*International Journal for Quality in Health Care* 2013; **Volume 25, Number 6:** pp. 656–663
Advance Access Publication: 16 October 2013
10.1093/intqhc/mzt067

# Impact of electronic chemotherapy order forms on prescribing errors at an urban medical center: results from an interrupted time-series analysis

K. ELSAID[1], T. TRUONG[1], M. MONCKEBERG[2], H. MCCARTHY[2], J. BUTERA[3] AND C. COLLINS[2]

[1]Department of Pharmaceutical Sciences, MCPHS University, Boston, MA 02115, USA, [2]Department of Pharmacy, Rhode Island Hospital, Providence, RI 02903, USA, and [3]Division of Hematology and Oncology, Brown University, Providence, RI 02906, USA

Address reprint requests to: Khaled A. Elsaid, Department of Pharmaceutical Sciences, MCPHS University, 179 Longwood Ave, Boston, MA 02115, USA. Tel: +617-879-5943; E-mail: khaled.elsaid@mcphs.edu

Accepted for publication 8 September 2013

## Abstract

**Objective.** To evaluate the impact of electronic standardized chemotherapy templates on incidence and types of prescribing errors.

**Design.** A quasi-experimental interrupted time series with segmented regression.

**Setting.** A 700-bed multidisciplinary tertiary care hospital with an ambulatory cancer center.

**Participants.** A multidisciplinary team including oncology physicians, nurses, pharmacists and information technologists.

**Intervention(S).** Standardized, regimen-specific, chemotherapy prescribing forms were developed and implemented over a 32-month period.

**Main Outcome Measure(s).** Trend of monthly prevented prescribing errors per 1000 chemotherapy doses during the pre-implementation phase (30 months), immediate change in the error rate from pre-implementation to implementation and trend of errors during the implementation phase. Errors were analyzed according to their types: errors in communication or transcription, errors in dosing calculation and errors in regimen frequency or treatment duration. Relative risk (RR) of errors in the post-implementation phase (28 months) compared with the pre-implementation phase was computed with 95% confidence interval (CI).

**Results.** Baseline monthly error rate was stable with 16.7 prevented errors per 1000 chemotherapy doses. A 30% reduction in prescribing errors was observed with initiating the intervention. With implementation, a negative change in the slope of prescribing errors was observed (coefficient = −0.338; 95% CI: −0.612 to −0.064). The estimated RR of transcription errors was 0.74; 95% CI (0.59–0.92). The estimated RR of dosing calculation errors was 0.06; 95% CI (0.03–0.10). The estimated RR of chemotherapy frequency/duration errors was 0.51; 95% CI (0.42–0.62).

**Conclusions.** Implementing standardized chemotherapy-prescribing templates significantly reduced all types of prescribing errors and improved chemotherapy safety.

**Keywords:** CPOE, chemotherapy, prescribing errors, interrupted time series



## Introduction

Medication errors pose a significant challenge to the safety of modern health care. The frequency of medication errors among hospitalized patients can be as high as 20% and is a significant contributor to adverse drug events [1–4]. Chemotherapy drugs are highly cytotoxic with complex dosing schedules and significant toxicities at recommended dosing ranges. Therefore, the potential for patient harm resulting from prescribing errors involving these agents is more significant than other drug classes.

In this work, we investigated the impact of standardized, regimen-specific, electronic chemotherapy-prescribing templates on incidence of prescribing errors in a mixed ambulatory and inpatient chemotherapy treatment setting. We hypothesized that computerization of chemotherapy prescribing reduces the risk of prescribing errors and improves chemotherapy safety.

## Methods

### Setting

This study was conducted at Rhode Island Hospital, an urban academic multidisciplinary hospital affiliated with Warren Alpert Medical School at Brown University, and a member of the Lifespan Healthcare system located in Providence, RI, USA. The hospital is a 700-bed tertiary care institution with a pediatric division and an ambulatory comprehensive cancer center. The institution uses a closed-loop medication safety process including computerized provider order entry (CPOE), a pharmacy interface, a clinical decision support system, a bar-code point-of-care electronic nursing administration check and an automated drug-dispensing system [5]. Prior to the intervention, infusion chemotherapy orders were handwritten and transmitted to the pharmacy. Analysis of monthly prevented chemotherapy-prescribing errors over a 48 months period (1 January 2002 to 31 December 2006) revealed a positive linear trend. While these errors were corrected by pharmacists and did not impact the quality of care, an opportunity presented itself to proactively design a quality improvement (QI) program with the goal of improving patient safety by reducing the risk of prescribing errors.

