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Using Computer Simulation to Study Nurse-to-Patient Ratios in an Emergency Department

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OBJECTIVE: To study the impact of nurse-to-patient ratios on patient length of stay (LOS) in computer simulations of emergency department (ED) care.
METHODS: Multiple 24-hour computer simulations of emergency care were used to evaluate the impact of different minimum nurse-to-patient ratios related to ED LOS, which is composed of wait (arrival to bed placement) and bedtime (bed placement to leave bed).
RESULTS: Increasing the number of patients per nurse resulted in increased ED LOS. Mean bedtimes in minutes were impacted by nurse-to-patient ratios.
CONCLUSIONS: In computer simulation of ED care, increasing the number of patients per nurse resulted in increasing delays in care (ie, increasing bedtime).

Emergency departments (EDs) in the United States are crowded. Crowding occurs when patient volumes exceed available resources. In overtaxed EDs, the quality of care can be diminished.[1,2] From the patient's perspective, crowding increases the entire length of stay (LOS) including the wait to be placed in an ED bed. A mismatch between patient volume and acuity and staffing is a primary cause of crowding.

Adjusting staffing levels in an ED to meet unpredictable volumes is a complex problem. Too few staff results in patient delays, and too many staff results in unnecessary cost. Many EDs use trial and error or historical-based models to adjust staffing.

Staffing and Quality

Studies report that higher hospital nurse staffing levels correlate with reduced adverse outcomes and complications.[1] Insufficient staffing not only adversely impacts the quality of care and patient safety, but it also compromises the satisfaction and safety of nursing.[3,4] Nurses often report perceptions of inadequate staffing. In 1 study, only one-third of hospital nurses reported that they had enough nurses to provide quality care and enough staff to get their work done.[4] Data also support negative outcomes related to insufficient staffing. In another study, the risk of needle-stick injury was 2 to 3 times higher for nurses in hospitals with low staffing levels or poor working climates.[5]

California is the only state to stipulate regulations requiring minimum nurse-to-patient ratios.[6] Seven states require hospitals to have staffing committees responsible for plans and staffing policy, and 5 additional states require some form of disclosure or public reporting.[6] In 2004, California mandated ratios of nurse-to-patient ratios in the ED to require 1 nurse for every 4 emergency patients and 1 nurse for every trauma patient.[7]

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Studies in California have shown that mandated staffing levels have positively impacted hospital nursing workloads, lowered patient mortality, lowered cost, shortened hospital stays, and increased nursing satisfaction.[6-10] Higher nurse staffing levels (ie, more nurses per patient) have been linked to higher market share in ED services.[11] Few studies have reported outcomes related to nurse-to-patient ratios in EDs.

The Emergency Nursing Association (ENA) does not recommend specific staffing ratios but rather provides a formula for the total number of RN full-time equivalents (FTEs) needed by a specific ED based on the number of patients seen in each billing level (evaluation and management [E&M] levels 1–6, CPT 99281-99285, 99292) and the average LOS for each billing level. The ENA does state that there must be at least 2 RNs in the ED at all times. Minimum baseline nursing staffing with administrative support has been reported to equate to 13 FTEs.[12,13] The impact of different nursing ratios on ED staff utilization, patient throughput, and cost has not been reported.

For this project, we have developed a 24-hour model of ED care to analyze the impact of various nurse-staffing models on patient wait for bed placement (ie, wait), patient time in the ED bed (ie, bedtime), staff utilization, and cost. Using computer simulation, we studied the impact of patient acuity, physician (MD) utilization, bed utilization, technicians, and patient arrival rates on ED patient LOS with varying nurse-to-patient ratios.

Methodology

The study was undertaken at an urban, academic hospital with an annual ED census of more than 100 000 in collaboration with a university. The study was approved by the hospital's institutional review board.

Methods

Using expert MD and nursing opinion, the study team designed a simple model of ED care. Inputs are reported in the Document, Supplemental Digital Content 1, http://links.lww.com/JONA/A421. The model has 6 levels of patient resource utilization matching the 6 facility E&M billing levels (CPT 99281-99285 and 99292). Resource utilization is used as a surrogate for acuity. All patients undergo arrival, triage, registration, bed placement, RN assessment, MD assessment, MD discharge, RN discharge, and bed turnover. Billing levels are used as a surrogate for patient acuity. Patients with higher billing levels (ie, higher acuity) utilize incrementally more resources, such as RN reassessment, MD reassessment, RN procedures, MD procedures, RN medications, electrocardiogram (ECG), laboratory testing, and diagnostic imaging (see Table, Supplemental Digital Content 2, http://links.lww.com/JONA/A422).

