ORIGINAL INVESTIGATION

Association of Interruptions With an Increased Risk and Severity of Medication Administration Errors

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Background: Interruptions have been implicated as a cause of clinical errors, yet, to our knowledge, no empirical studies of this relationship exist. We tested the hypothesis that interruptions during medication administration increase errors.

Methods: We performed an observational study of nurses preparing and administering medications in 6 wards at 2 major teaching hospitals in Sydney, Australia. Procedural failures and interruptions were recorded during direct observation. Clinical errors were identified by comparing observational data with patients' medication charts. A volunteer sample of 98 nurses (representing a participation rate of 82%) were observed preparing and administering 4271 medications to 720 patients over 505 hours from September 2006 through March 2008. Associations between procedural failures (10 indicators; eg, aseptic technique) and clinical errors (12 indicators; eg, wrong dose) and interruptions, and between interruptions and potential severity of failures and errors, were the main outcome measures.

Results: Each interruption was associated with a 12.1% increase in procedural failures and a 12.7% increase in clinical errors. The association between interruptions and clinical errors was independent of hospital and nurse characteristics. Interruptions occurred in 53.1% of administrations (95% confidence interval [CI], 51.6%-54.6%). Of total drug administrations, 74.4% (n=3177) had at least 1 procedural failure (95% CI, 73.1%-75.7%). Administrations with no interruptions (n=2005) had a procedural failure rate of 69.6% (n=1395; 95% CI, 67.6%-71.6%), which increased to 84.6% (n=148; 95% CI, 79.2%-89.9%) with 3 interruptions. Overall, 25.0% (n=1067; 95% CI, 23.7%-26.3%) of administrations had at least 1 clinical error. Those with no interruptions had a rate of 25.3% (n=507; 95% CI, 23.4%-27.2%), whereas those with 3 interruptions had a rate of 38.9% (n=68; 95% CI, 31.6%-46.1%). Nurse experience provided no protection against making a clinical error and was associated with higher procedural failure rates. Error severity increased with interruption frequency. Without interruption, the estimated risk of a major error was 2.3%; with 4 interruptions this risk doubled to 4.7% (95% CI, 2.9%-7.4%; $P<.001$).

Conclusion: Among nurses at 2 hospitals, the occurrence and frequency of interruptions were significantly associated with the incidence of procedural failures and clinical errors.

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THE ARGUMENT THAT INTERruptions lead to errors is persuasive. Controlled laboratory studies of task interruptions have clearly demonstrated their contribution to task inefficiency and errors.[1-3] Experimental studies suggest that interruptions produce negative impacts on memory by requiring individuals to switch attention from one task to another. Returning to a disrupted task requires completion of the interrupting task and then regaining the context of the original task.[2,4] In surveys and retrospective accounts of adverse incidents, interruptions have been implicated,[5] yet real-world evidence of the relationship between interruptions and clinical errors is scarce.[6]

Clinical environments are highly interruptive, with studies of emergency departments reporting rates of 6 to 15 interruptions per physician per hour.[7-9] Hospital ward clinicians experience lower, yet still noteworthy, rates.[9]

Interruptions have been suspected to be a potentially important contributor to hospital medication errors based largely on self-reports, surveys, and retrospective analyses of voluntary reports.[5,10,11] The incidence of medication errors is considerable, with estimates as high as 1 per patient per day in some settings.[5] The lack of multisite and comprehensive data suggests that the full magnitude of the problem is still unknown.[5,12] Although most errors do not result in patient harm, poor data about the incidence and nature of errors, particularly factors that contribute to the more se-

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rious errors, limit the development and testing of effective prevention strategies.[13]

One-third of all medication errors that cause harm to patients arise during medication administration.[14] The medication administration process is governed by standards and legal mandate. At the core of these standards are the "5 rights" (right patient, right drug, right dose, right time, and right route). Despite these being an essential part of nurses' education, medication administration errors are frequent. A study[15] of 36 US health care organizations found that 19% of medications administered were associated with some form of error.

To our knowledge, empirical evidence to substantiate the importance or impact of interruptions on medication error rates does not exist. We undertook a prospective observational study to test the hypothesis that interruptions increase the risk of medication administration errors in hospitals.

