td>
<td>538 (4.0)</td>
</tr>
<tr>
<td>Acetaminophen-hydrocortone</td>
<td>21 (3.3)</td>
<td>467 (3.0)</td>
<td>248 (4.3)</td>
<td>413 (3.0)</td>
</tr>
<tr>
<td>Fentanyl</td>
<td>19 (3.0)</td>
<td>288 (1.8)</td>
<td>167 (2.9)</td>
<td>276 (2.0)</td>
</tr>
<tr>
<td>Alprazolam</td>
<td>11 (1.7)</td>
<td>206 (1.3)</td>
<td>129 (2.2)</td>
<td>217 (1.6)</td>
</tr>
<tr>
<td>Furosemide</td>
<td>21 (3.3)</td>
<td>234 (1.5)</td>
<td>112 (1.9)</td>
<td>339 (2.5)</td>
</tr>
<tr>
<td>Oxycodone and combinations</td>
<td>30 (4.7)</td>
<td>338 (2.1)</td>
<td>209 (1.9)</td>
<td>408 (3.0)</td>
</tr>
<tr>
<td>Morphine</td>
<td>8 (1.3)</td>
<td>8 (0.1)</td>
<td>101 (1.7)</td>
<td>101 (0.7)</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>8 (1.3)</td>
<td>85 (0.5)</td>
<td>87 (1.5)</td>
<td>172 (1.3)</td>
</tr>
<tr>
<td>By cause, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human error</td>
<td>406 (63.8)</td>
<td>—</td>
<td>4063 (69.8)</td>
<td>9594 (70.7)</td>
</tr>
<tr>
<td>Transcription error</td>
<td>153 (24.1)</td>
<td>—</td>
<td>1479 (25.4)</td>
<td>3660 (27.0)</td>
</tr>
<tr>
<td>Distractions</td>
<td>72 (11.3)</td>
<td>—</td>
<td>490 (8.4)</td>
<td>1701 (12.5)</td>
</tr>
<tr>
<td>Communication</td>
<td>34 (5.3)</td>
<td>—</td>
<td>315 (5.4)</td>
<td>871 (6.4)</td>
</tr>
<tr>
<td>Policies</td>
<td>10 (1.6)</td>
<td>—</td>
<td>223 (3.9)</td>
<td>185 (1.4)</td>
</tr>
<tr>
<td>Pharmacy dispensing</td>
<td>24 (3.8)</td>
<td>—</td>
<td>170 (2.9)</td>
<td>446 (3.3)</td>
</tr>
<tr>
<td>Med unavailable</td>
<td>10 (1.6)</td>
<td>—</td>
<td>100 (1.7)</td>
<td>390 (2.9)</td>
</tr>
<tr>
<td>Delivered wrong med</td>
<td>17 (2.7)</td>
<td>—</td>
<td>90 (1.5)</td>
<td>133 (1.0)</td>
</tr>
<tr>
<td>Name confusion</td>
<td>18 (2.8)</td>
<td>—</td>
<td>84 (1.4)</td>
<td>176 (1.3)</td>
</tr>
</tbody>
</table>

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1 2006 reporting year includes errors reported from 10/1/2005 through 9/30/2006, and 2007 reporting year from 10/1/06 through 9/30/07.
2 Individual Event Reporting System (MEQI-IE).
3 Rural-urban commuting area (RUCA) code = 1.
4 Facilities using IE reporting can designate an error that recurs over several days as a single repeated error, while homes using the annual reporting (MEQI-AR) system tend to report repeat errors as multiple incidents. This artifact of the reporting interface causes error incidences to appear higher in homes using MEQI-AR.
5 MEQI-AR only requires sites to list ten medications used in error and how many times that medication was found in error. If a site submits more than ten errors they are asked to list the medications most frequently found in error, or the medications from the most serious errors.
6 Cause categories for MEQI-AR were not mapped to MEQI-IE until 2007, so the corresponding categories for MEQI-AR are not available for 2006.
to spontaneously reported adverse event data. The methods have demonstrated utility in supplementing other safety activities. Disproportionality analysis also has been applied to hospital discharge data and administrative claims to generate hypotheses about drug relationships of interest.

