Educational Targets to Reduce Medication Errors by General Surgery Residents

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OBJECTIVE: Hospitalized patients are exposed to more than 1 medication error per day, but there are limited data concerning the factors associated with medication order errors made by general surgery residents. The objective of this study was to identify patterns in medication order errors amongst general surgery residents, which may provide educational targets to reduce medication errors by this population of providers.

DESIGN: This study used a retrospective cohort design to review inpatient medication orders placed via a computerized physician order entry system by general surgery residents at a single academic medical center from July 2011 to February 2018.

SETTING: A single large academic medical center located in the Midwest, United States.

PARTICIPANTS: General surgery residents completing residency between July 2011 and February 2018 and their respective inpatient medication orders.

RESULTS: Of 571,811 included medication orders placed by 169 unique general surgery residents, 4.2% (n = 24,177) triggered pharmacist intervention, and 11 (0.001%) resulted in significant near-miss events. Of orders requiring pharmacist intervention, most were either duplicate therapies (n = 8703, 36.1%) or errors in renal dosing (n = 7576, 31.3%). Error rates were higher within pharmaceutical classes ordered less frequently, with the notable exception of antimicrobials and anticoagulants, which accounted for 20.1% (n = 5280) and 13.5% (n = 3270) of all order errors, respectively. In a multivariable model, errors were more likely to occur in the intensive care unit versus other units (OR = 1.21, 95%CI = 1.14-1.29) and in August versus other months (OR = 1.09, 95%CI = 1.01-1.17), but were independent of other resident and order characteristics.

CONCLUSIONS: This study identified that resident medication order errors are common and are associated with specific therapeutic classes, the beginning of academic years, and intensive care unit patients. These findings represent potential targets for educational interventions and highlight the role of interdisciplinary teams in providing quality surgical care. (J Surg Ed 76:1612−1621. © 2019 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: residency, education, errors, inter-professional, quality

COMPETENCIES: Patient Care, Medical Knowledge, Practice-Based Learning and Improvement, Systems-Based Practice

INTRODUCTION

For decades, the National Academy of Medicine has placed emphasis on identifying mechanisms to reduce medical errors, which include medication errors.[1,2]

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Despite attention paid to the issue, medication errors and adverse drug events are responsible for hundreds of thousands of emergency room visits annually.[3] Medication errors are also estimated to contribute to over 100,000 hospitalizations each year, and hospitalized patients are exposed to an average of more than 1 potential medication error per day.[2,3]

Residents are integral members of surgical teams and directly influence patient outcomes.[4] Many studies have been conducted that assess the factors associated with surgical resident performance,[5-12] but in addition to work done during surgery, surgical residents also routinely provide medication management for inpatients in the perioperative period. Despite this, the literature exploring factors associated with resident medication errors is limited almost exclusively to samples of residents in medical, rather than surgical, specialties.[13-18] The few studies that do include surgery residents often combine their medication orders with those of other specialties, and most were conducted before the passage of Health Information Technology for Economic and Clinical Health Act of 2009 and the subsequent widespread adoption of computerized physician order entry and electronic medical record (EMR) platforms.[19-22]

As such, despite the significant attention paid to medication errors, little is known about either the pattern of common errors or factors associated with their commission by surgery residents. In accordance with National Academy of Medicine priorities, this study aimed to identify potential targets for interventions that could improve both general surgery resident performance and patient safety by reducing medication errors. To address this aim, we describe associations between resident characteristics, medication order characteristics, and rates of errors in medication orders in a large sample of general surgery residents at a tertiary care academic center. The primary aim was to define the rate of medication order errors overall and by therapeutic class. Secondary investigations included assessment of the association of medication order errors with environmental characteristics (month of year, time of day), patient location (ward, intensive care unit [ICU]), and characteristics of the ordering provider (preliminary versus categorical, time taken away from clinical training for professional development, and postgraduate year [PGY]).