METHODS

SETTING AND SAMPLE

The study was undertaken at 2 major teaching hospitals in Sydney, Australia. Hospital A has 400 beds and hospital B, 326. They are geographically distant from each other, located approximately 40 miles apart. We undertook direct observation of 98 nurses (63 nurses across 4 wards in hospital A and 35 nurses across 2 wards at hospital B) as they prepared and administered medications to 720 adult patients.

The study wards had an average of 28 beds and included the specialty areas of geriatrics, respiratory medicine, renal/vascular medicine, orthopedics, and neurology and had both surgical and medical patients. Data collection at hospital A was conducted from September 2006 through February 2007 (340.0 hours of direct observation) and at hospital B from November 2007 through March 2008 (164.75 hours). Human research ethics approval was received from both hospitals and the University of Sydney. Both hospitals have individual patient distribution systems in which medications for patients are stored in locked bedside cabinets. Some medications, such as "drugs of addiction" (eg, opioids), are stored as ward stock in the ward medication room because they are listed as controlled substances (and are also known as "dangerous drugs") according to legislation and regulations. All injectable medications are stored and prepared in the ward medication room.

PROCEDURES

Nurses on the study wards were invited to participate during information sessions followed by a direct approach from the researchers prior to commencement of any observational sessions. At the 2 hospitals, 98 of 120 nurses participated in the study (a participation rate of 82%). We had access to details of nonparticipants through staff rosters and thus were able to establish that participants were representative of the total nurse population in terms of experience and classification (eg, enrolled endorsed nurse; registered nurse, new graduate with <1 year of experience; registered nurse with 2-4 years of experience; registered nurse with ≥ 5 years of experience; clinical nurse specialist; clinical nurse educator). Nurses were informed that one of the aims of the study was to identify errors in the administration and preparation of medications, including procedural failures and clinical errors. During the information sessions, the data collection tool was shown to the nurses. On each day of the study, researchers arrived on the study wards at the peak medication administration times during the day (7:00 AM–9:30 PM) and closely shadowed individual nurses who had provided written consent to participate. Observers were instructed in following a "serious error" protocol that allowed them to intervene if they witnessed an administration that was potentially dangerous to a patient. This occurred on 1 occasion during the training sessions and 9 times during the formal data collection periods.

A structured observational tool[16] was developed and incorporated into software on a handheld computer (a personal digital assistant [PDA]). During observation sessions, researchers recorded (1) nursing procedures related to medication administration; (2) details of the medications administered, such as medication name, dose, and route (researchers did not view the patient's medication chart during observation sessions); and (3) number of interruptions that the nurse experienced. Details of each nurse's work status (full time, part time, or on a casual basis), classification, and number of years of nursing experience were recorded at the time of obtaining written consent.

Initial pilot field observations revealed that the drug administration process is not linear. Nurses frequently move between drug preparation and administration as well as among patients during a medication round. For example, a nurse may commence the preparation of an intravenous (IV) drug and prior to its administration give the patient an oral drug and then subsequently return to the IV drug. The PDA software was thus designed to allow for this nonlinear process. The observer was able to collect information on multiple drugs via different tabs on the PDA and also in relation to multiple patients. Data items are time stamped, permitting interruptions to be linked to specific administrations and medication rounds. Interruptions were defined as situations in which a nurse ceased the preparation or administration task in order to attend to an external stimulus.

All observers (n=3, including one of us [A.W.]) were registered nurses or physicians and were trained in the use of the PDA and data definitions to gain acceptable levels of accuracy and speed of recording. Interrater reliability was calculated by 2 researchers independently observing the same nurse and then comparing agreement between captured data elements. We undertook interrater reliability tests for 16 observation sessions (7 prior to data collection and 9 sessions during the data collection phase), in which a total of 528 drug administrations were observed by 2 researchers at the same time and results compared. The κ scores[17] ranged from 0.94 to 0.96, showing very high levels of agreement among observers. Observers were required to be physically close to the study participants, and thus establishing good rapport and trust was essential. This was achieved by observers undertaking many practice sessions involving over 30 hours over several weeks with nurses prior to formal data collection so that they became comfortable with the observers' presence and accustomed to being studied. Direct observation was selected because it allowed identification of medication administration errors at higher rates than medication chart review or incident report review.[18]