### Intervention

A multidisciplinary team consisting of oncology physicians, nurses, pharmacists, cancer quality and information technology specialists was assembled and tasked with the mission of developing an intervention to reduce chemotherapy-prescribing errors. Analysis of types of prescribing errors at baseline identified the need for improvement in areas of high-risk, error-prone dosing calculations, e.g. body surface area (BSA) and area under the curve (AUC), use of unapproved abbreviations and aligning chemotherapy regimens' dosing intensity and frequency with goals of therapy.

While the hospital was already using a CPOE system for medication order entry, building the necessary add-on safety functionalities for prescribing chemotherapy regimens would have been a major re-programming task. The development and implementation of online, readily accessible, regimen-specific chemotherapy order forms with the necessary safety enhancements, e.g. *built-in* dosing calculators was viewed as an equally efficacious, yet more cost-effective, alternate strategy to infusion chemotherapy CPOE prescribing.

The chemotherapy-prescribing forms were developed using Adobe Acrobat. Acrobat offered an accessible Javascript programming environment that allows the building of custom functions that utilize data elements entered by prescribers. This concept is leveraged in our BSA, AUC and dose reduction calculators. Evidence-based recommendations, provided by the National Comprehensive Cancer Network and the American Society of Clinical Oncology, were used to identify regimen-specific agents, dosing intensities and frequencies, recommendations for dosing adjustments for toxicities or compromised renal or hepatic functions. The content of the prescribing forms was critically reviewed by pediatric and adult oncologists, institution-wide quality committees and were endorsed by the Pharmacy and Therapeutics committee. During the implementation phase of the project, regimen-specific chemotherapy templates were deployed for clinicians' use. Concurrent with the implementation of these forms, prescriber, nurse and pharmacist education was performed. Regular reminders and announcements of newly available chemotherapy regimen forms were communicated to all stakeholders. To evaluate adherence of prescribers to the use of these new forms, data regarding form utilization were prospectively gathered and routinely evaluated. At the end of the implementation phase, a clinical practice policy prohibiting the use of handwritten orders was instituted.

### Interrupted time-series analysis and segmented regression

The main outcome analyzed in this study was monthly prevented prescribing errors per 1000 dispensed chemotherapy doses. Prevented chemotherapy-prescribing errors are intercepted by oncology pharmacists and documented in an intervention database. These prevented prescribing errors are tabulated by the implicated drug component of the chemotherapy regimen, resulting in potentially more than one prescribing error for any specific chemotherapy regimen. We have identified three time segments: a pre-implementation phase between 1 January 2005 and 20 June 2007 (30 months), an implementation phase between 1 July 2007 and 28 February 2010 (32 months) and a post-implementation phase between 1 March 2010 and 30 June 2012 (28 months). A quasi-experimental interrupted time-series analysis approach was utilized [6]. A linear regression model was fitted to describe the magnitude of change in prescribing errors in transitioning from one phase to another and the trend of errors at any specific time segment. A graphical illustration of the analysis approach is depicted in Fig. 1. Parameters of interest included baseline error trend, immediate change in monthly errors from the last observation in the pre-implementation phase to the first observation in the implementation phase, change in the slope of error trend from pre-implementation to implementation, immediate change in monthly errors from the last observation in the implementation phase to the first observation in the post-implementation phase, error trend in the post-implementation phase and estimated reduction in monthly errors at 12 months into the implementation phase.

The regression model utilized was $Y_t = \beta_0 + \beta_1 T + \beta_2 D_A + \beta_3 P_A + \beta_4 D_B + \beta_5 P_B$, where $Y_t$ indicates prevented prescribing errors per 1000 chemotherapy doses at month $t$. $T$ is the time from baseline, $D_A$ is a dummy variable for the implementation phase (assumes a 0 during pre-implementation and post-implementation phases and 1 during the implementation phase), $P_A$ is period since first month in the implementation phase, $D_B$ is a dummy variable for the post-implementation phase (assumes a 0 during the pre-implementation and implementation phases and 1 during the post-implementation phase) and $P_B$ is period since first month in the post-implementation phase.