METHODS

This was a retrospective cohort study of all inpatient medication orders placed by general surgery residents at a large academic medical center. Resident level inclusion criteria were general surgery residents who had placed at least 500 total orders between July 2011 and February 2018. Resident level exclusion criteria included residents in designated preliminary internship years (urology, orthopedic surgery, and otolaryngologic surgery at our institution), and residents in integrated training programs (cardiothoracic surgery, plastic surgery, and vascular surgery at our institution). Order level exclusion criteria included individually customized medication orders, orders allowing inpatient use of home medications not on hospital formulary, orders for medications entered retroactively after use in cardiac or pulmonary arrest events, and orders used to create nursing events to verify presence and location of medication patches. This study was approved by the Institutional Review Board prior to initiation of the work.

The primary outcome was medication order entry errors, as determined by real-time pharmacist review of orders placed via a computerized physician order entry system. Our institution has used an electronic health record system for both electronic medication order placement as well as inpatient medication order review since 2001 (Epic Systems Corp., Verona, Wisconsin). Pharmacists use an embedded module for pharmacy interventions, documentation, and communication (iVent, Epic Systems Corp., Verona, Wisconsin). As part of their normal workflow, pharmacists manually verify all medication orders, review charts to assess for potential order errors, and communicate potential errors with the care team from within this platform. These reviewed inpatient medication orders can then be queried for order characteristics, including a pharmacist-identified error associated with the order. All iVent communications are categorized by pharmacists, and 5 categories are associated exclusively with communication about suspected medication errors. For our analysis, we defined a medication order error as an order that was associated with one of these 5 iVent categories: Allergy Detection/Caution, Drug Interaction, Duplicate Therapy, Order Needing Clarification, Renal Dose Monitoring/Adjustment Required. A sixth iVent category, Adverse Event/Safety Event Reporting System, is used when a pharmacist suspects a significant adverse event, ranging from a near miss to a patient death, may be associated with a medication regardless of whether there was an issue with the actual medication order. We report this iVent category separately, but because the category is used to communicate events that are not associated with ordering errors specifically, we did not include orders in this category as part of our definition of a medication order error. Detailed descriptions of the categories and examples of medication order errors appear in Appendix Table. It is important to note that the errors reported are in the orders, not in the delivery of medications.

For each medication order, we queried the ordering provider, the location of the order (ICU, step-down unit, postanesthesia care unit, inpatient ward, or other units), the order date, the order time (coded as a continuous variable and dichotomized as day or night depending on if the order was placed between 6:00 am and 5:59 pm or

6:00 pm and 5:59 am, respectively), the order's therapeutic class, and whether the order was associated with an error. This query was combined with a personnel database from the general surgery residency program using employee identification numbers as a linking variable. Each order was then associated with resident program designation (preliminary or categorical), training level (PGY1, 2, or 3-5), and interruption of training for dedicated professional development time (had taken at least 1 professional development year, had not yet but eventually took at least 1 professional development year, or never took any professional development years) associated with the resident at the time they placed the order.

Statistical Analysis

Characteristics of all medication orders and those associated with pharmacist-identified order errors were summarized with counts and percentages. The association amongst the order characteristics (location, month, placement during the day or night shift, and therapeutic class), order-associated resident characteristics (program designation, training level, and research status), and the probability of having an error was assessed with multivariable regression modeling. As there were multiple orders per provider, cluster-robust standard errors were generated using the *multiwayvcov* package in R in order to accommodate the order clustering within provider.[23] A significance level of 0.05 was assumed and all analyses were conducted with R statistical software (version 3.4.1, release date 6/2017, https://cran.r-project.org/).