CLASSIFICATION OF ERROR TYPE AND SEVERITY

Medication administration procedural failures were identified at the time of observation. The identification of clinical errors required comparison of the observational data with each patient's medication chart to determine whether the medication administered differed from that ordered. Comparisons between observational data and medication charts involved a clinical pharmacist as well as an experienced nurse, both of whom were members of the research team and independent of the hospitals being studied. Failures and errors were classified as follows:

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Procedural Failures

Failure to read medication label

Failure to check patient identification

Temporary storage of medication in unsecured environment (ie, nurses' station)

Failure to record medication administration on medication chart

Nonaseptic technique

Failure to check pulse/blood pressure before administration (when applicable)

Failure to check blood glucose level prior to administering insulin

If "dangerous drug" or IV medication:

- Failure of 2 nurses to check preparation
- Failure of 2 nurses to witness administration
- Failure of 2 nurses to check infusion pump settings (applicable for IV drugs)
- Failure of 2 nurses to sign the dangerous drug register (applicable for dangerous drugs)
- Failure of 2 nurses to sign medication chart

Clinical Errors

Wrong drug

Wrong dose

Wrong formulation

Wrong route

Wrong strength

Wrong timing: medication was administered >30 minutes before or after a meal when order specified the drug be taken with meals; or if 1 hour before or after the time ordered on the patient's medication chart.

Unordered drug administered: a patient was given a drug not listed on the medication chart. These are likely to represent drugs being administered to the wrong patient.

Extra dose administered

For Injectable Medications

Wrong solvent/diluent or additive

Wrong solvent/diluent/additive volume

Incompatible solvent/diluent/additive

Wrong infusion rate or bolus delivery time (IV medications)

Procedural failures and errors were further classified according to their potential severity on a 5-point Severity Assessment code[19] scale (**Table 1**). Two researchers rated the actual or potential severity. Disagreement was settled by consensus, and a clinical pharmacologist was consulted for additional advice when required. A panel was established to review all the most serious errors and a random selection of other errors.

Table 1. Potential Severity Assessment[a]

Severity Rating Level	Description	Categories Used in Analyses
1	Incident is likely to have little or no effect on the patient	Minor errors
2	Incident is likely to lead to an increase in level of care (eg, review, investigations, or referral to another clinician)	Minor errors
3	Incident is likely to lead to permanent reduction in bodily functioning leading to, eg, increased length of stay; surgical intervention	Major errors
4	Incident is likely to lead to a major permanent loss of function	Major errors
5	Incident is likely to lead to death	Major errors

[a] New South Wales Health Department.[19]

Table 2. Comparison of Medication Administration Errors and Interruptions at the 2 Hospital Sites[a]

Category of Drug Administrations With Interruptions and/or Errors	Drug Administrations		
	Hospital A (n=2592)	Hospital B (n=1679)	Total (n=4271)
Drug administrations with interruptions	1025 (39.5) (37.7-41.4)	1241 (73.9) (71.8-76.0)	2266 (53.1) (51.6-54.6)
Interruptions per drug administration, median	0.40 (0.38-0.41)	0.74 (0.71-0.76)	0.53 (0.51-0.54)
Drug administrations with procedural failures and/or errors	2001 (77.2) (75.6-78.8)	1425 (84.9) (83.2-86.6)	3426 (80.2) (79.0-81.4)
Drug administrations with procedural failures	1816 (70.1) (68.3-71.8)	1361 (81.1) (79.2-82.9)	3177 (74.4) (73.1-75.7)
Drug administrations with clinical errors	679 (26.2) (24.5-27.9)	388 (23.1) (21.1-25.1)	1067 (25.0) (23.7-26.3)

[a] Unless otherwise indicated, data are given as number (percentage) (95% confidence interval).

