JPPT | Two Site Retrospective Study

# Evaluation of the Effect of Smart Pump Interoperability on Infusion Errors in the Pediatric Hospital Setting

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**OBJECTIVES** Smart pump interoperability is a newer technology integrating intravenous medication infusion instructions from the electronic medical record into a smart pump. This technology has demonstrated significantly decreased medication errors in the adult population; however, this has not been reported in pediatrics. The purpose of this study was to compare the frequency and severity of infusion related errors before and after the implementation of smart pump interoperability at a pediatric institution.

**METHODS** This was a retrospective study conducted at multiple institutions within the same health care system to assess the effect of smart pump interoperability on infusion errors. Data were retrospectively analyzed for a 6-month period prior to (January–June 2020) and after (January–June 2022) smart pump interoperability implementation. All who received medications via a smart pump were included in the analysis. Infusions were excluded if administered via a patient-controlled analgesia pump, epidural pump, or intravenously pushed without using a smart pump.

**RESULTS** A total of 143,997 versus 165,343 infusions were administered in the before versus after interoperability group. There were significant decreases in mild, moderate, and severe harm averted events once interoperability was implemented ($p < 0.001$). Errors caught before administration decreased after interoperability implementation from 197 events to 20 events because of fewer overall errors ($p < 0.001$). The number of guardrail alert overrides was significantly reduced, from 23,751 to 5885 ($p < 0.001$), as was the number of high-risk overrides, from 5851 to 207 ($p < 0.001$).

**CONCLUSION** Implementing smart pump interoperability significantly reduced the frequency and severity of infusion errors and high-risk overrides at a pediatric institution.

**ABBREVIATIONS** EMR, electronic medical record; ISMP, Institute for Safe Medication Practices; IV, intravenous; NCH, Norton Children's Hospital; NCMC, Norton Children's Medical Center; NICU, neonatal intensive care unit

**KEYWORDS** alerts; drug library; infusion errors; interoperability; intravenous medications; programming; smart pump

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## Introduction

Intravenous (IV) medications can be high risk and have complex administration instructions, leading to the possibility of significant patient harm when an error occurs. Intravenous medication errors are twice as likely to result in patient harm compared with other routes of administration, and preventable adverse events from injectable medications have a significant economic burden.[1,2] Smart pump technology in hospitals has significantly reduced IV medication errors; however, a high rate of errors has persisted.[3,4] The Institute for Safe Medication Practices (ISMP) identifies a list of high-risk medications and reports the common errors that occur despite smart pump technology.[5,6] These include errors in secondary infusion administration, rate of administration errors, dosing errors, dosing weight errors, programming errors, and errors with the setup of lines and tubing, most of which can be overcome by smart pump interoperability.

As of 2020, 87.9% of US pediatric hospitals use smart infusion pumps; however, the use of smart pump interoperability is still an emerging technology found in only 13.4% of hospitals.[7] Smart pump interoperability integrates IV medication infusion instructions from the electronic medical record (EMR) into a smart pump and vice versa. This automatic programming facilitates dose error-reduction software, which consists of a customizable library embedded in the pump with standard concentration, dosing limits, and alerts. With the customizable library alone, there is still a risk for errors within the drug library limits because of the possibility of human error with manually programming

the infusion pumps. Interoperability can potentially prevent errors by reducing the frequency of manual pump programming, paired with a customizable drug library, which includes soft and hard limits on infusion rates and doses. Smart pump interoperability may also introduce new errors into the workflow due to the limitations with the drug library and alert fatigue. Because smart pump interoperability does not eliminate all infusion errors, characterization of infusion errors that persist despite this technology is essential to the quality improvement process.

Multiple studies at adult institutions have demonstrated that this technology has led to safer administration of IV medications by improved drug library compliance, increased accuracy of smart pump programming, increased documentation in the EMR, decreased alert overrides, and reduced total medication errors.[1,8–10] Skog et al[1] observed that total infusion errors significantly decreased by 15% after the implementation of smart pump interoperability, with a reduction of infusion errors associated with high-risk medications by 47%. In another retrospective study by Wei et al,[9] drug library compliance was reported to have increased from 73.8% to 82.9% after implementing interoperability technology. Currently, there is a lack of literature describing the effect of smart pump interoperability in pediatric institutions.

In September 2019, our institution implemented use of a new type of smart pump that serviced both large volume and syringe medication administration. In September 2020, smart pump interoperability was implemented. The purpose of this study was to evaluate the effect of smart pump interoperability on patient care by assessing the frequency and severity of infusion-related errors. The aim is to use these data to identify strategies to increase the safety of medication infusions to positively affect patient care.