RESULTS

Between July 1, 2011 and February 12, 2018, 174 unique general surgery residents placed a total of 574,132 medication orders. Five residents (2.9%) placed fewer than 500 total orders leaving 571,811 medication orders that met inclusion criteria (99.6% of total population of orders; Table 1). The median total number of medication orders placed per resident was 2744 (IQR = 1559-4610) with a range of 13,095. Per year, residents placed a median of 549 medication orders (IQR = 311-922). The majority of orders were placed by PGY1 residents (n = 275,018, 48%), which includes up to 9 additional nondesignated preliminary residents per year not present in more senior classes. Alternatively, PGY3's placed the most orders per resident (mean = 5882, SD = 3061), followed by PGY2's (mean = 5450, SD = 2744), PGY4's (mean = 5390, SD = 3541), PGY1's (mean = 4512, SD = 2525), and PGY5's (mean = 4247, SD = 3497). Orders peaked

TABLE 1. Description of Select Unadjusted Characteristics of Medication Orders Placed by General Surgery Residents

	Total Orders	Orders Associated With an Error
	571811 (100%)	24177 (4.2%)
Resident postgraduate year (PGY), n (%)		
PGY1	275018 (48.1)	11072 (45.8)
PGY2	136123 (23.8)	5904 (24.4)
PGY3-5	160670 (28.1)	7201 (29.8)
Resident designation, n (%)		
Preliminary	159289 (27.9)	6751 (27.9)
Categorical	412522 (72.1)	17426 (72.1)
Order unit, n (%)		
ICU	41480 (7.3)	2287 (9.5)
Inpatient floor	469217 (82.1)	19273 (79.7)
PACU	20584 (3.6)	870 (3.6)
Stepdown unit	34453 (6.0)	1509 (6.2)
Other	6077 (1.1)	238 (1.0)
Order month, n (%)		
July	54862 (9.6)	2359 (9.8)
August	53331 (9.3)	2461 (10.2)
Other months	463618 (81.1)	19357 (80.1)
Order time, n (%)		
Day (6:00 am-5:59 pm)	377384 (66.0)	16330 (67.5)
Night (6:00 pm-5:59 am)	194427 (34.0)	7847 (32.5)
Order relation to professional development (PD) year, n (%)		
Order placed before PD year taken	83015 (14.5)	3162 (13.1)
Order placed after PD year taken	26708 (4.7)	1191 (4.9)
Ordering provider did not take PD Time	462088 (80.8)	19824 (82.0)