STATISTICAL ANALYSIS

Several definitions were applied in the study to facilitate the reporting of results. For single drug administrations, total numbers and proportions of procedural failures and clinical errors and interruptions were calculated with 95% confidence intervals (CIs). Generalized estimating equations (PROC GENMOD in SAS software [SAS Inc, Cary, North Carolina]) were used to control for patient repeated measures specifying the distribution as Poisson with an exchangeable working correlation. The analyses were performed with total interruptions per administration as the primary independent variable and total procedural failures and total clinical errors, respectively, as dependent variables. Our initial models tested the influence of interruptions as well as hospital, age, and sex of the patient, nurse classification, years of experience, and employment status on errors. Variables were excluded if they did not attain significance at $P < .01$. Interactions between these variables and interruptions were included in the models and were found to be nonsignificant in all cases.

We also examined the association between interruptions and procedural failures and between interruptions and clinical errors occurring in individual patients during a medication round. The rate of interruptions in a round was calculated as the mean interruptions for each patient per medication round derived by summing total interruptions and dividing by the total number of drugs administered to an individual patient during that medication round. Medication rounds were classified as being error free or containing at least 1 error or failure.

Logistic regression was then performed to obtain the risk of at least 1 failure or error occurring as a function of interruptions, using the equation $l(x) = \text{logit}\, P(x) = \alpha + \beta$ (number of interruptions), and evaluated as $P(x) = 1/[1 + e^{-l(x)}]$, where x = mean interruptions.

Among single drug administrations, the mean number of failures and errors in each administration was calculated for each severity category (Table 1), and grouped as minor (severity levels 1 and 2) or major (severity levels 3-5).

Logistic regression was used to model binary outcomes for major errors (ie, the influence of interruptions on the risk of a major error). Generalizing estimating equations were also applied to control for the possibility of intrapatient correlation effects in the binary responses but resulted in very minor changes because the intraclass correlation was not significant.

RESULTS

We observed a total of 4271 drug administrations for 720 patients: 2592 administrations for 514 patients at hospital A and 1679 for 206 patients at hospital B. The mean age of patients differed by hospital: 72.6 years (95% CI, 71.1-74.0) for hospital A and 67.5 years (95% CI, 65.0-70.0) for hospital B.

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Table 3. Compliance With Specific Medication Administration Procedures

Procedure	Administrations Complying, No.	Administrations in Which This Procedure Was Required, No.	Compliance With the Procedure, % (95% CI)
Read medication label	4115	4271	96.3 (95.8-96.9)
Checked patient's identification	1762	4271	41.3 (39.8-42.7)
Used an aseptic technique	3527	4271	82.6 (81.4-83.7)
Recorded medication administration	4083	4271	95.6 (95.0-96.2)
No temporary storage of medication prior to administration	3244	4271	76.0 (74.7-77.2)
Checked patient's pulse or blood pressure as per protocol	45	52	86.5 (77.3-95.8)
2 Nurses checked an IV administration device where control device was used	15	70	21.4 (11.8-31.0)
2 Nurses checked the preparation of a dangerous drug	317	319	99.4 (98.5-100)
2 Nurses witnessed the administration of a dangerous drug	164	319	51.4 (45.9-56.9)
2 Nurses signed the dangerous drug register	299	319	93.7 (91.1-96.4)
All of the relevant procedures complied with	1094	4271	25.6 (24.3-26.9)

Abbreviations: CI, confidence interval; IV, intravenous.

Table 4. Frequency of Clinical Errors by Type and Percentage Rated as Level 3 or 4 Severity "Major" Errors

Clinical Error	No.[a]	All Medication Administrations, % (95% CI) (n=4271)	Errors Rated as Level 3 or 4 Severity in Each Error Category, %
Wrong timing	688	16.1 (15.0-17.2)	4.1
Wrong IV administration rate	207	4.8 (4.2-5.5)	35.7
Wrong dose	112	2.6 (2.1-3.1)	24.1
Wrong volume, solvent, or diluent	88	2.1 (1.6-2.5)	13.6
Wrong formulation	24	0.6 (0.3-0.8)	4.2
Wrong additive, solvent, or diluent	21	0.5 (0.3-0.7)	23.8
Wrong route	19	0.4 (0.2-0.6)	0
Wrong drug	13	0.3 (0.1-0.5)	46.2
Wrong strength	8	0.2 (0.1-0.3)	12.5
Extra dose	7	0.2 (0-0.3)	57.1
Unordered drug (most likely representing administrations to the wrong patient)	6	0.1 (0-0.3)	50.0
Incompatible solvent/diluent/ additive	3	0.1 (0-0.1)	0
Administrations with ≥1 of the above clinical errors	1067	25.0 (23.7-26.3)	10.8

Abbreviations: CI, confidence interval; IV, intravenous.
[a] Some medication administrations had more than 1 clinical error.