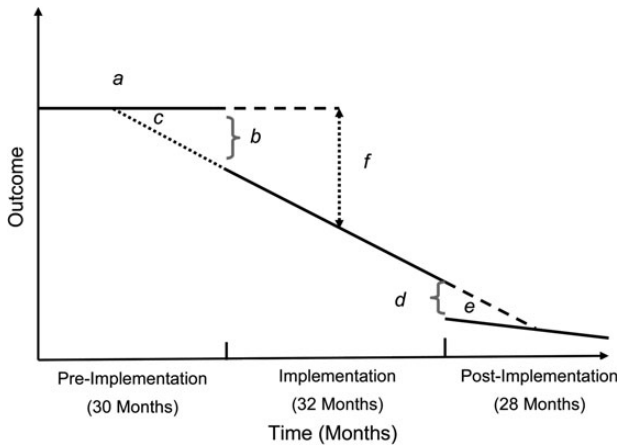


**Figure 1** Graphical illustration of interrupted time-series analysis assessing the impact of electronic chemotherapy templates on prescribing errors. Parameters of interest include *a* baseline error trend, *b* immediate change in monthly errors from the last observation in the pre-implementation phase to the first observation in the implementation phase, *c* change in the slope of error trend from pre-implementation to implementation, *d* immediate change in monthly errors from the last observation in the implementation phase to the first observation in the post-implementation phase, *e* error trend in the post-implementation phase and *f* estimated reduction of monthly errors at 12 months into the implementation phase.

### Descriptive analysis of prescribing errors

The pharmacist chemotherapy intervention database was queried to isolate intercepted prescribing errors during the study phases. Prescribing errors are identified as unintentional significant reduction in the probability of treatment being timely and effective or an increase in the risk of harm when compared with generally accepted practices [7, 8]. We have classified prescribing errors into three main categories. The first category included errors related to transcription/communication, incomplete prescriptions or a wrong drug selection. Errors in this category comprised errors of lack of clarity in drug's name or route of administration, incomplete dosing/frequency information, incomplete/inaccurate patient's clinical data, e.g. serum creatinine, platelet count and absolute neutrophil count among others. The second category included errors of drug dose calculation related to performing complex calculations, e.g. BSA or AUC calculations or failure to perform required dosing adjustments. Dosing errors were classified as overdoses or underdoses. The magnitude of drug overdose or underdose was calculated using the equation: percentage drug over-or underdose = (prescribed dose-correct dose)/correct dose × 100. The third category included errors of chemotherapy regimen frequency, duration of treatment, inappropriate drug/dosing intensity combination based on treatment goals.

Assessment of the severity of prevented overdose calculation errors was performed by a board-certified oncologist using an abbreviated version of the Medication Error Index scheme [9, 10]. Categories included no consequence for the patient (an error that would not cause patient harm), temporary damage (an error that could have contributed to temporary harm to the patient, requiring intervention, e.g. neutropenia), permanent damage (an error that could have contributed to permanent harm, e.g. irreversible nephropathy or neuropathy) and a significant possibility of a medical intervention required to sustain life (e.g. admission to intensive care unit due to a neutropenic sepsis).

### Statistical analyses

Parameter estimates of the regression model are reported along with the 95% CIs (CI). Where appropriate, values are reported with their 95% CI. Risks of specific types of prescribing errors in the three segments are reported. Reduction in risk of specific error types is expressed as relative risk (RR) and reported with 95% CI. The $\alpha$ level is set at 0.05. All statistical analyses were performed using SPSS Statistics Software, version 17.

## Results

### Development of chemotherapy-prescribing forms

A representative example of a standardized chemotherapy-prescribing template, depicting carboplatin–paclitaxel regimen for non-small cell lung cancer, is presented in Fig. 2. Section A contains entry fields for patients' demographic identifiers and biological data, e.g. height in inches or centimeters and weight in pounds or kilograms. Entry of height and weight data allows the calculation and display of BSA on the form. Additionally, section A contains entry field for physician-designated cutoff values for total bilirubin, serum creatinine, absolute neutrophil and platelet counts values to proceed with treatment. Section B of the form contains information regarding standardized pre-hydration and anti-emetic/premedication regimens. Section C contains the dosing guidelines of the drug components in the regimen. Selection of dosing level of paclitaxel and carboplatin allows the automatic calculation of drug dose and appropriate volume of diluents. Dosing adjustment calculators are also provided and allow the prescriber to indicate the clinical rationale for dosing reduction. Section D contains the frequency information and the total number of cycles along with selecting the intent of therapy (curative vs. palliative; adjuvant vs. neoadjuvant).

During the first 4 months of the implementation phase, a total of 33 regimens were developed and implemented. These included regimens, e.g. AC, CE, modified FOLOX and carboplatin–paclitaxel that are widely used in treatment of the most prevalent types of cancer. More than 100 regimen-specific prescribing forms were developed and implemented over a 32 months period. During the implementation phase, chemotherapy regimens that were not developed as an electronic regimen-specific prescribing form were prescribed using handwritten forms. Over the course of the implementation phase, the number of handwritten orders gradually declined but was not completely eliminated. Given the high number of chemotherapy regimens, used in routine clinical setting and in