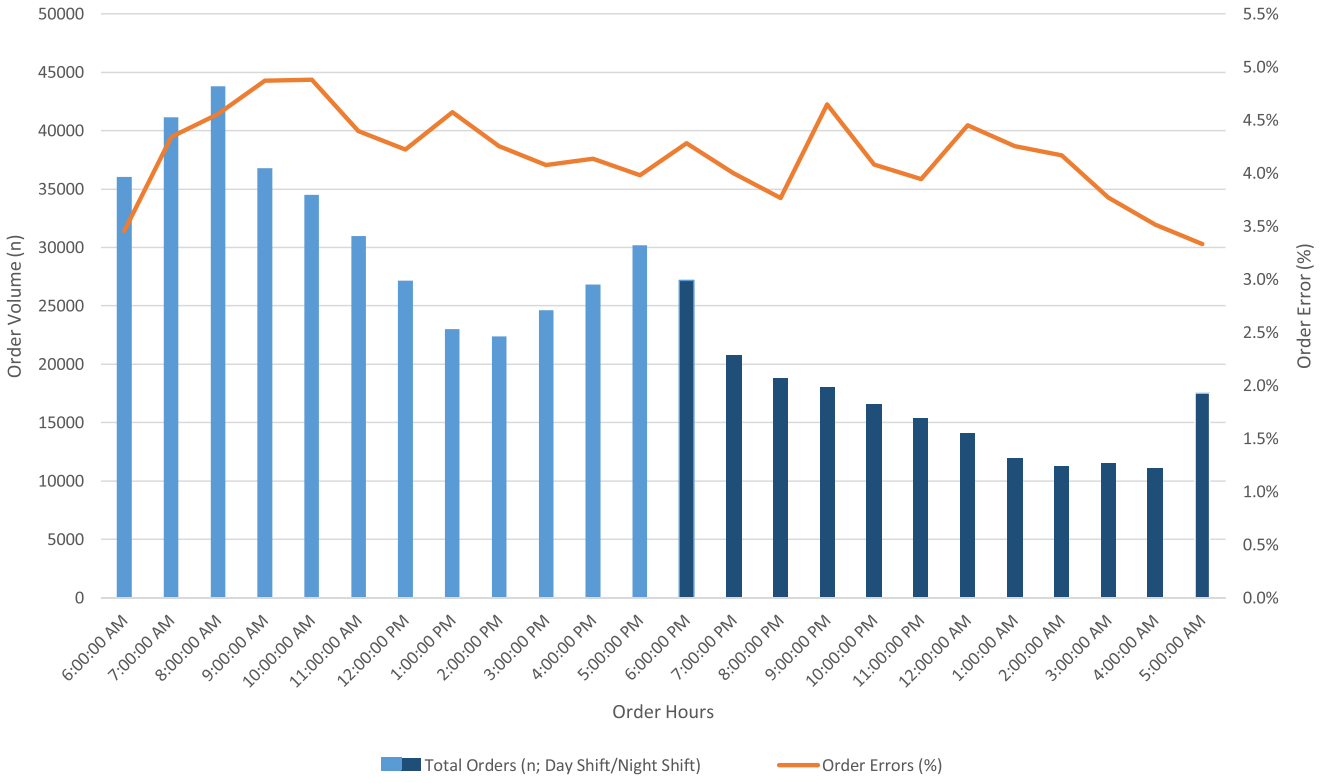

FIGURE 1. Patterns in Volume of Total Orders and Order Error Rates Stratified by Hour of the Day.

during the morning hours (Fig. 1), and 66.0% were placed during day shifts (n = 377,384). Classes of medications most commonly prescribed were electrolytes and nutrition (26.2%), analgesics and anesthetics (20.8%), and gastrointestinal medications (13.1%; Table 2), which remained consistent across PGY.

In total, 4.2% (n = 24,177) of orders triggered pharmacist intervention via the iVent system and were subsequently classified as medication order errors. An additional 11 (0.001%) were categorized by pharmacists as Adverse Event/ Safety Event Reporting System, or a significant near-miss event, but not considered medication order errors. Of orders requiring pharmacist intervention, most were either Duplicate Therapies (n = 8703, 36.1%), Errors in Renal Dosing (n = 7576, 31.3%), and Orders Needing Clarification (n=5977, 24.7%) while fewer were due to Allergy Cautions (n = 1128, 4.7%) and Drug Interactions (n = 788, 3.3%). The classes of medications associated with the highest rates of errors were colony stimulating factors (12.6%) antimicrobials (11.8%), anticoagulants (9.3%), biologics (8.6%), and antidotes (6.1%). In general, the higher rates of errors occurred for medications that were infrequently prescribed, with the exception of antimicrobials and anticoagulants. However, the medication classes associated with the largest absolute number of errors occurred in the more commonly prescribed classes of medications. Specifically, of all order errors, 4928 (20.3%) were from analgesics and anesthetics, 4856 (20.1%) were from antimicrobials, and 3270 (13.5%) were from anticoagulants.

In unadjusted comparisons, order error rates were slightly higher in the PGY3-5 years, in the ICU, amongst less often prescribed medication classes, amongst orders placed after a professional-development year had been taken, during the day, and in the summer months where August had the highest rate of errors (Fig. 2). In the multivariable model, which adjusted for multiple order and resident characteristics, order month and order unit location were associated with medication order errors (Table 3). Specifically, orders placed in July/August versus other months were significantly more likely to be associated with an error than those placed in other months (OR = 1.07, 95%CI = 1.01-1.14). This association was driven by orders placed in August, during which error rates peaked (aOR = 1.09; 95% CI = 1.01-1.18). Additionally, orders placed in the ICU were significantly more likely to be associated with an error compared with those placed in any other unit (OR = 1.21, 95%CI = 1.14-1.29). This included ICU versus general floor units (aOR = 1.19; 95% CI = 1.10-1.29), versus step-down units (aOR = 1.26, 95%CI = 1.14-1.39), versus PACUs (aOR = 1.43, 95%CI = 1.26-1.61), and versus other units (aOR = 1.63, 95%CI = 1.32-2.02). Order time of day and resident program designation, PGY, and professional development time were not significantly associated with error rates in the multivariable model.