PRR is the result of a calculation for the proportions of specified error characteristics for drugs or other error characteristics where the comparator is all other drugs in the database. Table 2 shows a two by two contingency table, where the PRR is \( \frac{a}{a+c} \) divided by \( \frac{b}{b+d} \), with examples of how PRR is calculated for a specific drug-cause pair at the state level and for a drug-home pair at the facility level. To define pairs that are highlighted for further evaluation, we applied the screening criteria that Evans et al. proposed: count \( n \) (denoted as \( a \) in the PRR formula) \( \geq 3 \), PRR \( \geq 2 \), and \( \chi^2 \geq 4 \). In the Table 2 example, oxycodone errors associated with name confusion have a PRR of 5.27, indicating that this drug-cause pair occurs disproportionately; while in the second example, PRR of 1.91 indicates that the example facility may not have a disproportionate number of medication errors involving oxycodone. We calculate 95% confidence intervals for PRR using the formula that Puijenbroek et al. describe.

We explored disproportionality analysis as a supplement to descriptive statistics such as raw counts and standardized frequencies. First, we applied the method to statewide data to generate hypotheses about relationships between drugs involved in error and their causes. We then purposefully selected a test facility that had a consistent reporting history and used this facility to illustrate a prototype report. For this facility, we benchmarked standardized error rates (using errors per 100 beds to control for variation in nursing home size against the state average, with equal weight for each facility) with state averages for the most frequently reported drugs. We compared descriptive data with the disproportionality analysis to demonstrate the benefits of this method as a supplemental approach in identifying priority quality improvement areas. This study focused on the relationship between homes, drugs, and root causes, although the method could be used to explore other relationships as well.

All calculations were performed using relational database software (Microsoft Access 2007, Microsoft Corp).

RESULTS

The statewide archive included 6459 individual-event error reports composed of 451 drugs, 23 cause categories, and a total of 1885 distinct drug-cause combinations. Evans et al.’s criteria for signal threshold identified 59 drug-cause relationships as associations that warrant further review. Figure 1 contains the disproportionate drug-cause pairs that occurred in 10 or more error reports. The comparison of pair frequency and PRR shows that important candidates for review would not be picked up by frequency analysis alone. For example, morphine and oxycodone were associated with name confusion and had the most disproportionate relationship, but occurred as pairs in only 10 and 11 reports, respectively.

Among drug errors at the facility level, 94 nursing homes generated at least one disproportionality signal and 8 homes generated at least 3 signals. The facility selected for illustration purposes reported 120 errors over the period. Figure 2 shows different drugs flagged through benchmarking (panel A) and disproportionality analysis (panel B) in this nursing home. The benchmark chart in panel A includes drugs that occurred in error reports five or more times and compares the standardized error frequencies with the state average. The disproportionality chart in panel B shows the PRR for drug-home pairs with error bars showing the 95% confidence interval. Of the 20 drugs involved in reported errors at this facility, 9 met the disproportionality threshold. Of these, enalapril,.

Table 2. Calculation of proportional reporting ratio from drug-cause pairs and drug-home pairs

<table>
<thead>
<tr>
<th>Cause or home of interest</th>
<th>Drug of interest</th>
<th>All other drugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>All other causes or homes</td>
<td>( a )</td>
<td>( b )</td>
</tr>
<tr>
<td>Total</td>
<td>( c )</td>
<td>( d )</td>
</tr>
<tr>
<td>PRR</td>
<td>( \frac{a}{a+c} ) divided by ( \frac{b}{b+d} )</td>
<td></td>
</tr>
</tbody>
</table>

Example of state-level PRR calculation using oxycodone and name confusion:

- Reports of name confusion: 11 of 194
- Reports of all other causes: 183 of 8463
- Total: 194 of 8463
- PRR = \( \frac{(11/194)/(91/8463)} = 5.27 \)