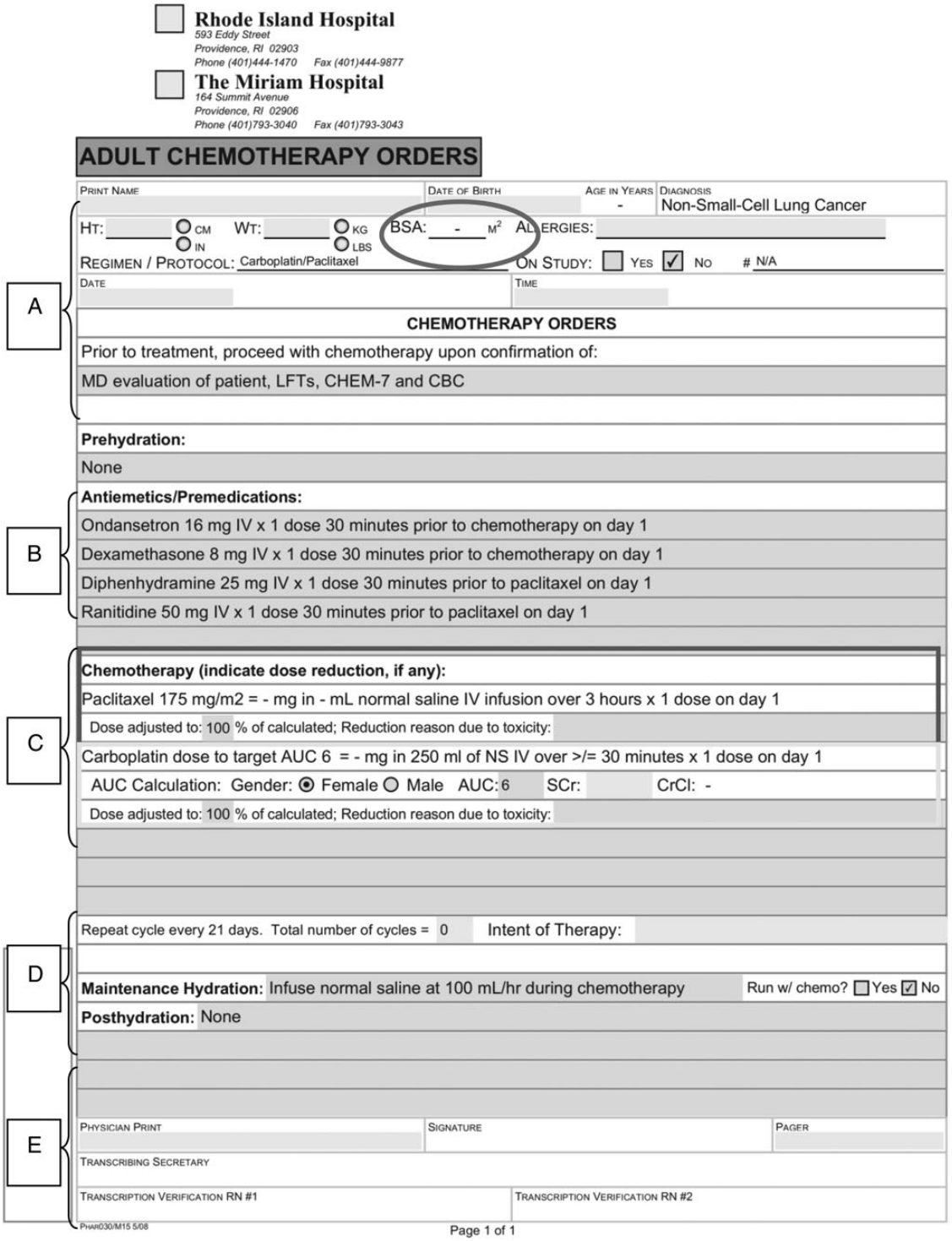


**Figure 2** A representative chemotherapy regimen-prescribing template with enhanced safety and dosing calculation functions. (**A**) Section for entry of patients' identifiers, allergy information, height and weight resulting in automatic calculation of BSA, and entry fields to enter most relevant clinical laboratory data, e.g. total bilirubin, serum creatinine, absolute neutrophil and platelet counts. (**B**) Drop-down selection of the most-appropriate anti-emetic/premedication regimens based on evidence-based guidelines and patients' prior history. (**C**) Section for chemotherapy dosing. Features include ability to select paclitaxel at 175, 200 or 225 mg/m$^2$, specification for magnitude of dosing adjustment and a selection menu for stating the reason of dose adjustments (impaired hepatic function or neutropenia). A carboplatin dosing calculator includes automatic dose calculation based on desired AUC (5 or 6), gender and value of serum creatinine. (**D**) Section outlining regimen frequency, total number of cycles (maximum selection is 4) and a drop-down menu for intent of therapy. (**E**) Authorized prescribers' names provided through a drop-down menu.