TABLE 2. Volume of Total Orders and Order Errors as well as Rates of Order Errors Stratified by Medication Therapeutic Class

	Total Orders	Orders Associated with an Error	Medication Order Error Rate (%)
	571811	24177	
Analgesics and Anesthetics	118682 (20.8)	4928 (20.4)	4.2
Antiarthritics	3001 (0.5)	253 (1.0)	8.4
Antiasthmatics	6723 (1.2)	243 (1.0)	3.6
Anticoagulants	35211 (6.2)	3270 (13.5)	9.3
Antidotes	445 (0.1)	27 (0.1)	6.1
Antihyperglycemics	12094 (2.1)	484 (2.0)	4.0
Antihistamines	15372 (2.7)	290 (1.2)	1.9
Antimicrobials	41172 (7.2)	4856 (20.1)	11.9
Antineoplastics	230 (0.0)	10 (0.0)	4.3
Anti-Parkinson Drugs	484 (0.1)	17 (0.1)	3.5
Antiplatelets	3029 (0.5)	53 (0.2)	1.7
Autonomic Drugs	4769 (0.8)	240 (1.0)	5.0
Biologics	915 (0.2)	79 (0.3)	8.6
Cardiovascular Drugs	26433 (4.6)	1258 (5.2)	4.8
CNS Drugs	5589 (1.0)	368 (1.5)	6.6
Colony Stimulating Factors	453 (0.1)	57 (0.2)	12.6
Diagnostic Preparations	3136 (0.5)	15 (0.1)	0.5
Diuretics	9098 (1.6)	153 (0.6)	1.7
Electrolytes and Nutrition	149542 (26.2)	2684 (11.1)	1.8
ENT Delivered Drugs	2068 (0.4)	48 (0.2)	2.3
Gastrointestinal Drugs	74666 (13.1)	2697 (11.2)	3.6
Hormones	10255 (1.8)	414 (1.7)	4.0
Immunosupressants	8558 (1.5)	329 (1.4)	3.8
Muscle Relaxants	1499 (0.3)	69 (0.3)	4.6
Other/Uncategorized	11069 (1.9)	417 (1.7)	3.7
Psychotherapeutic Drugs	13875 (2.4)	487 (2.0)	3.5
Sedatives and Hypnotics	5406 (0.9)	85 (0.4)	1.6
Skin Preps	3084 (0.5)	66 (0.3)	2.1
Vitamins	4953 (0.9)	280 (1.2)	5.7

Abbreviations: CNS, central nervous system; ENT, ear-nose-throat administered drugs
*Blue = most common orders; Yellow = most common order errors; Red = highest order error rates.

DISCUSSION

In this study of medication orders over 7 years at 1 large academic medical center, we found that 4.2% of all medication orders placed by general surgery residents contained pharmacist-identified errors. The most common types of errors were duplicate therapies and failure to adjust dosing for renal impairment. Order errors occurred more frequently in therapeutic classes that were less frequently ordered, with the notable exceptions of antimicrobials and anticoagulants. In adjusted models, the rate of medication order errors also varied by month of year and unit location. Specifically, the highest rate of order errors occurred during the month of August and declined throughout the academic year. The highest order error rates occurred in the ICU.

Many studies aim to describe the factors that influence the performance of surgical residents, but most report outcome metrics such as residents' surgical skills or service-wide aggregated quality measures.[5-12] These studies rarely describe the types of pre- or postoperative medication management errors made by surgery residents. Given the volume of patients whose medications are exclusively ordered by surgical residents, understanding details about errors is critically important in designing interventions to reduce them.