Only 19.8% of administrations were free of procedural failures or clinical errors. At least 1 procedural failure occurred in 74.4% of administrations, and 25.0% had at least 1 clinical error (**Table 2**). Procedural failures and clinical errors by type are shown in **Table 3** and **Table 4**. Not checking the patient's identification against their medication chart was the most frequent procedural failure. In only 41.3% (n=1762) of administrations was the identification procedure undertaken. Wrong timing of medication administration was the most frequent clinical error (n=688 administrations), but only 4.1% were rated as being of major severity. Wrong IV administration rate was the second most frequent clinical error (n=207 administrations), with 35.7% of these errors rated as being of major severity.

Interruptions occurred in 53.1% of all administrations. Hospital B had significantly higher rates of interruptions and procedural failures than did hospital A (see Table 2 for 95% CIs).

RELATIONSHIP BETWEEN INTERRUPTIONS AND PROCEDURAL FAILURES AND CLINICAL ERRORS

Proportions of procedural failures increased with interruptions, commencing at a baseline procedural failure rate of 69.6% (95% CI, 67.6%-71.6%) for administrations with no interruptions (n=2005 administrations) to 76.7% (95% CI, 74.0%-78.9%) for those with 1 (n=1333), 78.7% (95% CI, 75.5%-81.9%) for those with 2 (n=643), 84.6% (95% CI, 79.2%-89.9%) for those with 3 (n=175), and 92.2% (95% CI, 87.3%-97.1%) for those with 4 or more interruptions (n=115). This relationship was assessed using logistic linear regression with a significant trend coefficient of 0.41 (SE, 0.08; $P<.001$). The proportion of clinical errors did not increase monotonically, as for procedural failures. However, overall, there was an increase in clinical errors with increasing interruptions (coefficient, 0.18; SE, 0.05; $P<.001$). For administrations with no interruptions, 25.3% (95% CI, 23.4%-27.2%) experienced clinical errors. Those with 1 interruption had a clinical error rate of 22.5% (95% CI, 20.3%-24.7%); those with 2, 24.4% (95% CI, 21.1%-27.7%); those with 3, 38.9% (95% CI, 31.6%-46.1%), and those with 4 or more, 30.4% (95% CI, 22.0%-38.8%).

Procedural failures were modeled in terms of a number of factors using generalized estimating equations to fit a Poisson regression. Variables found to be nonsignificant were dropped from the model (patient age [$P=.27$], sex [$P=.05$], the 6 categories of nurse classification used (enrolled endorsed nurse [$P=.36$]; registered nurse, new graduate [$P=.83$]; registered nurse with 2-4 years of experience [$P=.03$]; registered nurse with ≥5 years of experience [$P=.54$]; clinical nurse specialist [$P=.05$]; and not applicable). The final model is reported in **Table 5** and shows that every interruption was associated with an increase of 12.1% in mean procedural failures. This effect of interruptions remained, regardless of the other factors, namely, hospital, nurse employment status, and years of experience. Although these 3 factors were associated with procedural failures, they were not associated with interruptions.

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Table 5. Modeled Effect of Interruptions on Procedural Failures and Clinical Errors, Controlling for Hospital, Nurse Employment Status, and Years of Experience

	Estimate (SE)	*z* Score	*P* Value	Effect on Mean Failures, % (95% CI)
		Procedural Failures		
Intercept	0.13 (0.04)	–3.21	.001	
Interruptions	0.11 (0.01)	7.84	<.001	12.1 (8.9-15.3) higher per interruption
Hospital				
B	0.16 (0.05)	3.53	<.001	17.5 (7.4-28.4) higher than Hospital A
A	0			
Employment status of nurse	–0.36 (0.08)			
Part time/casual		–4.73	<.001	30.1 (18.9-39.8) lower than full time
Full time	0			
Nurse experience				
Years of experience	0.01 (0.05)	4.73	<.001	1.0 (0.6-1.4) higher per year of experience
		Clinical Errors		
Intercept	–1.21 (0.07)	–16.54	<.001	
Interruptions	0.12 (0.03)	3.46	<.001	12.7 (5.3-20.5) higher per interruption
Hospital				
B	–0.33 (0.10)	–3.39	<.001	28.0 (13.0-40.4) lower than Hospital A
A	0			
Employment status of nurse				
Part time/casual	0.12 (0.13)	0.96	.34	No effect
Full time	0			
Nurse experience				
Years of experience	0.00 (0.00)	–0.01	.99	No effect

Abbreviations: CI, confidence interval; SE, standard error.

