This study purports to show the relationship between volume and patient harm due to health care error. Using 5 measures of volume and incident reports weighted for patient harm over the course of 515 days, it is shown that increased volume is related to increased harm to patients. As the number of areas in the hospital experiencing high volume increased, the likelihood of patients sustaining serious harm because of health care error also increased. This is attributed to reaching system capacity causing support services (ie, lab, pharmacy, radiology, housekeeping and engineering) to be overwhelmed and unable to keep up with requests from caregivers. (Am J Med Qual 2008;23:336-341)

Keywords: tipping point; staffing ratios; volume; patient harm; health care error

INTRODUCTION

This study seeks to understand the relationship between volume and patient harm due to health care errors. Health care errors are defined as potential and actual errors that can occur in the health care system involving any level of personnel at any point along the continuum of care. Preliminary evidence reported in this article suggests that there is a tipping point at which systems are likely to break down and the probability of patient harm increases. It is widely experienced that spikes in the census are often accompanied by some degree of chaos, or at worst, harm to patients, even when there is an increase in staffing numbers. If staffing levels are held constant, as occurs to some extent in California by mandated nursing staffing ratios, how does system capacity affect the genesis of health care error?

McManus et al., Litvak et al., and Cook and Rasmussen have suggested that our systems behave differently depending on the number of patients being served by them. Cook and Rasmussen suggest that systems operate reasonably well under normal conditions but break down at a point of overload. If this is true and the point can be identified at which systems are no longer reliable, then hospital administrators and clinical staff could take steps to raise or eliminate the tipping point. If the tipping point is known, an early warning system would enable a proactive response to prevent patient harm. Through the identification of a set of indicators that predict stresses on the system, leaders would have the ability to provide additional resources or system fixes that would make the operation less vulnerable to health care error and patient harm.

Ideally, the tipping point is a moving target (ie, we can increase a systems' capacity). Thus, coming to grips with that reality and developing a response plan may blunt the effect of critical volume levels on patient safety. Patients are far better served if we respond to increases in volume than to the exigencies of chaos. It remains for us to determine the level of volume that our systems can handle and take steps to avoid a system breakdown that may lead to patient harm.

There is evidence to suggest a notable relationship between patient volume and error that may lead to patient harm. Investigators from Massachusetts General and Brigham and Women's Hospital suggested that there is an increased risk...
of adverse events that may injure patients when hospitals operate at or over capacity. In this study, a major urban teaching hospital with consistently high occupancy rates exceeding 100% for more than 3 months, the resultant workload increases and higher patient-to-nurse ratios were associated with an increase in adverse events. The study suggested that hospitals operating at the high end of capacity would benefit from prospectively examining safety systems that intervene during periods of high occupancy.

METHODOLOGY

The objective of the current study was to explore the relationship between volume and patient harm caused by health care error, first in exploratory and qualitative terms and then quantitatively. During the exploratory phase, the leadership team investigated the issues surrounding system capacity in relation to volume. No formalized qualitative research was undertaken because it was not known whether these issues were truly relevant to the increase in health care errors observed, nor was there any attempt to quantify the findings. The leadership team speculated on the following questions and the team facilitator made notes of these discussions. A summary of the discussions has been incorporated into this article. The questions discussed were:

1. What is it like when you get busy?
2. Do we make more mistakes at these times?
3. We are looking at systems capacity as one of the underlying causes of errors. Do you have any experiences that validate this premise?
4. If we were to attempt to derive a mathematical model to identify the tipping point (the volume at which we begin to make medical mistakes), what do you think would be the most sensitive measure of volume?

During the quantitative phase, the objective was to assess whether volume could be used to predict the point at which health care errors increase and patients become vulnerable. Data on the volume indicators selected from the exploratory interviews were measured and compared to patient harm on those same days to determine whether high-volume days were related to days in which harm came about as a consequence of health care error. Patient volume was defined as the number of patients cycling through a given location in a single 24-hour period.

To assess the level of patient harm due to health care error on a given day, we used incident reports weighted for harm to patients. Research tells us that incident reports are the weakest method for uncovering errors; however, there are virtually no false positives. Incidents that staff report can be confirmed as real. From this we conclude that there may have been days during which errors were not reported, but all the high error days can be reasonably assumed to be high error days.