## Materials and Methods

**Study Design and Data Collection.** This was a retrospective study conducted at 2 facilities within the same health care system to assess the effect of smart pump (Beckton Dickinson Alaris Pump Module 8100 and Alaris Syrine Module 8110, Franklin Lakes, NJ) interoperability on infusion errors. The 2 facilities included Norton Children's Hospital (NCH), which is a 274-bed hospital with a level IV neonatal intensive care unit, and Norton Children's Medical Center (NCMC), a 16-bed outpatient surgical center with a 24-hour emergency department. Data were retrospectively analyzed for a 6-month period prior to (January–June 2020) and a 6-month period after (January–June 2022) smart pump interoperability implementation. Patients were identified through quarterly infusion reports, patient safety reports, and EMR reports. All infusions administered via a smart pump at the 2 facilities were included in the analysis. Infusions were excluded if not infused by a smart pump or are not included in the pump library. Patient-controlled analgesics and epidurals were also considered out of scope because of a lack of interoperability functionality at this time.

Data collected included the following: total number of infusions administered, total guardrail alerts (i.e., continuous dose alert, intermittent dose alert, bolus dose administration rate), guardrail compliance, total guardrail alerts overridden, severe harm averted events, good catches identified through the infusion report, high-risk overrides, time to override, and pump profile. There is a neonatal and a pediatric smart pump profile. Any patient admitted in the neonatal intensive care unit used the neonatal profile, and all other units in the hospital used the pediatric profile. The primary objective was to compare the frequency, type, and severity of infusion errors before and after smart pump interoperability implementation at our institution. Secondary objectives included comparing drug library use compliance, number of guardrail alert overrides, number of high-risk alert overrides, number of alerts susceptible to rapid bypass in less than 2 seconds, top 5 medications with override alerts, and cost savings associated with potential adverse drug events averted before and after smart pump interoperability implementation. Previous literature identifies alerts overridden in less than 2 seconds as nuisance alarms, highlighting a higher risk for errors and therefore included in the objectives.[9] A harm index was created by the National Coordinating Council for Medication Error and Prevention, which assigns a harm category based on the inherent drug risk and dose the clinician attempted to infuse above the maximum limit. This harm index is standard for all using this smart pump and is recorded on the smart pump infusion report.[11] Mild harm is defined by the smart pump infusion report as no or minor clinical patient effect, moderate harm is defined as having a likely significant clinical effect, and severe harm is defined as the inherent risk of the drug infused to be life threatening. Events are stratified as severe harm averted if the inherent risk of the drug infused is high and it was programmed 2.5 times or greater than the institution-established limit, if the inherent risk of the drug infused is medium and programmed 5 times or greater than the institution-established limit, or if the inherent risk of the drug infused is low and programmed 10 times or greater than the institution-established limit.

**Statistical Analysis.** Descriptive statistics were used to describe the categoric variables. A $\chi^2$ test was used to determine significance when comparing all primary and secondary objectives aside from cost savings. Significance was defined as a p value less than 0.05.

## Results

A total of 143,997 infusions were administered in the preinteroperability group compared with 165,343 in the postinteroperability group. In the preinteroperability

group, 142,547 of the total infusions were infused at NCH, whereas 1450 were at NCMC. In the postinteroperability group, 163,443 of the total infusions were infused at NCH, whereas 1900 were at NCMC. A total of 27.2% of the total infusions used the neonatal library in the preinteroperability group and 23.7% of total infusions in the postinteroperability group. There were 1731 total harm averted events in the preinteroperability group compared with 295 events in the postinteroperability group, as shown in Table 1. There was a significant decrease in mild, moderate, and severe harm averted events once interoperability was implemented ($p < 0.001$). Although there was a total decrease in mild harm averted events after interoperability was implemented, there was a higher percentage of mild harm averted events compared with moderate and severe (197 [67%] mild, 29 [9.8%] moderate, and 69 [24%] severe) in the postinteroperability group. There was a similar occurrence of mild versus moderate versus severe events in the preinteroperability group (739 [42%] mild, 339 [20%] moderate, and 657 [38%] severe). In the preinteroperability group, the most common drugs involved in a severe harm averted event were pantoprazole, albumin 5%, midazolam, hydromorphone, morphine, ceftaroline, fentanyl, propofol, penicillin G, and dexmedetomidine. The implementation of interoperability eliminated severe harm averted events for albumin 5%, midazolam, hydromorphone, and pantoprazole, which were primarily manual pump programming errors (Figure 1). There were also notable reductions in severe harm averted events for fentanyl and propofol after the implementation of interoperability.