Table 6. Risk of at Least 1 Procedure Failure or Clinical Error per Patient per Medication Round as a Function of Interruptions

Mean Interruptions (x), No.	Administrations, No.	Estimated Risk of Procedural Failure $P(x)=1/[1+e^{-l(x)}]$, %	Observed Procedural Failure, % (95% CI)	Estimated Risk of Clinical Error $P(x)=1/[1+e^{-l(x)}]$, %	Observed Clinical Error Rate, % (95% CI)
0	700	74.5	72.3 (69.0-75.6)	39.2	36.1 (32.5-39.7)
>0 to ≤1	632	81.4	82.1 (79.1-85.1)	43.6	43.5 (39.6-47.4)
>1 to ≤2	237	86.8	85.2 (80.7-89.7)	48.1	52.7 (46.3-59.1)
>2 to ≤3	59	90.8	100	52.5	59.3 (46.8-71.8)
>3 to ≤4	28	93.6	85.7 (72.7-98.7)	57.0	60.7 (42.6-78.8)
>4 to ≤5	10	95.7	100	61.3	70.0 (41.6-98.4)
>5 to ≤6	3	97.1	100	65.4	33.3 (0.0-86.6)

Abbreviation: CI, confidence interval.

The number of clinical errors was also positively associated with the occurrence of interruptions (Table 5). Again, nonsignificant variables were dropped from the model (patient age [$P=.73$], sex [$P=.054$], nurse classification [enrolled endorsed nurse, $P=.02$; registered nurse, new graduate, $P=.08$; registered nurse with 2-4 years of experience, $P=.24$; registered nurse with ≥5 years of experience, $P=.19$; clinical nurse specialist, $P=.08$; and not applicable]). The nonsignificant variables, nurse employment and years of experience, are also displayed in the "clinical errors" section of Table 5 to maintain consistency. Each interruption was associated with an increase of 12.7% in mean clinical errors per drug administration. "Hospital" was also associated with clinical errors, but nurse employment status and years of experience were not. The baseline estimates of mean clinical errors were 0.21 in hospital B, and 0.30 in hospital A.

There were 720 unique patients in the study. On average, each patient was observed receiving drugs in 2.3 separate medication rounds over the course of the study (ie, on a total 1671 occasions). Procedural failure and clinical error rates and mean interruptions per patient per medication round were calculated. Logistic regression showed that the risk of at least 1 failure or error per patient in a medication round increased significantly with interruptions, shown in **Table 6**, which also shows that, if there were 5 interruptions during a medication round for an individual patient, it was almost certain that a procedural failure would occur. Similarly, the risk of at least 1 clinical error occurring during a medication round to a single patient also increased with interruptions, from 39% with 0 interruptions to 61% with 5 interruptions.

SEVERITY OF DRUG ADMINISTRATION ERRORS AND THEIR RELATIONSHIP TO INTERRUPTIONS

The mean severity rating of drug administration failures and errors was 1.13. Most errors (79.3%) were rated as

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Table 7. Risk of a Major Clinical Error by Number of Interruptions for a Single Drug Administration

Interruptions (x), No.	Estimated Major Error $l(x)$	% (95% CI)[a] Estimated Risk of a Major Error $P(x)=1/[1+e^{-l(x)}]$	% (95% CI)[a] Observed Major Errors	Administrations, No. of Total
0	3.77	2.3 (1.8-2.9)	2.1 (1.5-2.8)	43 of 2005
1	3.58	2.7 (2.3-3.2)	2.8 (1.9-3.7)	37 of 1333
2	3.39	3.2 (2.6-4.1)	3.4 (2.0-4.8)	22 of 643
3	3.20	3.9 (2.8-5.4)	5.7 (2.3-9.2)	10 of 175
4	3.02	4.7 (2.9-7.4)	2.6	2 of 78
5	2.83	5.6 (3.1-10.0)	0.0	0 of 29
6	2.64	6.7 (3.2-13.4)	12.5	1 of 8

Abbreviation: CI, confidence interval.
[a]Confidence intervals were calculated only where there were sufficient data.

insignificant (severity level 1). Only 115 (2.7%) were rated as major (106 at level 3 and 9 at level 4) (Table 4). None were rated at level 5.