Every incident included an assessment of patient harm (ie, no injury, minor injury, major injury, death) using an ordinal scale. Because an error that leads to a minor injury is more than 1 step up and a major injury is more than 2 steps up, we used a geometric scale rather than an arithmetic scale to quantify this scale. An arithmetic scale assigns a 1 if there is no injury, a 2 for a minor injury, a 3 for a major injury, and a 4 for an injury that results in death. A geometric scale assigns a 1 (1^1) for no injury, a 4 (2^2) for minor injury, a 9 (3^2) for major injury, and a 16 (4^2) for death due to health care error. The justification for this is twofold. According to Vickers, medical distributions are better explained as geometric relationships using logs rather than arithmetic relationships because, in health care, there is rarely a normal distribution. Many health care measures such as mortality, length of stay, age, and health care error have a skewed distribution. Outliers create a tail of the distribution. Converting to a logarithmic scale tends to normalize the distribution. In this study, we use that supposition and give each error a value of 1^2 (1), 2^2 (4), 3^2 (9), or 4^2 (16), corresponding to no injury, minor injury, moderate injury, or death, respectively.

Another reason for using a geometric scale rather than an arithmetic scale is because we know that on average 5 other errors occurred prior to the injury event—the holes in the Swiss cheese. Non-weighted errors would not take this into account, thus the use of the geometric severity system.

Error data was collected from a 400-bed acute care facility in the San Diego area for the 17-month period of June 1, 2005 through November 27, 2006 (515 days). Each of the 515 days had a calculated score associated with patient harm, which was the summation of the incidents weighted for harm to patients that occurred on that day. A hypothetical day illustrates the approach (Table 1). On day 160,
for example, there were 5 incidents: 1 death, 1 major injury, 1 minor injury, and 2 incidents in which no injury occurred. These incidents were weighted as 16 for the death, 9 for the major injury, 4 for the minor injury, and 1 each for the 2 incidents in which no injury occurred. These incidents total 31 \((16 + 9 + 4 + 1 + 1)\). The score for patient harm for Day 160 is 31.

There were 5 measures of volume: 3 related to surgery, 1 to medical/surgical, and 1 to the emergency department (ED). Volume measures were:

- **Total census**: The midnight census.
- **Number of surgeries**: The total number of scheduled and unscheduled surgeries performed that day.
- **Add-ons**: The number of unscheduled surgeries.
- **Percentage add-ons**: The number of add-ons as a percentage of the total surgeries performed.
- **Behavioral health admissions**: The number of behavioral health patients admitted each day from the ED. In this facility, behavioral health admissions were a stress to the system.

Each day had 5 measures of volume and a weighted score for patient harm on that day. All were converted to z-scores so that all of the data had a mean of 0 and a standard deviation of 1. Thus, we had the ability to compare all measures and define high volume across all measures. For the purposes of this analysis, high volume was set arbitrarily as \(z \geq 1.5\). This was approximately 10% of the patient population for the error database utilized in this study.

One additional variable was created: The number of high-volume measures on that day. The number of high-volume measures was determined by counting the number of z scores \(\geq 1.5\), the previously defined measure of high volume. Table 2 offers a hypothetical analysis of 1 day for which the total number of high-volume indicators was calculated.

<table>
<thead>
<tr>
<th>Date Number</th>
<th>Incident</th>
<th>Patient Harm</th>
<th>Weight*</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>1</td>
<td>Death</td>
<td>16</td>
</tr>
<tr>
<td>160</td>
<td>2</td>
<td>Major injury</td>
<td>9</td>
</tr>
<tr>
<td>160</td>
<td>3</td>
<td>Minor injury</td>
<td>4</td>
</tr>
<tr>
<td>160</td>
<td>4</td>
<td>No injury</td>
<td>1</td>
</tr>
<tr>
<td>160</td>
<td>5</td>
<td>No injury</td>
<td>1</td>
</tr>
</tbody>
</table>

*a Harm score = 31.

<table>
<thead>
<tr>
<th>Date Number</th>
<th>Volume Indicator (VI)</th>
<th>Z-Score</th>
<th>High/Low*</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>1</td>
<td>0.6</td>
<td>0</td>
</tr>
<tr>
<td>160</td>
<td>2</td>
<td>1.2</td>
<td>0</td>
</tr>
<tr>
<td>160</td>
<td>3</td>
<td>−0.2</td>
<td>0</td>
</tr>
<tr>
<td>160</td>
<td>4</td>
<td>1.7</td>
<td>1</td>
</tr>
<tr>
<td>160</td>
<td>5</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>160</td>
<td>6</td>
<td>2.1</td>
<td>1</td>
</tr>
</tbody>
</table>

A database was created that consisted of z-scores for errors and volume indicators for the 17-month period from June 1, 2005 through November 27, 2006 (515 days). Each day had a measure of harm, the weighted score for patient harm, and a set of z-scores, 1 for each volume indicator. The following dichotomous variables were created for all volume measures: 1 for high volume \((z \geq 1.5)\) and 0 for low volume \((z < 1.5)\). If \(z \geq 1.5\), the volume indicator = 1, and if \(z < 1.5\), the volume indicator = 0.