In addressing this gap in the literature, this study's large sample size of residents and medication orders are strengths. Our data highlight that the influence of surgery residents on their patients extends beyond the operating room to the thousands of medication orders they place. While many studies have explored factors that may influence residents' surgical performance,[24-26] this study is one

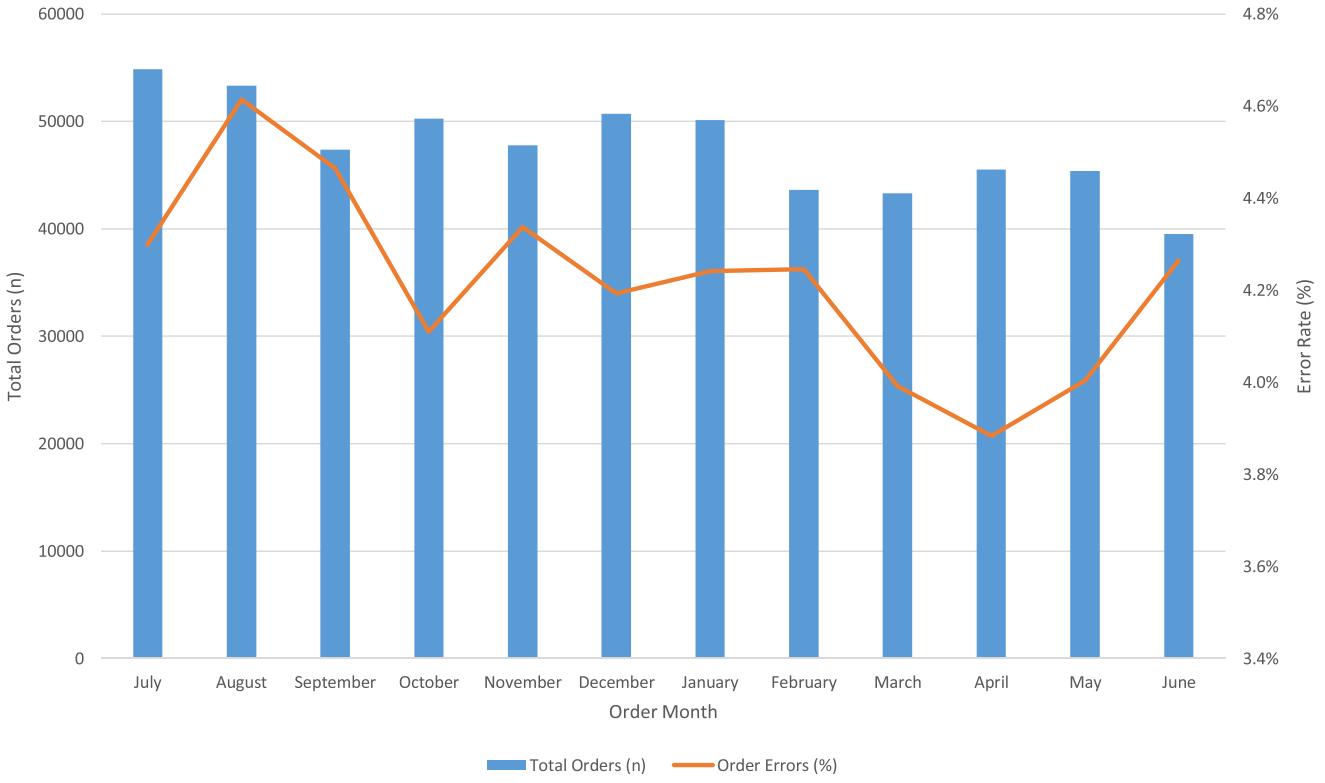

FIGURE 2. Patterns in Volume of Total Orders and Order Error Rates Stratified by Month of the Year.