Errors caught before administration also decreased after interoperability implementation from 197 events to 20 events ($p < 0.001$). There were fewer errors for the smart pump to identify because manual programming had been significantly reduced. The most common errors decreased as a result of interoperability included dose or rate errors, decimal point programming errors, and double-digit entry errors (Table 2). There were also fewer patient safety reports entered regarding smart pump infusion errors after interoperability (Table 3). Errors such as the wrong medication programmed on the pump, rate programming errors, exceeding guardrail limits, and wrong weight entered all decreased. However, one issue that persisted despite interoperability was not having the medication in the drug library, which must be manually programmed.

Drug library compliance improved from 94% at NCH at the beginning of the study period to 97.9% at the end of the study period (Figure 2). At NCMC there was an increase in compliance from 94% preinteroperability to 96.7% by the end of the postinteroperability period. This facility administers a much lower number of

**Table 1.** Total Harm Averted

| Harm Averted Severity | Preimplementation, n (%); n = 1731 | Postimplementation, n (%); n = 295 | Absolute Difference, % | p value |
|---|---|---|---|---|
| Mild | 735 (42) | 197 (67) | 25 | <0.001 |
| Moderate | 339 (20) | 29 (9.8) | −10.2 | <0.001 |
| Severe | 657 (38) | 69 (24) | −14 | <0.001 |

**Figure 1.** Top 10 "severe harm averted" medications.

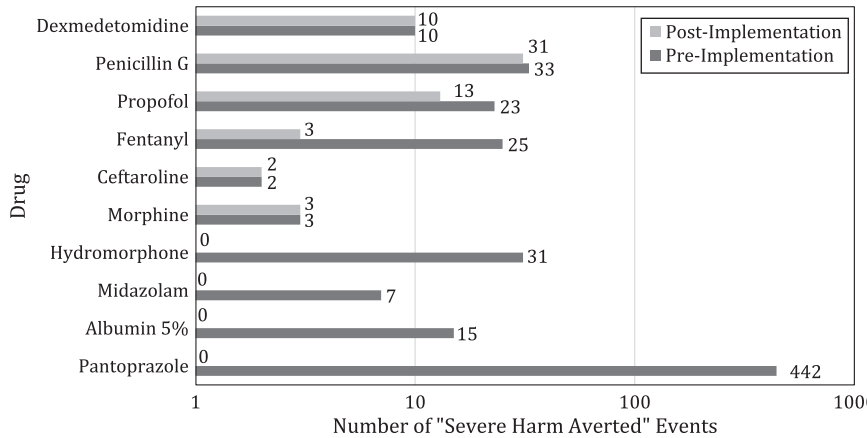


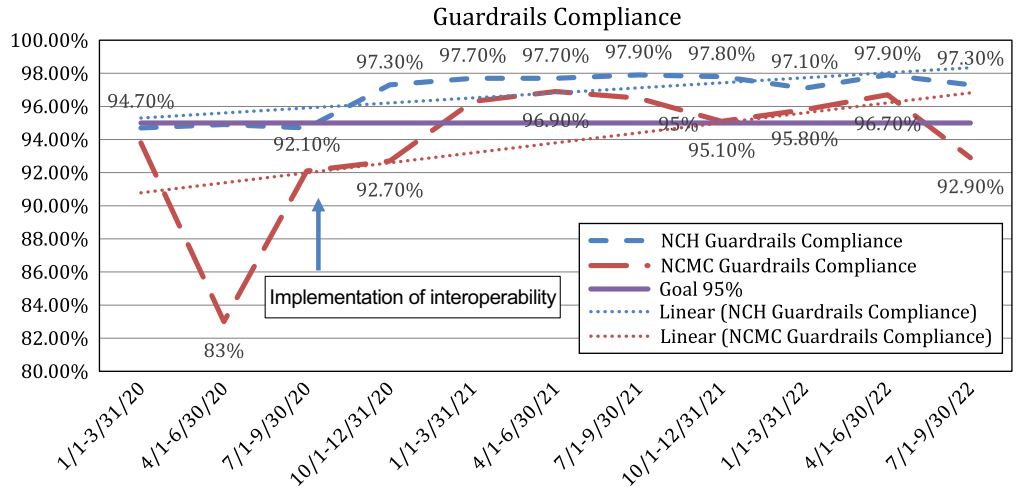
**Table 2.** Errors Caught Before Administration