## RESULTS

### Phase I: Exploratory Phase

Two community hospitals in California were the sites for the exploratory phase: one in Los Angeles (200 beds) and the other in San Diego (400 beds). There was agreement among the respondents from both hospitals, and therefore the results were aggregated. In response to the question, “What is it like when you get busy?” were exclamations of, “It’s chaotic!” When pressed, no one felt that nursing ratios made any difference. Most expressed surprise that this should be so, but held fast that even with the advent of ratios, they experienced the feeling of “being slammed” when volumes were high. When asked whether more errors were made during busy times, most respondents agreed that errors are more likely when it was busy. Some reasons offered for this were that you make more mistakes when you’re in a hurry or have the pressure of so much to do. Other reasons related to system capacity. Several scenarios described in Appendix 1 validated the premise that system capacity is an issue for the chaos that may lead to patient harm. The last question posed concerned which measure of volume is most sensitive. Appendix 2 lists the volume measures proposed.
During this exploratory stage a number of common themes, basic concepts, and a complex web of relationships among hospital operations were uncovered. Among these themes are:

- More mistakes occur during times of high volume. What is not known is how busy the system can become before an error occurs.
- All departments have war stories associated with spikes in the census—not just the clinical areas. (Appendix 1)
- Although overall census may be the driver, it was noted that there are other measures of volume more sensitive to system capacity. For example, the number of surgeries may not be as sensitive for predicting error as the number of add-ons. Proposed volume indicators are provided in Appendix 2.
- Inpatient care operates as a system of multiple, interrelated entities, held together by ancillary support and facility-related services. Volume increases that occur simultaneously in 2 or more of the major systems may be unknown to each other but may have a drastic effect on support services.
- Some measures of volume may be generalizable across hospitals, such as percentage of new admissions, but others are unique to the organization. The ED of one hospital that participated in this study could not accommodate more than 3 acute psychiatric patients at a time. The fourth such patient inevitably led to chaos in the ED.
- Most believe that the relationship between medical mistakes and volume is nonlinear. Patient care proceeds at a steady pace with the likelihood of making a medical mistake remaining within certain control limits. When a certain volume level is reached, the likelihood of making a medical mistake increases precipitously—the tipping point.

The data from patient volume and incident reports denoting harm to patients were used to assess the relationship between these 2 measures. As the number of areas in the hospital experiencing high volume increased, the percentage of high harm days increased. No high harm days occurred when all 5 measures were at low volume ($z < 1.5$). No day had volume $\geq 1.5$ on all measures, but on 3 days 4 measures were $z \geq 1.5$. Of those days, 2 of the 3 had weighted harm scores of $\geq 1.5$. Of the 11 days that had 3 or more high measures of high volume, 6 (54%) were also high harm days. The findings are detailed in Table 3.

### DISCUSSION

The association of patient harm with high volume is highly suggestive of a system capacity explanation. When a hospital experiences high volume in several quarters of the facility, the underlying systems (ie, lab, radiology, pharmacy, engineering, housekeeping) are pulled in multiple directions. In these circumstances caregivers move from one crisis to another solving problems associated with underperforming support. This corresponds to the chaos described in the exploratory discussions. These results suggest that there is a greater likelihood of patient harm when there is high volume in multiple locations and the need to look to system capacity for solutions.

The challenge for hospitals is that one part of the institution does not always know that another part is under siege, adversely affecting support services. To respond to these volume increases a hospital would have to provide a daily dashboard to middle management so that departments could implement strategies to take the pressure off the systems until volume subsided.

### LIMITATIONS

Data from the exploratory phase were not rigorously collected or analyzed. The discussions that ensued after empirical evidence suggest that serious incidents tend to occur during hospital surges. The quantitative approach and rigorous design were created after multiple discussions in which participants attempted to understand this phenomenon and

### Table 3

<table>
<thead>
<tr>
<th># of High-Volume Measures/day</th>
<th>Total Days</th>
<th># of High Error Days</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>265</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>197</td>
<td>27</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>42</td>
<td>16</td>
<td>38</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td>67</td>
</tr>
<tr>
<td>Total</td>
<td>515</td>
<td>49</td>
<td></td>
</tr>
</tbody>
</table>
identify solutions to keep patients safe. Fresh insights occurred when the leadership team suggested system overload as the overarching theme. More systematic data collection is recommended in subsequent research.

To further explore this relationship, a larger dataset with additional measures of volume is needed. A number of volume measures identified by operational experts were not included (Appendix 2). Furthermore, volume calculations will vary depending on what part of the hospital is measured. Replicating this study in multiple locations is needed to understand the specifications that are needed for the volume indicators. The finding that only 11 days showed 3 or more high-volume indicators suggests the possibility that, because more than half are also high harm days (6 high error days out of 11 total high volume days [54%]), there may be a relationship, but a larger pool of data is needed before results can be considered conclusive.