Task times were determined in a clinical study at the study institution (see Table, Supplemental Digital Content 2, http://links.lww.com/JONA/A422).[14] In the model, patients were initially assigned a bed based on their Emergency Severity Index (ESI). ESI distribution either matched that seen in the National Hospital Ambulatory Medical Care Surveys,[13] henceforth referred to as *national ED*, or the study institution, referred to as *high-acuity ED*. Once patients were placed in an ED bed, they were assigned a billing level to define their resource utilization; the ESI to billing level conversion was similar to that seen in the study institution and was adjusted to obtain the desired overall testing frequencies. Test utilization in the national ED model was similar to national levels of testing, and test utilization in the high-acuity ED were similar to that seen in the study ED.[15] Hourly nursing cost (ie, salary and benefits) was set at $35 per hour based on a national median.[16] Patient arrival rates were then varied over 24 hours in the same hourly proportions as in the study ED. Patients were assigned a primary nurse and doctor. Patient care was prioritized by acuity/billing level with the sickest being cared for the 1st. The admission rate in the model was set at the 2008 national average of 17%.[15] Baseline boarding time distributions (ie, the holding of admitted patients in the ED waiting for an inpatient bed) were arbitrarily set with an average of 37 minutes. The model was studied in an ED with 34 beds and 50 000 annual patient visits.[17] The computer simulation was based on an ED process model defined using a language known as Little-JIL[18,19] (see Document, Supplemental Digital Content 3, http://links.lww.com/JONA/A423).

The resource optimization program assigned hourly nursing and MD levels based on the number of patients in the ED the previous hour and the desired minimum staff-to-patient ratio.[18] Hourly staffing levels were then converted to 8-, 10-, or 12-hour shifts. The number of triage nurses, diagnostic imaging room, and clerical staff were set so as to not cause delays in any simulations. The nonnursing resource variables were fixed while studying the following minimum nurse-to-patient ratios: 1:2; 1:3, 1:4, and 1:5. We posited that the desired minimum nurse-to-patient ratio was achieved if that ratio was met for more than 90% of the hours simulated.

Baseline MD staffing was set at a 1:3 ratio (MD to patient). This was presumed to represent low MD utilization. A MD-to-patient ratio of 1:6 was studied to determine the impact of higher MD utilization on nurse-to-patient ratios. To study the impact of increased patient acuity (ie, resource utilization), simulations were run with the high-acuity ED where there were higher percentages of the higher billing levels. The impact of adding technicians on RN-to-patient ratios was studied using 1 technician per 6 RNs as recommended by the ENA; technicians performed ECGs and blood draws.[13] To study the impact of crowding, we simulated increases in arrival rate and boarding time without changing resources. We studied a 10% increase in arrival rates over 24 hours, as this occurs 10% of the time in an ED, as well as an increase in boarding from our baseline triangular distribution (10-25-75 minutes) to a triangular distribution using national data (10-79-245 minutes).[20] Finally, we studied the impact of bed utilization by decreasing the number of beds in the national ED model by 50% (ie, from 34 beds to 17 beds).

Two hundred simulations of 72 hours each were performed for each studied result; the 1st and last 24 hours of each simulation were discarded to minimize the impact of the beginning and end of the simulation. Two hundred simulations of a 24-hour period include approximately 27 400 virtual patients. Each simulation is independent and different because of the variations in patient arrival, resource needs and availability, and task times. Simulations are restrained by the model of care and the number of resources (eg, patients, beds, doctors, nurses, etc), much like a regular ED. Primary variables measured were LOS (arrival to discharge), wait (arrival to bed placement), bedtime (bed placement to discharge), resource utilization (time resource utilized divided by total time), and RN cost per 24 hours. Delays in care are defined as bedtime minus the average time to complete the tasks in the process of care (ie, it is a measure of the delay time between patient tasks). Sufficient simulations were run such that the 95% confidence intervals for all primary variables were within 5% of the mean.

Results

Results are reported for an ED with annual census of 50 000 patient visits (137 patients per day). Figure 1 demonstrates the impact of different RN-to-patient ratios in our national ED model. The minimal bedtime averaged over all acuities/billing levels in the national

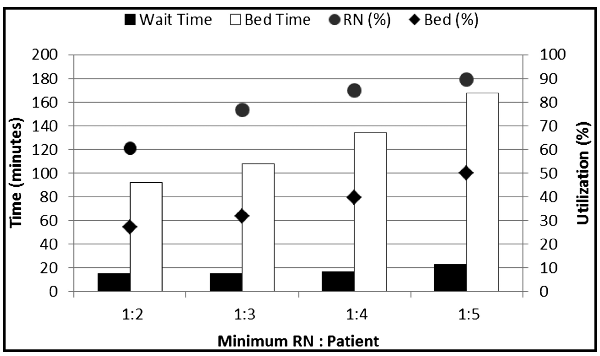

Figure 1. Impact of nurse-to-patient ratios in national ED.