investigational studies, coupled with the need to prescribe single chemotherapy doses apart from established protocols, handwritten orders were still in use. To completely eliminate handwritten orders, we have used Adobe Acrobat to build blank-prescribing forms that contain BSA and AUC calculators and allow the prescriber to electronically type in the drug name, dose, route of administration and frequency. This effort was accompanied by a change in clinical practice policy prohibiting the use of handwritten orders. Assessment of the monthly chemotherapy prescriptions received by the pharmacy department during the post-implementation phase revealed that prescribers utilized the regimen-specific chemotherapy forms for 76% of the total prescriptions received by the department and used the electronically fillable generic form for 24% of the prescriptions.

## Trend of prescribing errors during pre-implementation, implementation and post-implementation phases

Trend of prevented prescribing errors in the pre-implementation, implementation and post-implementation phases is presented in Fig. 3. The linear regression model had a Durbin–Watson statistic of 1.96, indicating the lack of autocorrelation in the data set. We have further examined the potential for collinearity in our model using tolerance and variance inflation factor values. These values were found to be within acceptable ranges. Table 1 summarizes the parameter estimates from the segmented regression model. The $r$ value for the regression model was 0.704 and the adjusted $r^2$ value was 0.466. The baseline error rate was estimated to be 16.7 monthly errors per 1000 chemotherapy doses. The error rate in the baseline segment was stable with no observable trend. With the start of the implementation phase, an immediate reduction of 5.104 errors per 1000 chemotherapy doses, corresponding to ~30% reduction in the prescribing error rate, was observed. In addition to the immediate reduction in monthly prescribing errors, a significant change in the slope of error trend was observed. There was a significant reduction in monthly error rate in transitioning from the implementation phase to the post-implementation phase. Finally, there was no change in the slope of trend of prescribing errors when transitioning from the implementation phase to the post-implementation phase. The predicted monthly error rate, in the absence of implementing the intervention, was hypothesized to remain stable at 16.7 errors per 1000 chemotherapy doses; 95% CI (13.13–20.33). The predicted error rate at 12 months into the implementation phase was 10.35 errors per 1000 chemotherapy doses, 95% CI (8.46–12.24). This reflects an estimated 38% reduction in prevented monthly errors. The predicted error rate at the first month in the post-implementation phase was 9.17 errors per 1000 chemotherapy doses, 95% CI (5.63–12.71), corresponding to an estimated 45% reduction in monthly errors.

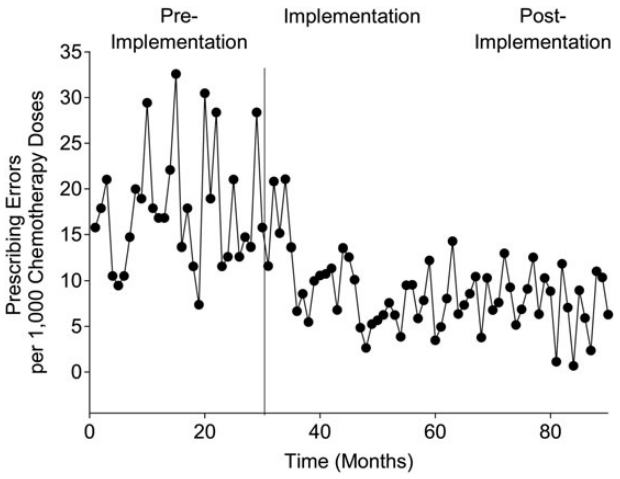


**Figure 3** Changes in monthly prevented prescribing errors per 1000 chemotherapy doses during the baseline (pre-implementation) phase (30 months), implementation phase (32 months) and post-implementation phase (28 months).

## Analysis of prescribing errors during pre-implementation, implementation and post-implementation phases

Table 2 describes the breakdown of prevented prescribing errors in the three study phases. During the pre-implementation phase, there were 507 errors, corresponding to 17.8 errors per 1000 chemotherapy doses. In the implementation phase, there were 345 prevented errors corresponding to 9.1 errors per 1000 chemotherapy doses. In the post-implementation phase, there were 340 prevented errors corresponding to 7.9 errors per 1000 chemotherapy doses. The estimated RR of transcription errors in the post-implementation phase compared with the pre-implementation phase was 0.74 and a 95% CI (0.59–0.92; $P < 0.01$). Similarly, the estimated RR of dosing calculation errors in the post-implementation phase compared with the pre-implementation phase was 0.06 and a 95% CI (0.03–0.10; $P < 0.001$). Additionally, the estimated RR of chemotherapy frequency/duration errors was 0.51 and a 95% CI (0.42–0.62; $P < 0.001$).

