Pediatric Dose Calculation Issues and the Need for Human Factors–Informed Preventative Technology Optimizations

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Abstract

Background: Dose calculation errors are one of the most common types of medication errors impacting children and they can result in significant harm. Technology-based solutions, such as computerized provider order entry, can effectively reduce dose calculation issues; however, these technologies are not always optimized, resulting in potential benefits not being fully realized.

Methods: We analyzed pediatric dose-related patient safety event reports submitted to the Pennsylvania Patient Safety Reporting System using a task-analytic approach that focused on information being used in the dose calculation, calculation errors during ordering, and errors during dose preparation or administration. From these reports, we identified whether the patient was impacted by the error, the type of medication involved, and whether a technology optimization could have mitigated the issue.

Results: Of the 356 reports reviewed, 326 (91.6%) met the criteria for a dose calculation issue. The 326 reports meeting criteria had the following dose calculation issue types: wrong information used in the calculation (49 of 326, 15.0%), incorrect calculation during ordering (97 of 326, 29.8%), and calculated dose was not properly used or incorrect calculation during preparation/administration (180 of 326, 55.2%). Most of these dose calculation issues impacted the patient (219 of 326, 67.2%). Analysis of these issues by patient age group and drug class also revealed interesting patterns. Technology optimizations potentially could have addressed 81.6% of the dose calculation issues identified.

Conclusion: While many healthcare facilities have adopted health information technology and other devices to support the medication process, these technologies are not always optimized to address dose calculation issues. Human factors–informed recommendations, a safety checklist, and test cases for optimizing technology are provided in the context of these findings.

Keywords: *medication errors, pediatrics, human factors, health information technology*

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Introduction

Medication errors are one of the most common patient safety issues impacting children and occur at a higher rate in children compared to adults.[1] The Joint Commission cites several reasons for children being more prone to medication errors and harm, which include most medications being formulated and/or packaged for adults, most healthcare settings being geared toward adult care, the inability for children to communicate effectively about medication issues, and the inability for young children to tolerate medication errors.[1] Within the category of medication errors, dosing errors are the most frequent and harmful.[2,3] Dosing error rates are notoriously difficult to quantify and compare, given differences in clinical setting, clinician training, and technology use. Further, it is widely recognized that many types of medical errors are underreported. Nonetheless, studies have estimated pediatric dosing error rates ranging from .03 per 100 admissions to over 4 per 100 admissions.[4,5]

Within the category of dosing errors, dose calculation errors are the most common issue in pediatric populations for several reasons.[6] Unlike adults, children often require dose calculations at the individual patient level, and this is performed using age, gestational age, weight, and/or surface area, which can require complex calculations that are error-prone.[3,6] Pediatric patient weight, especially for infants, may change rapidly, which requires close monitoring and documenting since a change in weight may require a change in medication dose.[3] Further, many medications are only available in adult concentrations, which then require careful dilution.[3]

Previous Research and Interventions

Recognizing the frequency of dose calculation errors and the significant impact they have on children, there has been extensive research and exploration of interventions to reduce these errors. This body of work has generally focused on people, processes, and technology. From a people perspective, several studies have examined clinician knowledge of how to perform dose calculations, with numerous studies focused on nurse abilities.[7–9] One study that examined pediatric medication errors, most of which were wrong dose and dose calculation issues, highlighted that insufficient nurse knowledge was the leading challenge when administering medications.[10] In response to research suggesting a knowledge gap contributing to most types of medication errors, training and education have been identified as the most common interventions recommended to reduce medication errors, including dose calculation issues, in pediatrics.[11]

Process-oriented studies and recommendations have focused on the inclusion of pharmacists in the medication process, safety checks at various stages of the medication process, and improved communication between care team members.[1,2,12–14] Including pediatric clinical pharmacists in the medication process has been shown to mitigate inpatient prescribing errors; however, involving pharmacists did not address administration errors.[13] A recent systematic review suggests there is insufficient evidence to conclude that two nurses checking a medication during administration, also referred to as "double checks," are more effective at preventing medication administration errors compared to a single nurse.[15] While communication challenges are a recognized contributor to medication errors in pediatrics, there has been little work to develop and test interventions that can improve communication.[14]