ED was 78 minutes (ie, no delays). Increasing the number of patients per RN resulted in increased RN utilization, bedtime, and bed utilization. As RN utilization increases, nurses are less available for the next step in the process of care; hence, there are more delays in care or longer bedtime. Bedtime and RN utilization increase from 92 minutes and 60% with an RN-to-patient ratio of 1:2 to 168 minutes and 90% with a 1:5 ratio. As bedtime increases, so does bed utilization. The 24-hour cost of nursing in the national ED model was $3360 for 1:5, $3570 for 1:4, $3990, for 1:3, and $4970 for 1:2. In our national ED model, waits are minimal because bed utilization is less than 70%. The Table, Supplemental Digital Content 4, http://links.lww.com/JONA/A424, shows the tabular results for Figure 1.

Figure 2 shows the impact of RN-to-patient ratios in the high-acuity ED. Higher-acuity/billing patients require more resources and cause increased RN utilization and bedtime compared with the patient in the national ED model. The minimal bedtime, averaged over all acuities, was 101 minutes in the high-acuity ED (ie, no delays). In the high-acuity ED, nurse utilization is higher than in the national ED, so bedtime is greater. Bedtime and RN utilization increase from 116 minutes and 64% with an RN-to-patient ratio of 1:2 to 181 minutes and 88% with a 1:5 ratio. Bed utilization is again less than 70%, so there are no waits in the high-acuity ED model. The 24-hour cost of nursing in the high-acuity ED was $4410 for 1:5, $4480 for 1:4, $4760, for 1:3, and $6160 for 1:2. The Table, Supplemental Digital Content 4, http://links.lww.com/JONA/A424, shows the tabular results for Figure 2.

Figure 3 shows the 24-hour variation in mean bedtime by RN-to-patient ratio in the national ED. Bedtime fluctuates in a 24-hour period because of variations in arrival rate, bed occupancy, and staffing but is always shortest when there are more RNs. The Table, Supplemental Digital Content 4, http://links.lww.com/JONA/A424, shows tabular results for Figure 3.

Figure 4 shows the impact of adding technicians and separately, of decreasing MDs, in 1:3 and 1:4 RN-to-patient ratios in the national ED model. Adding technicians reduces bedtime for both ratios. With technicians, a 1:4 ratio had RN utilization and bedtime that were similar to those for the 1:3 ratio without technicians. Decreasing MDs (ie, increasing MD utilization) results in increased bedtime for each RN-to-patient ratio. The Table, Supplemental Digital Content 4, http://links.lww.com/JONA/A424, shows the tabular results for Figure 4.

Figure 5 shows the impact of crowding on 1:3 and 1:4 RN-to-patient ratios in the national ED. Crowding has a different impact on RN utilization and patient bedtime with different RN-to-patient

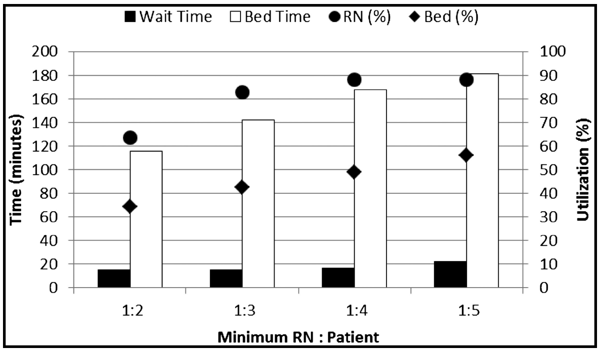

Figure 2. Impact of nurse-to-patient ratios in high-acuity ED.

ratios. Increasing patient arrival rate increased bedtime and RN utilization from 126 minutes and 83% for 1:3 RN-to patient ratio to 197 minutes and 92% for 1:4 RN-to-patient ratio. Increasing boarding time also increases bedtime and RN utilization to varying degrees, depending on the RN-to-patient ratio. The Table, Supplemental Digital Content 4, http://links.lww.com/JONA/A424, shows the tabular results for Figure 5.