Of the 115 errors rated as major, all were clinical errors. The effect of interruptions on the risk of a major error was determined using logistic regression, and the outcome was $l(x) = \text{logit}\, P\,(\text{Major Error}) = 3.7679 - 0.1877 \times \text{Interruptions}$ where x = mean interruptions. When evaluated, these results show that the estimated risk of a major clinical error occurring in a single drug administration doubled from 2.3% with 0 interruptions to 4.7% with 4 interruptions (**Table 7**).

COMMENT

We found a significant dose-response relationship between interruptions and procedural failures and clinical errors in medication administration at both study hospitals. The more interruptions nurses received, the greater the number of errors. Furthermore, we found that, as interruptions increased within a single drug administration, the greater the severity of error. The risk of a patient experiencing a major clinical error doubled in the presence of 4 or more interruptions. Although interruptions to clinical work have been hypothesized[5,7,10,20-25] as a potential contributor to errors for both physicians and nurses, to our knowledge, this is the first substantial study that has demonstrated a direct association between interruptions and clinical error in hospitals. Flynn et al[26] showed that interruptions and distractions during drug dispensing in an ambulatory setting were associated with errors, most frequently incorrect drug label information (80% of errors). To date, that study has been used as the basis for recommending strategies to reduce interruptions in clinical environments.[27]

A particular strength of our study is the consistency of the findings regarding the effect of interruptions on procedural failures and clinical errors at both hospitals. Although these hospitals had different nurse profiles, which affected their baseline rates of procedural failures, the association between interruptions and procedural failures and clinical error rates at each hospital was consistent. This demonstrates that the association between interruptions and error rates was independent of the hospitals' baseline error rate and adds to the possible generalizability of the findings to other hospitals.

There are few observational studies of medication administration errors against which to compare our results. Where comparative studies are available, our rate of clinical errors is similar. For example, Haw et al,[28] in a study of 2 psychiatric wards in the United Kingdom, reported a medication administration error rate of 25.9% of 1423 administrations. This rate is very similar to ours (25.0%). Also, they applied a definition of clinical errors similar to that used in our study. An observational study[29] in a surgical ward of a hospital in the United Kingdom reported a clinical error rate of 7% in 1344 administrations but excluded timing errors. Removal of timing errors from our study would have yielded a clinical error rate of 11.9%. A study[15] of 3316 administrations across 36 US hospitals reported a clinical error rate of 19%. That study applied fewer error categories and measured interrater reliability on test cases before data collection but not during the study, which may explain their lower rate.

Failure to check a patient's identification significantly contributed to our high procedural failure rate. However, Franklin et al[29] found that nurses checked the identification of patients prior to drug administration in only 17.4% of 1344 administrations, a considerably lower rate than the 41% observed in our study.

A recent review[30] identified 21 studies that included measurement of interruptions to nurses' work, none of which evaluated the association between interruptions and medication errors. These studies focused on counting interruptions, rarely reporting a denominator of total tasks (interrupted and not interrupted). Two studies provide some indication that our high rate of interruptions (53%) during medication tasks is consistent with other hospital populations. Both found that of all interruptions to nurses' work, the highest proportion occurred during medication tasks: 24% of all interruptions in an Australian study of 52 nurses[31] and 30% in a Swedish study of 6 nurses.[32] An observational study[33] of 151 nurses in the United States found that there was a risk of an interruption or distraction on each medication round.