| Type of Errors Caught Before Administration | Preimplementation, n (%); n = 197 | Postimplementation, n (%); n = 20 | Absolute Difference, % | p value |
|---|---|---|---|---|
| Decimal point programming errors | 74 (38) | 12 (60) | 22 | 0.05 |
| Double digit entry error | 7 (3.5) | 0 (0) | −3.5 | 0.39 |
| Rate/dose error | 113 (57) | 7 (35) | −40 | 0.055 |
| High rate error | 3 (1.5) | 1 (5) | 3.5 | 0.27 |

**Table 3.** Patient Safety Reports

| | Preimplementation, n (%); n = 39 | Postimplementation, n (%); n = 29 | Absolute Difference, % | p value |
|---|---|---|---|---|
| Wrong drug | 3 (7.7) | 2 (6.9) | −0.8 | 0.9 |
| Rate programming error | 19 (49) | 11 (38) | −11 | 0.38 |
| Medication not in drug library | 3 (7.7) | 3 (10.3) | 2.6 | 0.7 |
| Guardrail limits | 3 (7.7) | 1 (3.4) | −4.3 | 0.46 |
| Order verification error | 8 (21) | 5 (17.2) | −3.8 | 0.73 |
| Paused drip not restarted | 0 (0) | 6 (20.7) | 20.7 | 0.003 |
| Discontinued—still infusing | 1 (2.5) | 0 (0) | −2.5 | 0.4 |
| Wrong weight programmed | 1 (2.5) | 0 (0) | −2.5 | 0.4 |
| User error—wrong channel | 1 (2.5) | 1 (3.4) | 0.9 | 0.83 |

**Figure 2.** Drug library use compliance.




infusions, and therefore small changes in compliance result in large fluctuations in drug library compliance. Drug library use compliance goals for both facilities were higher than 95%. The number of guardrail alert overrides significantly reduced from 23,751 (73% of 32,422 total alerts) to 5885 (70.6% of 8,335 total alerts; $p < 0.001$). The number of high-risk overrides reduced from 5851 (24.6% of 23,751 total overrides) to 207 (3.5% of 5885 total overrides; $p < 0.001$), and the number of alerts overridden in less than 2 seconds decreased

from 14,602 (61.5% of 23,741 total overrides) to 3445 (58.5% of 5885 total overrides; $p < 0.001$). The cost savings associated with severe harm averted events decreased from $5,748,750 to $603,750 because there were less severe harm averted events in the postinteroperability group (Table 4).

The top 5 medications with the most override alerts before and after interoperability implementation were the same, including hydromorphone, fentanyl, IV fluids, midazolam, and total parenteral nutrition. However, there was a significant decrease in the number of alerts, as mentioned above (Figure 3). The top 5 medications with the most alerts overridden in less than 2 seconds before and after implementation of interoperability were also fentanyl, hydromorphone, IV fluids (without potassium), midazolam, and total parenteral nutrition (Figure 4). After characterizing the smart pump alerts susceptible to rapid bypass by nurses, it was identified that fentanyl and midazolam administration rate errors in the neonatal library were more susceptible to overrides in less than 2 seconds.

## Discussion

This retrospective study comparing preimplementation and postimplementation of smart pump interoperability found a significant reduction in the number and severity of infusion errors in pediatric institutions. The number of mild, moderate, and severe harm averted events significantly decreased, presumably due to limiting the amount of manually programmed infusions and the ability to implement safety thresholds for infusions. Of the total harm averted events in the postimplementation group, there was a higher percentage categorized as mild harm averted compared with the preimplementation group, indicating the effectiveness of interoperability to identify medication errors prior to the start of infusions. The ability of the EMR to send information directly to the smart pump has reduced errors such as wrong infusion rates, medication types, and programming patients' weight. One of the top medication errors eliminated with interoperability was pantoprazole intermittent infusions being programmed

**Table 4.** Secondary Outcomes

| | Preimplementation | Postimplementation | Absolute Difference, % | p value |
|---|---|---|---|---|
| Guardrail alert overrides* | 73% (23,751/32,422) | 70.6% (5885/8335) | −2.4 | <0.001 |
| High-risk overrides† | 24.6% (5851/23,751) | 3.5% (207/5885) | −21.1 | <0.001 |
| Alerts overridden in <2 sec† | 61.5% (14,602/23,751) | 58.5% (3445/5885) | −3 | <0.001 |
| Cost savings associated with the potential severe adverse drug events averted | $5,748,750 | $603,750 | −$5,145,000 | N/A |

*N/A, not applicable*

* Denominator is total alerts.
† Denominator is total overrides.