During the pre-implementation phase, ~12% of all prescribing errors were linked to carboplatin and 8% of all prescribing errors were linked to methotrexate. During the post-implementation phase, carboplatin accounted for 5% of all prescribing errors and methotrexate accounted for 6.9% of all prescribing errors. Drug-specific categorization of overdoses and underdoses is presented in the Supplementary data, Appendix A. In the pre-implementation phase, the number of drug overdose errors of 50% or more was 15 accounting for 11% of all dose calculation errors. In the post-implementation phase, the number of drug overdose errors of 50% or more was 1 accounting for 8.3% of all dose calculation errors. There were 24 overdose errors linked to carboplatin in the pre-implementation period compared with 7 errors during the implementation phase and five errors in the post-implementation period.

Table 3 summarizes the physician-based assessment of severity of prevented overdose calculation errors. In the pre-implementation phase, 59% of overdose errors could have contributed to patient harm ranging from temporary harm (38%) to a medical intervention to sustain life (15%). In the

**Table 1** Parameter estimates, 95% CIs and *P*-values from segmented regression model describing trend of monthly prevented errors per 1000 chemotherapy doses

| | Coefficient | Lower limit of CI | Upper limit of CI | *P*-value* |
|---|---|---|---|---|
| Intercept, $\beta_0$ | 16.727 | 13.126 | 20.328 | <0.001 |
| Baseline trend, $\beta_1$ | 0.066 | −0.137 | 0.269 | 0.519 |
| Level change from last point in the pre-implementation to the first point in the implementation phase, $\beta_2$ | −5.104 | −9.988 | −0.220 | 0.041 |
| Slope change from pre-implementation to implementation, $\beta_3$ | −0.338 | −0.612 | −0.064 | 0.016 |
| Level change from last point in the implementation to the first point in the post-implementation phase, $\beta_4$ | −11.563 | −21.859 | −1.268 | 0.028 |
| Slope change from implementation to post-implementation, $\beta_5$ | −0.158 | −0.461 | 0.145 | 0.302 |

The model describes trend and changes in the error rate during the pre-implementation, implementation and post-implementation phases.
*Calculated using Student's *t*-test.

**Table 2** Analysis of prevented prescribing errors during the pre-implementation, implementation and post-implementation periods stratified by error type

| | Pre-implementation: 507 errors per 28 560 doses | Implementation: 345 errors per 37 808 doses | Post-implementation: 340 errors per 43 206 doses |
|---|---|---|---|
| Transcription, communication errors, incomplete prescriptions, wrong drug selection | 140 (28%) | 149 (43%) | 156 (46%) |
| Dosing calculation errors | 142 (28%) | 37 (11%) | 12 (4%) |
| Chemotherapy regimen frequency, duration of treatment | 225 (44%) | 159 (46%) | 172 (50%) |
| Total | 507 (100%) | 345 (100%) | 340 (100%) |

**Table 3** Physician assessment of severity of prevented overdose calculation errors during pre-implementation, implementation and post-implementation phases

| Error severity category [9, 10] | Pre-implementation ($n = 71$) | Implementation ($n = 29$) | Post-implementation ($n = 9$) |
|---|---|---|---|
| No consequence for the patient | 29 (41%) | 13 (45%) | 6 (67%) |
| Temporary damage | 27 (38%) | 12 (42%) | 2 (22%) |
| Permanent damage | 4 (6%) | 1 (3%) | 1 (11%) |
| Possibility of a medical intervention to sustain life | 11 (15%) | 3 (10%) | 0 (0%) |
| Total | 71 (100%) | 29 (100%) | 9 (100%) |

implementation phase, 55% of overdose errors could have contributed to patient harm ranging from temporary harm (42%) to a medical intervention to sustain life (10%). In the post-implementation phase, 33% of errors could have contributed to patient harm. No errors that could have required a medical intervention to sustain life were documented during the post-implementation phase.

## Discussion

Prescribing errors in oncology practice remains a significant problem that leads to patient harm despite decades of increased awareness of chemotherapy agents' toxicities and implementation of rigorous safety standards [11–19]. Among prescribing errors, transcription/communication errors and dosing errors

are the most common types of errors encountered in chemotherapy prescribing [10, 20]. At our institution, errors related to chemotherapy frequency, treatment duration and dose calculation collectively accounted for 72% of prevented prescribing errors with errors involving carboplatin and methotrexate accounting for ∼20% of all prevented errors. The significant contribution of carboplatin to the overall chemotherapy prescribing errors has also been reported by Ranchon *et al.* [21] who found that protocols involving carboplatin are more than twice likely to involve prescribing errors compared with protocols that do not contain carboplatin.