Example of facility-level PRR calculation using oxycodone at example facility:

- Reports from home of interest: 9 of 129
- Reports from all other homes: 231 of 6099
- Total: 129 of 6330
- PRR = \( \frac{(9/129)/(231/6330)} = 1.91 \)

The unit of analysis is a drug-characteristic pair appearing on a medication error report. The total number of pairs is higher in drug-cause analysis because personnel can indicate multiple causes on a single error report.
divalproex, nitrofurantoin, and clonidine were not of priority concern when looking at frequencies or error rates alone, but the disproportionality analysis shows they are involved in error more frequently in this home than across the state. This information could serve as a signal that further exploration of these drug errors may be warranted in this facility.

Another important message from the comparison of facility and statewide error frequencies with disproportionality analysis in Figure 2 is that several drugs are frequently reported but not disproportionately reported. For example, warfarin, lorazepam, and oxycodone errors occur most frequently at this home but not disproportionately compared with other homes, implying that the factors involved in these errors are related to usage or practice environment across the state rather than characteristics specific to the facility. While these errors are generally important because of their frequency, in this case the administrator could conclude that these errors are probably not related to systems or processes of care unique to their facility, but rather that characteristics of the drugs make them more prone to error (or error reporting). The value of PRR is particularly evident for a home that has higher than average overall rate of reported errors, since higher error rates relative to the state average may be related to extra vigilance and consistent reporting practices rather than safety hazards. In this case, benchmarking with statewide data yields only limited information, while disproportionality helps this facility to target its inquiries.

DISCUSSION
Existing approaches to quantify and evaluate medication errors are mainly descriptive.\textsuperscript{4,5,13,15–18} Analysis of medication error rates with descriptive techniques alone may be limited for several reasons. First, medication error reporting systems capture only a fraction of actual errors. Thus some error types are more likely to be reported than others, and trends identified in error reports are subject to bias. Furthermore, the error rate depends on the number of opportunities for error. While the standardized frequencies (i.e., reports per 100 beds) control for the size of the home, they are nonetheless sensitive to the underlying volume of medication use and to a facility’s level of overall reporting. Since it is impossible
to know whether higher frequencies reflect true error rates, error opportunity, or reporting practices, characterizing errors with frequency rates alone may be misleading.

We show how disproportionality analysis supplements existing methods to identify targets for medication-error quality-improvement in nursing homes that are different from potential problems identified with frequency analysis alone. This exploratory analysis looks at associations among elements of the error reports and seeks to identify relationships that occur disproportionately from others. While the approach is popular for mining spontaneously reported adverse drug event data, we are unaware of anyone using or testing this approach in the context of error reporting and believe it is a useful addition to existing quality improvement tools.

Previous work has suggested that reporting systems that lack feedback on reported errors can be a barrier to future reporting and other quality improvement efforts. Currently, nursing homes in North Carolina receive annual reports with univariate summaries of the most frequently occurring types of errors, and they also can access summaries of their own reported error data. We propose that the systematic analysis and distribution of summary reports based on data submitted to the North Carolina MEQI can help identify priority areas for patient safety efforts. We assume that adding disproportionality analysis to existing frequency and benchmarking reports would be valuable for identifying potential safety signals. But further qualitative assessment of the associations being identified by this technique is necessary before MEQI or other centralized reporting systems widely adopt this approach.

While we believe our approach provides significant advantages over existing descriptive summary reporting mechanisms, its prospective application for quality improvement may face barriers. For example, when applied prospectively, there may be insufficient volume of medication error reports over short intervals for early detection of error signals. One solution would be to provide disproportionality analysis at the chain level, since many chains have policies and processes that are common across facilities. This issue might also be addressed through other efforts to maximize reporting. Participation in MEQI is mandatory under North Carolina licensing regulations, but reporting is effectively voluntary in that there is no auditing process. Even among the homes that frequently report their errors, the accuracy of safety signals depends on the correct classification of causes and other error characteristics. Therefore, to maximize the ability to generate meaningful signals it is important that MEQI