Figure 6 shows the impact of RN-to-patient ratios in the national ED with a 50% bed reduction (ie, high bed utilization setting). When beds are more highly utilized, beds are less available, and new patients wait. With a 1:3 RN-to-patient ratio, a 50% reduction in beds increases bed utilization from 32% to 65%, and waiting time increases from 15 to 28 minutes. With a 1:4 RN-to-patient ratio, a 50% reduction in beds increases bed utilization from 40% to 79%, and waiting time increases from 16 minutes to 83 minutes. Interestingly, RN and MD utilization does not change with a 50% reduction in beds. The Table, Supplemental Digital Content 4, http://links.lww.com/JONA/A424, shows the tabular results for Figure 6.

Discussion

Computer simulation allowed us to estimate the impact of different minimum RN-to-patient ratios on patient LOS in an ED. This would be a very difficult

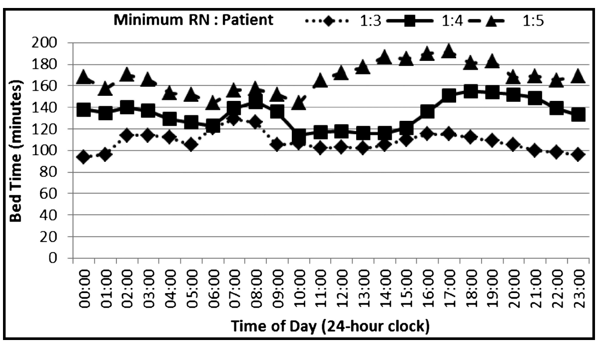

Figure 3. Impact nurse-to-patient ratios on mean bedtime over 24 hours in national ED.

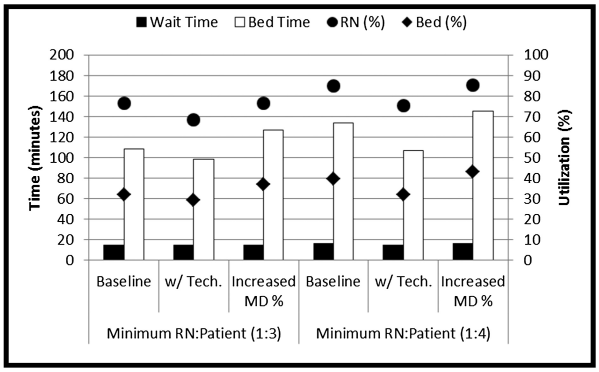

Figure 4. Impact adding technicians[a] and decreasing physicians[b] on nurse-to-patient ratios in national ED. [a]Technicians performed ECG and blood draws, and 1 technician was added for every 6 nurses. [b]The number of physicians to patients was decreased from 1 physician to 3 patients (1:3) to 1 physician to 6 patients (1:6).

clinical study to reproduce, especially trying to control for all the variables that impact patient LOS. Our model, however, is not designed to predict actual patient wait and bedtimes by RN-to-patient ratio but rather to show the qualitative impact of different RN-to-patient ratios on patient LOS, resource utilization, and staff costs in a variety of ED settings.

Our simulations demonstrate that RN-to-patient ratios can have a significant effect on patient waiting and bedtime in a model of ED care, depending on patient acuity, bed utilization, MD utilization, presence of technicians, and crowding. Using a minimum staffing level of 1 RN to 4 patients may be adequate in smaller, lower-acuity EDs, especially if there are technician support and minimal crowding. However, it may be inadequate for larger, higher-acuity EDs with regular crowding, especially if one takes into account the additional time involved in nonclinical activities and interruptions.

The ENA position statement states that "Staffing based solely on nurse-to-patient ratios or nursing hours

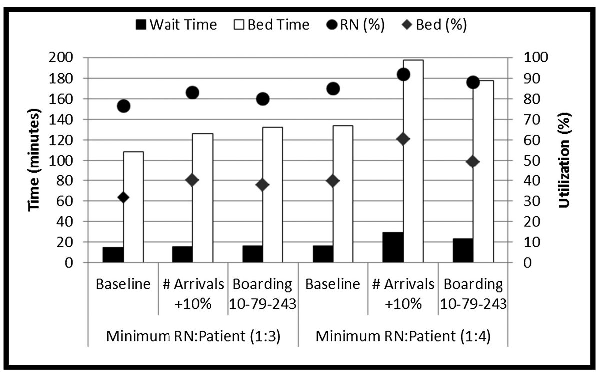

Figure 5. Impact of crowding on different nurse-to-patient ratios in national ED. Crowding was simulated by either a 10% increase in arrival rate or by increasing mean boarding time from 37 minutes to the national level of 110 minutes.