With the widespread adoption of health information technology (health IT) and devices to support the medication process by healthcare facilities, using technology to address dose calculation issues has been a central focus. Computerized provider order entry (CPOE), computer-aided prescribing, and smart infusion pumps are specific technologies that have been shown to reduce dose calculation issues in certain contexts.[6,16,17] However, despite these technologies effectively reducing dose calculation issues in some contexts, these issues persist in many healthcare facilities across the country. One reason for the persistence of dose calculation issues is that these technologies are customized and configured differently across healthcare facilities with little to no safety testing of the technology. For example, one study examining the task completion time and error rates associated with ordering a medication at four different emergency departments across four different healthcare systems, two using a Cerner electronic health record (EHR) and two using an Epic EHR, showed wide variability with over a threefold difference in task completion time and error rates when ordering a medication at one site compared to another.[18] This variability existed even at healthcare facilities using the same vendor product. There are also usability challenges, such as poor visual displays and ineffective alerts, as well as challenges with interoperability that prevent the safety benefits of health IT from being fully realized.[19,20] Optimizing these technologies that have already been adopted by most healthcare facilities can serve to reduce dose calculation issues.

Leveraging a Human Factors Approach

Applying the science of human factors, which focuses on understanding human capabilities and designing processes and technologies to meet these capabilities within the constraints of the work environment, provides a different and promising approach to addressing pediatric dose calculation issues.[21] Using human factors to address safety has been effective in other high-risk domains, such as aviation and defense, as well as in other areas of medicine.[22] In this study, we leverage human factors in two ways: using a task-analytic approach to understand and categorize dose calculation issues and then focusing on technology optimizations and solutions that mitigate the risk of dose calculation issues by designing error-prone steps out of the medication process.

First, we use a task-analytic approach to understand dose calculation issues. A task-analytic approach focuses on identifying necessary process stages and steps to completing a task without consideration for the specific individuals (e.g., physician, nurse) that need to complete the steps.[23] With medication process stages already established and used to study medication errors, we used these medication process stages as a starting point and identified the task-analytic steps within these stages that could contribute to dose calculation issues.[24] Through this process, we identified three important task-analytic components.

1. The wrong information, typically collected during the pre-ordering stage, could be used in the dose calculation process (e.g., a wrong weight is documented).
2. The wrong calculation could be performed (e.g., a mathematical error) during the ordering stage.
3. Finally, the correctly calculated information used during the ordering stage could be used incorrectly during preparation/administration (e.g., misreading the measurement markers on the syringe) or a calculation required during the preparation/administration stage could be done incorrectly.

While it is customary to discuss medication preparation and administration as separate phases of the medication process, the task-analytic approach notes that the final process step for completing the medication administration task is often inclusive of both the final preparation of medications as dispensed by the pharmacy and physically administering the medication. Often this requires an additional calculation at the point of administration, such as determining the volume of liquid required to administer the prescribed dose of a medication suspended in a liquid form. A calculation may also be required to ensure that an intravenous medication is administered at the appropriate rate of infusion. We use this framing to understand the task-analytic step in which pediatric dose calculation issues arise.

Second, when considering technology optimizations to reduce the likelihood of dose calculation issues, we focus on engineered, strong solutions which are oriented toward designing errors out of the work system rather than focusing on weaker, hard-to-sustain solutions such as training and education, which have been shown to have limited impact on patient safety.[25] Given the pervasive use of health IT, such as smart pumps used in the medication process, optimizing technology-based solutions that are already being used in healthcare facilities can serve to address dose calculation issues.

Study Focus

We analyzed patient safety event reports to identify those related to pediatric dose calculation issues which included incorrect information used in a calculation, incorrect calculations during ordering, and/or calculation issues during dose preparation or administration. From each report, we identified which of these three dose calculation issues occurred, whether the dose issue impacted the patient, and the medication involved in the report. Further, if we could identify a technology optimization that could have prevented the issue, that optimization was captured during analysis. This study provides specific areas for technology improvements that healthcare facilities can use to prevent or mitigate the impact of pediatric dose calculation issues.