**Figure 3.** Top 5 medication with override alerts.

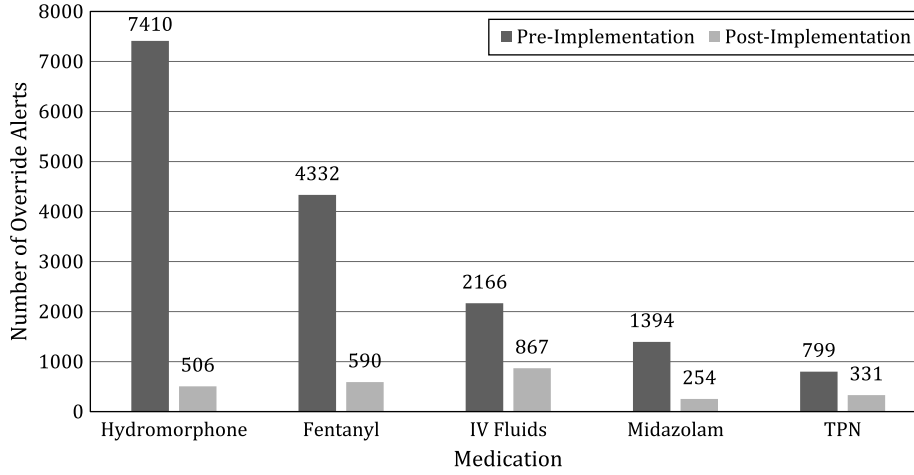
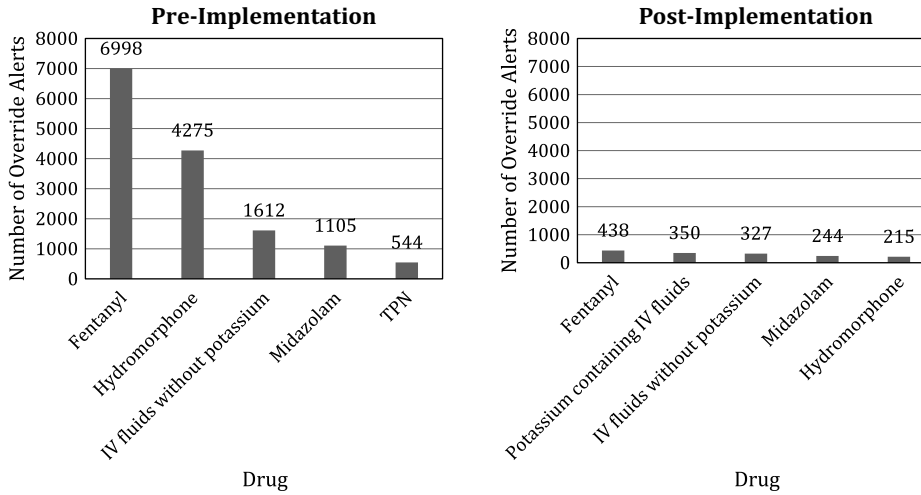


**Figure 4.** Top 5 medications overridden in less than 2 seconds.




as a continuous infusion, which would have led to 100-fold overdoses with manual programming of the pump. Other high-risk errors, such as decimal point errors, programming incorrect units, and programming the incorrect rate of medications, such as albumin 5%, midazolam, and hydromorphone, were also eliminated.

Errors persisting despite smart pump interoperability include dose and rate programming for continuous infusions of fluids, errors when the infusion rate range was not entered upon initial order verification, and errors with medications that are not within the scope of interoperability and require manual programming (i.e., penicillin G due to the pump not being able to program 6-digit units). Nurses have to manually titrate continuous infusions if there is a rate or dose change, which cannot be resolved with interoperability and has led to errors. Some orders built into the EMR, such as methotrexate and methylprednisolone, which historically have been IV pushed without using a smart pump, did not have the infusion rate automatically populate. Therefore, nurses had to calculate and manually enter the rate for these orders if placed on the infusion pump. There were also multiple errors identified with the infusion rate of albumin 5% for nephrotic syndrome. The infusion duration that prepopulated into the EMR was 30 minutes, but the ordering providers intended it to be more than 120 minutes for this specific indication. Adding the infusion time on order entry was a new concept for ordering providers. Another persisting issue included several alerts in both groups being overridden in less than 2 seconds for infusions in the neonatal library because of default administration times being longer in duration than nurses used in the past. Programming default administration times that were safe for the smallest of neonatal patients but also appropriate for infants proved to be a challenge.