of the few to document factors specifically associated with medication order errors. Our focus on medication order errors is especially important as evidence suggests a majority of medication errors manifest in the ordering phase, as opposed to the dispensing or administration phases, and that interventions at the ordering phase can reduce harms that reach patients.[27-29] This study is also one of the few large explorations of medication errors amongst residents in any specialty since the widespread adoption of EMRs.[18,20,30] Our study suggests that ordering errors still occur despite the use of EMRs, and that patterns can be used to identify areas for focused education or targeted surveillance. However, our study also demonstrated that very few ordering errors reached patients, providing additional evidence of how technologic systems[31-33] and interdisciplinary teams[34] protect patients from ordering errors. Increased utilization of pharmacists on collaborative care teams, as recommended by the American College of Clinical Pharmacology,[35] can improve patient safety and satisfaction[36] while increasing the team's medical knowledge.[37,38] In this way, pharmacists can be integral to patient safety, identifying areas for improvement in medication management, and actually being a part of any education interventions.

There is evidence that medication errors are more likely to occur when completing unfamiliar tasks,[39] which may explain why medications that were less often prescribed were associated with higher order error rates. Within this study, colony stimulating factors, which made up only 0.2% of the orders placed, had a 12.6% order error rate. However, the plurality of order errors were still related to the most commonly prescribed medications, especially antimicrobials. Of note, at our institution, vancomycin dosing is often managed by a pharmacist service that adjusts dose based on serum levels and renal function, so the order error rate within the antimicrobial drug class is largely reflective of errors made ordering antimicrobials with a relatively high therapeutic index.

These findings also highlight the need to be aware of both the relative and absolute frequencies of errors when targeting interventions to reduce them. Quality improvement should target ordering habits regarding medications that are ordered in both high volumes and associated with high error rates or focus resources on improving resident familiarity with concrete ordering tasks that can be applied to multiple classes of medication. Based on our results, efforts could focus on antimicrobials, anticoagulants, and dose-adjusting medications for renal impairment. Because results were derived from the EMR, it is also possible to select specific residents with the highest rates of order errors for additional education, further targeting quality improvement efforts.

Multiple studies show medical errors,[40-42] including medication errors,[43] are common amongst ICU patients. Our results suggest that surgery residents may

TABLE 3. Multivariable Model For the Association Between Resident And Order Characteristics And Odds Of A Medication Order Error*

Variable		OR	95% CI	p
Resident postgraduate year (PGY)				
	PGY1 (ref)	1.00	-	
	PGY2	0.96	0.89, 1.04	0.303
	PGY3-5	0.99	0.90, 1.09	0.893
Resident designation				
	Categorical (ref)	1.00	-	
	Preliminary	0.95	0.86, 1.05	0.335
Order month				
	Other months (ref)	1.00	-	
	August	1.09	1.01, 1.17	0.028
Order unit				
	ICU (ref)	1.00	-	
	Inpatient floor	1.21	1.12, 1.31	<0.001
	Stepdown	1.29	1.16, 1.42	<0.001
	PACU	1.45	1.28, 1.65	<0.001
	Other	1.67	1.35, 2.05	<0.001
Order time				
	Day (6:00 AM-5:59 PM)	1.00	-	
	Night (6:00 PM-5:59 AM)	1.03	0.97,1.09	0.408
Order relation to professional development (PD) year				
	Order after PD time	1.00	-	
	Order before PD time	1.08	0.93, 1.25	0.300
	Order not associated with PD time	0.97	0.89,1.08	0.552

*Model also adjusted for therapeutic class.

contribute to the medical errors that occur in ICU settings. Previous interventions have shown that the presence of pharmacists in the ICU,[44] as well as improved computerized clinical decision support,[45] can reduce medication errors in this setting. The critical care units at our institution follow the multiprofessional team rounding model, and while increased vigilance by pharmacists on rounds may account for some increased detection of medication errors, education might also target management of the critically-ill patient.