Methods

Data Source and Selection

We analyzed patient safety event reports, submitted to the Pennsylvania Patient Safety Reporting System (PA-PSRS)[a] between January 1 and December 31, 2020.[26] All nonfederal, acute care facilities in Pennsylvania are required to report patient safety events through PA-PSRS. As this includes both teaching and nonteaching facilities, the full range of providers, including medical doctors, physician assistants, nurse practitioners, and associated trainees, may have entered medication orders in EHRs. Our analysis focused on reports classified under the Medication Error event type category by the reporter and comprised 46,569 reports from 281 facilities. PA-PSRS reports contain additional mandatory structured fields for information, such as facility type, facility name, and report severity, which consisted of near miss reports (harm scores A, B1, and B2) and reports that reached the patient and may have caused harm (harm scores C–I). In addition, each report has a mandatory free-text field for the reporter to describe the event.

To identify reports involving pediatric dose calculation issues, 100 Medication Error reports that had been manually reviewed by a pharmacist (NN) and indicated as potentially being related to dose calculation issues in either children or adults were randomly selected and reviewed by a nurse (EF) and physician (SK). From these reports, six elements commonly associated with reports involving dose calculation issues were identified and used to develop regular expression algorithms. These were then applied to all pediatric Medication Error reports submitted in 2020, including reports received from all care area types—including general inpatient pediatrics, pediatric and neonatal intensive care units, and pediatric ambulatory surgery settings—for a comprehensive approach to identifying pediatric dose calculation issue reports. The different elements, related regular expression search parameters, and number of reports identified are shown in **Table 1**. Each search parameter was not mutually exclusive, meaning a single report may appear under two different search elements.

Because there are healthcare facilities that specialize in pediatrics and have a large volume of pediatric patients, and therefore a greater number of reports from these facilities, there is a skewed distribution of reports by facility. To address the issue of oversampling from a single facility, for near miss (i.e., harm score A, B1, and B2) reports we randomly selected a maximum of five reports from each facility. All reports with harm scores C–I were included in this analysis. Based on these criteria, a total of 356 reports from 52 facilities were manually reviewed by the coders.

[a]PA-PSRS is a secure, web-based system through which Pennsylvania hospitals, ambulatory surgical facilities, abortion facilities, and birthing centers submit reports of patient safety–related incidents and serious events in accordance with mandatory reporting laws outlined in the Medical Care Availability and Reduction of Error (MCARE) Act (Act 13 of 2002).[26] All reports submitted through PA-PSRS are confidential and no information about individual facilities or providers is made public.

Table 1. Elements Commonly Associated With Dose Calculation Issues, Search Parameters, and Number of Reports Identified

Elements Commonly Associated With Dose Calculation Issues	Search Parameters	Number of Pediatric Reports
Weight-based issues	Dose calculation indicates value per kilogram per value (e.g., "unit/kg/hr" or "mEq/kg/4hrs")	4,704
	Narrative language indicating weight incorrect (e.g., concern/accurate/verify + weight)	71
	Two kg values and narrative language indicating incorrect (e.g., # kg + instead of/despite/rather than + # kg)	13
Unit of measurement–based issues	Two mL, mLs, or cc values and narrative language indicating incorrect (e.g., # mL/mLs/cc + instead of/despite/rather than + # mL/mLs/cc)	144
	Units (e.g., unit + instead of/despite/rather than + mL/mLs/cc)	3
	mg + instead of/despite/rather than + mcg	4
Pump programming issues	Narrative language indicating pump settings are incorrect	57
Body surface area–based issues	Body surface used in calculation as indicated by "m2"	142
Calculation-based issues	Narrative language indicating calculation incorrect (e.g., concern/accurate/verify + calculation)	8
Concentration-based issues	Narrative language indicating standard concentration issues	0

Coding Taxonomy and Analysis Methods

Our coding taxonomy was iteratively developed by three nurses (JR, JG, EF) and a physician (SK). We operationally defined a safety report as a dose calculation issue if the free text described any one of the following:

- Wrong information is used in the calculation. For example, the wrong weight being documented in the EHR and used in a calculation.
- The calculation itself is done incorrectly resulting in an incorrect dose being ordered.
- A correct dose may be ordered, but the calculated dose is not properly used during preparation and/or administration, resulting in a dose issue, or a calculation is done incorrectly during preparation/administration. Examples include incorrect smart pump programming, incorrect interpretation or reading of measurement increments on a syringe or medication cup, and incorrect calculations during medication administration.