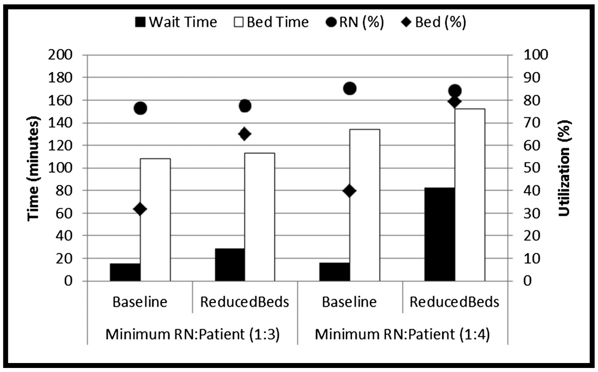

Figure 6. Impact of nurse-to-patient ratios in national ED with high bed utilization. High bed utilization (ReducedBeds) was simulated by decreasing the number of beds from 34 to 17.

per patient visit may be limited in scope and does not consider the variables that affect the consumption of nursing resources."[13] Our findings support this statement. The ENA has developed a staffing tool that calculates total nursing positions or FTEs required to staff a given ED; their guidelines utilize patient census, patient acuity, patient LOS, nursing time for interventions and activities by patient acuity, skill mix for providing patient care, and non–patient care time.[12] This tool estimates total FTEs needed. The 1st 5 components in the ENA tool are variables in our computer simulation. Our model allows us to estimate hourly staffing levels with specific RN-to-patient ratios.

In our models, RN utilization ranges between 85% and 88% with 1:4 RN-to-patient staffing. This utilization is probably too high as it results in increased bedtime and delays in care. If as much as 17% of RN time is spent on nonclinical activities, then RN utilization for clinical activities should ideally be 70% or less. In our model, this equates to an RN-to-patient ratio of 1:2 without technicians or 1:3 with technicians.

Some have opposed specific RN-to-patient ratios, as it may increase costs from hiring more nurses. This reasoning, however, does not include the cost created by delays in care and the lost revenue from patients who walk out without being seen because of long waits for bed placement.[21] Others have opined that the mandated staffing levels have had little or no impact on the quality of care, although subsequent articles have provided more evidence of a positive impact.[22]

Limitations

Results from computer models can only make predictions. The reliability of a model's predictions depends on the accuracy of the model and the validity of the inputs. Our model is relatively simple, and all inputs are derived from either national or institutional data sets (see Document, Supplemental Digital Content 1, http://links.lww.com/JONA/A421). National-based inputs include patient arrival rates, ED size, ESI distribution, test frequencies, and nurse hourly costs. Institutional-based inputs include task times, ESI to E&M billing conversion, and ESI and billing mix for high-acuity ED.

Two of the critical inputs to the model are RN and MD time by acuity/billing level. These times were not measured directly but were instead estimated by measuring task times that make up each billing level; this methodology is a similar to that used by the ENA tool for determining total FTEs in an ED.[12,13] Using this methodology, our model predicts similar MD time per patient as previously published.[23] We were unable to find published reports on emergency nurse time by facility billing level. Recently, patient LOS by facility billing level at a single institution were reported but were not separated into staff time and delays in care.[24] Table 1 lists the average RN, MD, and patient time by acuity/billing level used in the study.

Our model includes only clinical tasks; it does not include nonclinical staff time or the impact of interruptions.[25] Although a limitation of our model, we submit that it does not detract from our findings that RN-to-patient ratios will have variable impacts on the different EDs.

Table 1. *Mean Nurse and Physician Time by Facility Billing Level[a] in the National and High-Acuity ED Models*

Facility Billing Level[a]	National Distribution	High-Acuity Distribution	Nurse (minutes)	Physician (minutes)
1	2%	1%	16	14
2	15%	8%	16	17
3	40%	28%	27	16
4	25%	29%	56	26
5	17%	32%	89	32
6 (Critical care)	2%	2%	108	45
National ED time per patient			45	22
High-acuity ED time per patient			52	25

[a]Facility billing levels are a surrogate for patient acuity and correspond with E&M billing levels 99291-99295 and 99292.

Conclusion

In summary, different RN-to-patient ratios in a computer model of ED care result in different waiting and bedtimes for patients. In addition, these times are also affected by patient acuity (billing mix), MD utilization, bed utilization, the use of technicians, and degrees of crowding. Nurse executives should use innovative vehicles to add to the body of knowledge in developing staffing models that are adaptable to patient acuity, census, and volumes while maintaining safety.

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