New errors introduced with the implementation of smart pump interoperability were also identified. Multiple libraries exist in the smart pump, which led to the use of the incorrect library at times. For example, there were instances when anesthesia selected the pediatric library to administer propofol, which is dosed in mg/kg/hr, whereas the library for anesthesia use only is dosed in mcg/kg/min. The result was an incorrect rate programmed into the pump. There were also reports of titratable infusions unintentionally being restarted at the lower end of the dosing range when a patient was transferred from the operating room to the unit, even if the patient had been on higher doses prior to the order change. This was due to titrations occurring on the pump that were not recorded in the EMR, so when the infusion was due to be replaced, it defaulted back to the last recorded dose. Our institution plans to address some of these persisting and new errors by providing nursing, operating room, and sedation service education, as well as workflow changes on these common errors. For example, there will be a standardized transition of care handoff from anesthesia providers to intensive care unit nursing staff that includes reconciliation between smart pump and EMR orders of all currently infusing titratable medications. In addition, implementing a double-check process through the EMR for nurses at key points in time, such as with infusions that have restarted after being paused or with a syringe or bag change, would help eliminate the human error still existing in this process.

This is one of the first studies to evaluate the effectiveness of smart pump interoperability in reducing infusion errors in a pediatric institution. Previous studies in adult institutions found that total infusion errors, administration errors, and high-risk errors were significantly reduced after the implementation of smart pump interoperability, which was similarly reflected in our study.[1,3] A notable difference between our study and the study conducted by Schnock et al[3] is that they

compared errors with manually programmed infusions to errors with infusions programmed from interoperability during the same time frame. Our study design may introduce bias compared with previous studies because of continual updates to our drug library during preimplementation and postimplementation. However, our study design has the advantage of tracking the effect of smart pump interoperability on patient care and safety through the smart pump quarterly reports.

There were multiple limitations identified in this study. This was a retrospective study, which limits the ability to determine the reason for overrides and introduces other confounding variables. If the smart pump was not reprogrammed, we were unable to determine how the infusion was administered. The time frame was also limited to 6 months before and after interoperability implementation, which could miss potential errors as nurses become more familiar with interoperability. The start of the COVID-19 pandemic did occur during the preimplementation time, which resulted in less admission rates and staffing shortages that could potentially have led to higher error rates during this time frame. The postinteroperability time frame was chosen to start 6 months after interoperability went live to avoid the confounding variables of new technology training. The patient safety data provided additional information on different types of errors that occurred; however, these reports can vary by individual reporter and have the potential to introduce bias because these are a recall of events from the medical team member. This limitation was mitigated by assessing the patient's EMR to determine a more objective conclusion about the error.

These findings help support the utility of smart pump interoperability in reducing infusion errors in a pediatric setting. Additional education may be required to reduce errors with medications that are out of scope for interoperability, including education on the dosing conversion needed to program penicillin G, and educating on the limitations of the alerts in the neonatal library. For systematic changes, we will implement an alert for nursing in the medical record for medications that require manual programming as well as optimize the bolus infusion rate limits for the neonatal library to minimize alert fatigue. The errors surrounding propofol infusion may require changes to the library options to limit errors in addition to educating anesthesia staff about using the anesthesia library as opposed to the pediatric library. To reduce errors with titratable medications, double-checks may be implemented to catch these errors before they reach the patient. Reducing medication errors is a continuous process, so these implementations may be the next step in reducing infusion errors at these institutions.

## Conclusion

Smart pump interoperability is a novel technology that has the ability to greatly affect patient care. The implementation of smart pump interoperability resulted in a significant decrease in the frequency, type, and severity of medication errors in a pediatric institution. There are still medication errors that exist after interoperability was implemented; however, this study was able to define those persisting errors to help implement strategies like standardized workflow changes, drug library customization, clinical advisory alerts, and education to decrease these errors in the future.

## Article Information

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**Ethical Approval and Informed Consent.** The University of Louisville Institutional Review Board reviewed IRB No. 22.0523, approved the application to conduct the research study at Norton Children's Hospital, and declared the study exempt from needing informed consent.

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