Figure 2. Prototype error-targeting tool for example facility. Left-hand panel (A) displays standardized frequencies (errors per 100 beds) for drugs appearing most frequently in error reports \( (n \geq 5) \), where the gray bar is the state average and black bars are specific to this home. The right-hand panel (B) displays drugs meeting PRR signal threshold \( (n \geq 3, \text{PRR} \geq 2, \text{and} \chi^2 \geq 4) \). Gray error bars indicate 95% confidence intervals for PRR; upper 95%-confidence limits greater than 14 are not shown on this figure. Arrows indicate drugs that appear in one panel but not the other.
pursue strategies to incentivize more complete and consistent error reporting by homes.

Another barrier and potential limitation is that the facility selected for the prototype was atypical with respect to the total number of errors it reported, and running the analyses for other facilities may be less informative. However, if home specific data are insufficient for use with this tool, it might be possible to supplement home specific data with aggregated statewide data. Although this feedback does not help the individual home prioritize based on its own experience, it may identify useful trends that are consistently disproportionate statewide (e.g., drug-cause relationships). Furthermore, even when targeted reports do not include facility-level disproportionality analysis, state-level disproportionality analyses can supplement frequency counts and benchmarking to convey important information targeting patient safety efforts to specific processes.

Disproportionality analysis addresses some of the problems of unknown underlying frequency of medication use and incomplete reporting as long as underreporting is independent of medication or error type. However, if there is a correlation between propensity to report an error and other relevant variables—such as drug, error type, or personnel—the method is subject to reporting bias. The most useful signals are novel and accurate: that is, they alert administrators to a previously unknown problem or confirm suspicions for which there was not enough evidence, and they identify a meaningful underlying structural or process problem rather than inconsistencies in reporting. Additional exploration is necessary to determine whether the signals generated by disproportionality analysis satisfy these criteria before MEQI implements the method in feedback reporting. Further studies using sales and prescription data to benchmark error rates may add valuable context to the signals identified through disproportionality. Additional work is necessary to address the limitations of counting repeat errors as a single event, since errors that occur repeatedly over a period of time have the capacity to cause more severe effects in patients. It is important to emphasize that as with all adverse event data mining, disproportionality analysis generates hypotheses that are only the first steps in a quality improvement process. In practice, these signals would trigger further investigative tools such as root cause or process flow analysis.

Systematic mechanisms for documenting medication errors are generally not found in the nursing home environment. MEQI is the first statewide, Web-based error reporting system for nursing homes, and as such has several advantages over existing paper-based or facility standalone error tracking systems. Real-time error data analysis enables quality improvement teams to identify potential problems where trends differ from similar facilities and on a broader level can inform recommendations about potential risks with specific medication name confusions or administrative procedures. North Carolina’s experience may or may not be generalizable to all nursing home environments because reporting is mandatory and because participation from nursing homes has been strong. Nonetheless, this database and our analysis provide an example of the utility of our exploratory approach to identifying safety signals.

CONFLICT OF INTEREST
No authors have a perceived conflict of interest related to the content of this study. Richard Hansen has received research support from NIH, AHRQ, GlaxoSmithKline and Takeda Pharmaceuticals during the past 3 years. Patrick Ryan is an employee of GlaxoSmithKline. Charlotte Williams’ spouse is employed by GlaxoSmithKline.

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KEY POINTS
- Medication-error data from nursing homes create opportunities to identify safety hazards to patients, but are difficult to analyze when the underlying rates of medication use and propensity of homes to report actual errors are unknown.
- We explore disproportionality analysis to examine medication error data for potential safety hazards, a technique that has not been documented in analysis of error data.
- Disproportionality techniques can generate safety signals at both the state aggregate and facility levels that are not identified using raw or standardized frequencies alone.
- We show how feedback to facilities that incorporates both frequency and disproportionality analysis could generate richer information on quality-improvement targets.
REFERENCES