Our finding that medication order error rates peak in August adds to the debate about the effects of annual house staff turnover on outcomes. For example, in one of the largest studies on the topic, Philips and Barker[30] found evidence of a "July Effect," noting that fatal medication errors increased by 10% in July in US counties with teaching hospitals. A separate systematic review also concluded that end-of-year staff turnover decreases care efficiency and can impact outcomes.[46] Alternatively, there are multiple studies from various surgical disciplines, including trauma,[10] cardiothoracic,[9] spine,[47] and surgical oncology,[48] that show little evidence of worse outcomes at the beginning of academic years, though these studies do not specifically report rates of medication errors or medication order errors that may have adverse effects that do not manifest in mortality. Our finding that medication order errors were elevated at the beginning of academic years may be due to residents' unfamiliarity with new formularies or a new EMR system. Additionally, it is notable that the downtrend in errors throughout the academic year reverses at the end of the year in May and June. This finding may identify another target for education. The conclusion of the academic year often is another transition to increased autonomy and our results support this should also be an area of focus in designing interventions to reduce medication order errors. Although autonomy is integral to resident learning, more gradually removing supervision may be key to avoiding patient harm.

Our multivariable analysis also showed that neither taking time for professional development, nor program designation (preliminary or categorical), were related to medication order errors. Protected professional development time has been shown to be formative for general surgery residents,[49,50] and our findings are encouraging that time away from a clinical schedule does not appear to negatively affect this aspect of care. Similarly, career outcomes of general surgery residents completing preliminary years are ultimately similar to those in categorical positions,[51,52] so it is unsurprising no difference was found between the 2 designations at our institution.

Our study has several limitations. First, it was retrospective and conducted at a single institution, which may limit generalizability. However, our findings are similar to smaller studies published prior to adoption of the EMR,[53] and our large sample attends to some of these concerns. Second, we were only able to report medication order

errors by predefined categories, some of which may be less clinically significant than others, which may not be complete. As such, the absolute frequencies of each type of order error should be interpreted with caution, though this limitation is unlikely to impact the relative frequency of aggregated order error rates across time, order location, or resident characteristics. Third, only order errors detected by pharmacists were analyzed, so results may have been impacted by pharmacist staffing levels or experience. While this is a limitation, real-time pharmacist surveillance of medication errors is one of many methods used to study medication error rates in inpatient settings.[54] Fourth, while our results are patterns in medication order errors, not patterns in harm from medication errors, the near misses described usually track with adverse drug events and are therefore regularly used as surrogate measures.[55] Finally, this study reports patterns in medication order errors but did not assess a specific intervention to reduce the errors rates, which should be the subject of future work.

CONCLUSION

We found errors occur in 4.2% of all inpatient medication orders placed by general surgery residents at a large academic medical center. Furthermore, we identified that medication order error rates were higher earlier in the year, in the ICU, and amongst less-often prescribed medications, but were not associated with factors such as program designation or professional development time. While these results are from a single center, they are derived from a large sample of residents and orders and could inform administrators about potential targets that may warrant research and intervention. Finally, these results highlight the importance of interprofessional collaboration between pharmacy and surgery teams, both of whom may be involved in crafting the interventions to address order errors.

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APPENDIX TABLE. DEFINITIONS OF IVENT CATEGORIES

Category	Definition	Example Where the iVent Category Would be Used
Allergy detected/ Allergy caution	Electronic medical record identifies a potential drug allergy that is reviewed by the pharmacist.	Resident ordered cephalexin for a patient despite a documented allergy (e.g. the resident overrode the warning in the electronic medical record).
Drug interaction	Pharmacist recognizes an actual or potential drug interaction.	Resident orders voriconazole for a patient taking sirolimus.
Duplicate therapy	Epic identifies a therapeutic duplication of drug therapy during order processing or a pharmacist detects duplication on profile review.	Resident orders polyethylene glycol when an identical order (same dose and frequency) already exists, or resident orders polyethylene glycol when lactulose has already been ordered.
Order requiring clarification	Pharmacist receives a drug order that is unclear or incomplete.	Resident orders as-needed labetalol without instructions stating when the medication should be given.
Renal dose monitoring/Adjustment required	Pharmacist identifies potential need for therapy adjustment based on a patient's renal function and the drug prescribed.	Resident orders ciprofloxacin 500 mg by mouth twice daily (standard dose for a patient with normal renal function) in a patient with end-stage renal disease treated with hemodialysis.