A QI intervention that was shown to reduce prescribing errors across multiple settings and for different drug classes is the implementation of CPOE systems [22, 23]. CPOE implementation reduced the risk of prescribing errors of oral chemotherapy agents [24], pediatric [25, 26] and adult infusion chemotherapy [27, 28]. With the use of chemotherapy CPOE in these settings, as high as 70% reduction in prescribing errors was observed with elimination of certain types of dosing errors calculations. Our standardized regimen-specific chemotherapy prescribing templates contained the same safety functionalities that a fully integrated CPOE system would contain, but with the added benefit of a more cost-effective and flexible approach [29]. With using the standardized chemotherapy templates, we observed an ∼50% reduction in the annual incidence of prescribing errors per 1000 chemotherapy doses.

We have utilized interrupted time series and segmented regression to analyze the impact of our QI intervention on chemotherapy-prescribing errors. Interrupted time series is a robust quasi-experimental approach that uses the baseline trend of the outcome of interest as the control group. Interrupted time-series analysis is uniquely suited to analyze the impact of QI initiatives where the design of an experimental study is not feasible. Interrupted time series has been successfully utilized to analyze the impact of various QI programs [30–32]. Using this approach, we have demonstrated that the reduction in prescribing errors with the implementation of the electronic chemotherapy templates was immediate and that the reduction persisted throughout the implementation and post-implementation phases. The greatest impact with implementing computerized chemotherapy regimens was in reducing dosing calculation errors. The risk of dosing errors was reduced by 94% as a result of the intervention. The number of prevented serious overdose errors, identified as dosing errors that would have resulted in >50% increase in the chemotherapy dose, was also reduced as a result of the intervention. Additionally, the severity of prevented dosing calculation errors was reduced as a result of our intervention. Prescribing errors that would have resulted in permanent damage or a medical intervention to sustain life were eliminated in the post-implementation period. Specifically, the intervention was successful in eliminating dosing error calculation for carboplatin. The five errors related to carboplatin in the post-implementation phase were due to the value of patients' serum creatinine not reflective of the most recent reading. We have also observed a significant reduction in errors of communication, transcription and errors of chemotherapy regimen frequency and duration. However, the magnitude of this reduction was lower compared with the effect on dosing calculation errors with estimated 26% reduction in transcription/communication errors and 49% reduction in chemotherapy frequency/treatment duration errors. The residual transcription/communication errors in the post-implementation phase resulted from prescribers reporting inaccurate or outdated clinical laboratory data. The residual chemotherapy regimen frequency and duration errors in the post-implementation phase were linked to patients where the regimen's dosing frequency or duration of treatment not supported by evidence-based guidelines.

In conclusion, we herein describe our institution's experience in developing computerized chemotherapy regimens and report the impact of this QI strategy on prevented prescribing errors. The development of electronic chemotherapy prescribing templates eliminated dosing calculation errors and improved chemotherapy safety. Our intervention is robust, cost-effective and can be adapted to healthcare institutions of various sizes.

## Supplementary material

Supplementary material is available at *INTQHC* online.

## Funding

The funding for this study was provided by the department of pharmacy at RIH. The authors have no conflict of interest to declare.

## References

1. Barker KN, Flynn EA, Pepper GA *et al.* Medication errors observed in 36 healthcare facilities. *Arch Intern Med* 2002;**162**:1897–903.
2. Tully MP. Prescribing errors in hospital practice. *Br J Clin Pharmacol* 2012;**74**:668–75.
3. Bates DW, Boyle DL, Vander Vilet MB *et al.* Relationship between medication errors and adverse drug events. *J Gen Intern Med* 1995;**10**:199–205.
4. Runciman WB, Roughead EE, Semple SJ *et al.* Adverse drug events and medication errors in Australia. *Int J Qual Health Care* 2003;**15**(Suppl. 1):i49–59.
5. Mahoney CD, Berard-Collins CM, Coleman R *et al.* Effects of an integrated clinical information system on medication safety in a multi-hospital setting. *Am J Health Syst Pharm* 2007;**64**:1969–77.
6. Wagner AK, Soumerai SB, Zhang F *et al.* Segmented regression analysis of interrupted time series studies in medication use research. *J Clin Pharm Ther* 2002;**27**:299–309.
7. Dean B, Barber N, Schachter M. What is a prescribing error? *Qual Health Care* 2000;**9**:232–7.
8. Ghaleb MA, Barber N, Dean Franklin B *et al.* What constitutes a prescribing error in paediatrics. *Qual Saf Health Care* 2005;**14**:352–7.