The converging evidence of the high rate of interruptions occurring during medication preparation and administration adds impetus to the need to develop and implement strategies to improve communication practices and to reduce unnecessary interruptions within ward envi-

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ronments. While it is clear that some interruptions are central to providing safe care, there is a need to better understand the reasons for such high interruption rates. A study[34] of over 5325 interruptions to nurses in 4 units in a Canadian pediatric hospital revealed that the most frequent sources of interruption were from the external environment (eg, monitor alarms), accounting for 37% of interruptions, followed by other nurses (25%), patients (9%), family members (8%), and physicians (5%). Only 11% of interruptions were judged to have a positive outcome.

Simple strategies, such as providing easy access to core information resources (eg, using whiteboards), can be effective in reducing interruptions.[25] The use of interruption vests, which have written on them "Do not interrupt medication round in progress," or something similar, is another strategy.[35] Recent reports of hospitals in the United States[36] introducing such vests have been published, but, to our knowledge, there has been no robust published evidence of their effectiveness in the scientific literature. While new information technologies, such as electronic medication management systems, show promise in reducing medication errors, they are also a potential new source of interruption. Collins et al[37] showed that when such a system was used during ward rounds, system users were interrupted and were required to interrupt others in order to use the system effectively. However, it is also possible that, if well designed, system features could reduce some of the negative effects of interruptions and support memory recall of interrupted tasks.[4]

Future research is needed both to better understand why interruptions occur and to develop strategies[6] that allow staff to make judgments about when it is safe to interrupt, and how to manage interruptions generated by others, in essence making the environment "interrupt resilient."[6,38] Some clinical tasks are more likely to be interrupted than others.[31] Possible reasons for this may be perceived "interruptability" of individuals[39] during some tasks, which may also coincide with activities in which clinicians are highly visible and physically easily accessible, such as at a patient's bedside. Thus, solutions to the high rate of interruptions may also lie in reexamination of the ways in which physical spaces in clinical areas are configured, as well as redesign of work practices. Simulating clinical situations in which a variety of interruptions to the prescribing and administering of medicines need to be dealt with, and performance can be measured, may be a useful educational approach.

We did not observe nurses during the night or at weekends, and thus the applicability of the results for work at these times is unknown. It is possible that nurses changed their behaviors when observed because they were generally aware that they were being observed to identify problems in the preparation and administration of medicines. The effect of this possible bias would be to lead to an underestimation of the error rates. However, the length of the study, which involved researchers being on the wards for many months, reduces the likelihood of sustained behavior change by nurses on busy hospital wards. Furthermore, observational studies of clinicians at work have suggested that the extent of behavior change is minimal.[40-42]

Interruptions, while identified as a consistent and independent source of error at our sites, are clearly only 1 contributor to errors. We demonstrated a mean baseline clinical error rate of 0.3 for drug administrations in which no interruptions occurred. We controlled for nurses' experience and work status and surprisingly found that nurse experience did not reduce the risk of making a clinical error, and status also had no impact. These results suggest that a range of external, rather than nurse-specific, factors may be important contributors to clinical error production on hospital wards and should be the focus of intervention efforts. Such external, contextual factors may have an equal impact on the safety of clinical work for physicians.

Part-time and less experienced nurses had lower rates of procedural failures. We found the most frequent procedural failure was not checking the patient's identification prior to drug administration.[16] Full-time, experienced nurses may believe that they can easily visibly identify patients and thus a formal identification process is not necessary. However, recognizing a patient does not ensure that you have the correct medication chart. Franklin et al[29] reported that the introduction of bar-coding for medication administration increased patient identification procedural compliance from 17.4% to 82.4%.

Our data confirm conclusions from a review published recently by the US Agency for Healthcare Research and Quality that the rate of medication administration errors is "truly staggering."[5(p52)] A priority is to build the very limited evidence on which to base interventions.[5] Our results elevate the importance of interruptions as a contributor to medication errors in hospitals and provide a direction for prevention strategies and further research.

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INVITED COMMENTARY

Giving Medication Administration the Respect It Is Due

Over the past decade, the health care industry has directed an increasing amount of attention to the problem of patient safety errors. A major area of focus has been medication errors, which are among the most common and costly of clinical errors in US hospitals. Conservatively, 450 000 medication errors occur every year, and annual hospital costs due to errors are estimated at $3.5 to $29 billion.[1-6]

The process of providing a new medication to a hospital patient is complex; 50 to 100 steps occur from the

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