CONCLUSION

In 1999, the groundbreaking Institute of Medicine report birthed the new field of patient safety. Prior to its publication, few had suggested that this was a serious public concern. This report created the field of patient safety. The call to action has come from several quarters. Research has provided evidence-based practices that are likely to reduce the harm that may befall patients during the course of treatment. The 100 000 Lives Campaign and 5 Million Lives Campaign have challenged health care to reduce harm by using proven methods. Hospital leaders are charged with the responsibility to deliver these solutions reliably. Our regulatory bodies and our legislatures are contributing to the safety movement by requiring that preventive measures be put in place. Yet, in all this activity, the importance of system capacity with respect to patient safety has not been sufficiently explored. It is not known which volume indicators best measure system capacity or which methodology will appropriately assess this theory. This study has begun the analysis of the basic concept of the relationship between volume and harm to patients. The critical point at which error, or the risk for error, increases has not been clearly determined. More important, intervention strategies to prevent error as volume increases have not been adequately determined and tested. The relationship of system capacity to patient safety needs further study so that hospitals and health care systems can find ways to make hospitals safer for patients.

ACKNOWLEDGMENTS

The author would like to thank Lee Suyenaga, COO, Olympia Medical Center, Los Angeles, California; Suellyn Ellerbe, COO/CNE, Tri-City Medical Center, Oceanside, California; and countless management and staff for working to clarify the relationship between volume and patient harm.

APPENDIX 1

Sample Results of Exploratory Research

Case Study 1

The lab reported that when the census went up it took longer for the phlebotomist to make her way around the house for the morning draws. That meant that she returned to the lab later and perhaps there was an extra run of the centrifuge. The doctors who normally round at 10:00 AM came a bit early because they had so many patients in the hospital, but they did not have their lab results. So now, just when the lab is going as fast as they can to get everything done, there are 10 phone calls from the floor. More work in the same amount of time means everyone is moving faster to get everything done, thereby creating an environment ripe for medical mistakes.

Case Study 2

The clerk from Central Supply makes rounds on Wednesday. He checks the par levels of the supplies on the floor. The census spikes on Tuesday and the floor runs out of needed supplies. The nurse on the floor calls materials management who sends up the tech to deliver the supplies causing a delay in service, or worse, the supplies are not available from Central Supply and a drop shipment is necessary. Now we not only have a delay in service, a possible risk to the patient, but we have injected non-value-added cost into the system.

Case Study 3

The emergency department volume increases between 4:00 PM and 8:00 PM every day. Turnaround time for lab results increases because the emergency
medical technician or the registered nurse who are required to run the specimen to the lab find that they can’t break away. Worse, the specimen sits at the nursing station too long, the blood hemolyzes and needs to be redrawn, keeping the patient on the gurney for extra time just when you need the free bed right away.

**Case Study 4**

When a medical/surgical unit is busy, there are many transfers to make room for a female bed, an isolation room, etc. Predictably, the unit secretary misses one of the transfers and the room change is not entered into the computer. In that case, the medication goes to the wrong floor. If nurses do not have the medication, they need to complete a Pharmacy Action Notice (a PAN Slip). These are faxed to the pharmacy where a pharmacist dispenses the medication and a pharmacy technician runs it up to the floor. But, if the pharmacy is busy (which they are if the floor is busy), the pharmacist does not get around to the fax right away. Now the nurse is impatient and calls the pharmacist. With an angry nurse on the phone, the medication is dispensed immediately. Finally, life calms down in the pharmacy and the pharmacist reviews the PAN Slip. It takes him 15 minutes to determine that he’s already filled this order, or worse, he dispenses the medication again because his colleague took the call from the nurse. Now we have delays in service and additional costs.

**APPENDIX 2**

**Preliminary List of Volume Measures**

**Medical/Surgical**

- Census
- Change in census from the day before/shift before/last hour
- Number of admissions to the medical/surgical unit in a given period of time
- Number of surgeries/postoperative patients admitted in a given period of time

**Surgical Services**

- Number of surgeries
- Number of add-ons
- Number of surgeons
- Number of anesthesiologists

**Emergency Department (ED)**

- Patients seen in the ED by day
- Patients in the ED by hour of day
- ED length of stay by day/hour of day
- Left without being seen by day/hour of day
- Ambulance runs by day/hour of day
- Number of acute psych patients

**Errors**

- Number of errors
- Severity of errors
- Multiplier for severe errors
- Time of day errors occur

**REFERENCES**