9. National Coordinating Council on Medication Error Reporting and Prevention. (http://www.nccmerp.org/aboutMedErrors.html).
10. Ranchon F, Salles G, Spath HM *et al*. Chemotherapeutic errors in hospitalized cancer patients: attributable damage and extra costs. *BMC Cancer* 2011;**11**:478.
11. Ford CD, Killebrew J, Fugitt P *et al*. Study of medication errors on a community hospital oncology ward. *J Oncol Pract* 2006;**2**: 149–54.
12. Klys M, Konopka T, Scislowski M *et al*. Fatality involving vinblastine overdose as a result of complex medical error. *Cancer Chemother Pharmacol* 2007;**59**:89–95.
13. Chu G, Mantin R, Shen YM *et al*. Massive cisplatin overdose by accidental substitution for carboplatin. *Cancer* 1993;**72**:1166–8.
14. Erdelenbruch B, Lakomek M, Bjerre LM. Editorial: chemotherapy errors in oncology. *Med Pediatr Oncol* 2002;**38**:353–6.
15. Pichon R, Zelger GL, Wacker P *et al*. Analysis and quantification of prescribing and transcription errors in a paediatric oncology service. *Pharm World Science* 2002;**24**:12–5.
16. Rinke ML, Shore AD, Morlock L *et al*. Characteristics of pediatric chemotherapy medication errors in a national reporting database. *Cancer* 2007;**110**:186–95.
17. ASHP Council on Professional Affairs. ASHP guidelines on preventing medication errors with antineoplastic agents. *Am J Health Syst Pharm* 2002;**59**:1648–68.
18. Cohen MR, Andersen RW, Attilio RM *et al*. Preventing medication errors in cancer chemotherapy. *Am J Health Syst Pharm* 1996;**53**:737–46.
19. Walsh K, Dodd K, Seetharaman K *et al*. Medication errors among adults and children with cancer in the outpatient setting. *J Clin Oncol* 2009;**27**:891–6.
20. Schwappach DLB, Mernli M. Medication errors in chemotherapy: incidence, types and involvement of patients in prevention. A review of the literature. *Eur J Cancer Care* 2010;**19**:285–92.
21. Ranchon F, Moch C, You B *et al*. Predictors of prescription errors involving anticancer chemotherapy agents. *Eur J Cancer* 2012;**48**:1192–9.
22. Wolfstadt JI, Gurwitz JH, Field TS *et al*. The effect of computerized physician order entry with clinical decision support on the rates of adverse drug events: a systematic review. *J Gen Intern Med* 2008;**23**:451–8.
23. Ammenwerth E, Schnell-Inderst P, Machan C *et al*. The effect of electronic prescribing on medication errors and adverse drug events: a systematic review. *J Am Med Inform Assoc* 2008;**15**: 585–600.
24. Collins CM, Elsaid KA. Using an enhanced oral chemotherapy computerized provider order entry system to reduce prescribing errors and improve safety. *Int J Qual Health Care* 2011;**23**: 36–43.
25. Kim GR, Chen AR, Arceci RJ *et al*. Error reduction in pediatric chemotherapy: computerized order entry and failure modes and effects analysis. *Arch Pediatr Adolesc Med* 2006;**160**:495–8.
26. Chen AR, Lehmann CU. Computerized provider order entry in pediatric oncology: design, implementation, and outcomes. *J Oncol Pract* 2011;**7**:218–22.
27. Gandhi TK, Bartel SB, Shulman LN *et al*. Medication safety in the ambulatory chemotherapy setting. *Cancer* 2005;**104**:2477–83.
28. Voeffray M, Pannatier A, Stupp R *et al*. Effect of computerization on the quality and safety of chemotherapy prescription. *Qual Saf Heath Care* 2006;**15**:418–21.
29. Gallagher J, Rogala JL, Pharm L *et al*. Challenges of creating a one-size-fits-all oncology CPOE application. *Stud Health Technol Inform* 2006;**122**:902.
30. Willemsen I, Cooper B, Van Buitenen C *et al*. Improving quinolone use in hospitals by using a bundle of interventions in an interrupted time series analysis. *Antimicrob Agents Chemother* 2010;**54**:3763–9.
31. Ansari F, Gray K, Nathwani D *et al*. Outcomes of an intervention to improve hospital antibiotic prescribing: interrupted time series with segmented regression analysis. *J Antimicrob Chemother* 2003;**52**:842–8.
32. Lépéé C, Klaber RE, Benn J *et al*. The use of consultant-led ward round checklist to improve paediatric prescribing: an interrupted time series study. *Eur J Pediatr* 2012;**171**:1239–45.