Reports that met the dose calculation definition above were further reviewed to determine:

- The criterion that was met to constitute a dose calculation issue type:
  - Coder indicates the single criterion that was met and if multiple criteria were met the coder indicates the one that occured earliest in the task-analytic process (e.g., ordering before medication preparation/administration):
    - Wrong information is used in the calculation.
    - Calculation is done incorrectly at ordering.
    - Calculated dose is not properly used during preparation/administration or calculation is done incorrectly at preparation/administration.
- Whether the error impacted the patient:
  - Coder indicates yes if the error resulted in the patient's care being altered in any way, such as a delay in care or the wrong procedure being performed, or resulted in a patient receiving the wrong treatment or information, such as test results or discharge instructions; otherwise, coder indicates no/can't tell.
- The medication(s) involved in the safety report:
  - The reporter may have indicated the drug involved either in a structured field or in the free-text report description, and the coder documented the drug name, which was then mapped to general drug classes.
- Whether there is a technology optimization that potentially could have prevented the error:
  - Coder indicates one of the following:
    - Within System Cross-Checking: Improved cross-checking of information within a single health IT system (e.g., weight entered for medication order matches documented weight) or comparison of health IT information to norms (e.g., determining

whether documented weight is within normal range for a patient that age) could have addressed the dose calculation issue.

- Cross-System Interoperability: Improved information flow between two or more health IT systems and/or devices could have addressed the dose calculation issue.
- No Technology Optimization: A technology optimization could not be identified.

Analyses were stratified by patient age with five categories defined as follows: neonate- 0 to 30 days, infant- 31 days to 1 year, toddler- 1 to 3 years, child- 4 to 12 years, adolescent- 13 to 18 years.

Coding Process

Two nurses (JR and JG) manually reviewed and coded all reports identified from the algorithm search process. Ten percent of the reports were dually coded to establish inter-rater reliability (IRR). Across all coding categories, except whether a technology optimization could have potentially prevented the error, the average percent agreement was 89% (range: 72%–100%). To determine whether a technology optimization could have prevented the error, each report was coded by one nurse and then checked by the second nurse for agreement with any discrepancies discussed and a final code was selected by the two coders.

Results

Of the 356 reports reviewed, 326 (91.6%) met the criteria for a dose calculation issue, with 23.3% of reports (76 of 326) related to neonates, 26.1% (85 of 326) to infants, 18.4% to toddlers (60 of 326), 20.6% to children (67 of 326), and 11.7% (38 of 326) to adolescents.

As shown in **Figure 1**, the 326 reports meeting criteria had the following dose calculation issue types: wrong information used in the calculation (49 of 326, 15.0%), incorrect calculation during ordering (97 of 326, 29.8%), and calculated dose was not properly used or incorrect calculation during preparation/administration (180 of 326, 55.2%). Most of these dose calculation issues impacted the patient (219 of 326, 67.2%).

Dose Calculation Issues by Patient Age Category

Figure 2 shows the frequency count of dose calculation issue type by patient age category with percentages relative to all dose calculation issue types within each patient age category. Across all patient age categories, calculated dose used incorrectly during preparation/administration or calculation error at preparation/administration was the highest percentage, except for toddlers. Compared to neonates (6.6%) and infants (7.1%), toddlers (31.7%), children (19.4%), and adolescents (15.8%) had a higher percentage of dose calculation issue reports associated with wrong information being used in the dose calculation.

Dose Calculation Issues by Drug Class

To identify medications that were frequently associated with dose calculation issues, medications were classified into general drug classes. Classes mentioned in 5% or more of the reports accounted for most reports (210 of 326, 64.4%) and included: antibiotics (49 of 326, 15.0%), total parenteral nutrition (TPN)/partial parenteral nutrition (PPN) (40 of 326, 12.3%), sedation/anesthesia (33 of 326, 10.1%), opioids (30 of 326, 9.2%), intravenous (IV) fluid (23 of 326, 7.1%), nonopioid pain relievers (18 of 326, 5.5%), and steroids (17 of 326, 5.2%).

Figure 3 shows the frequency count of dose calculation issue types by drug class with percentages relative to all dose calculation issue types within each drug class category. Antibiotics were mostly associated with incorrect calculations during

Figure 1. Dose Calculation Issue Type Identified in PA-PSRS Reports Meeting Inclusion Criteria (N=326)

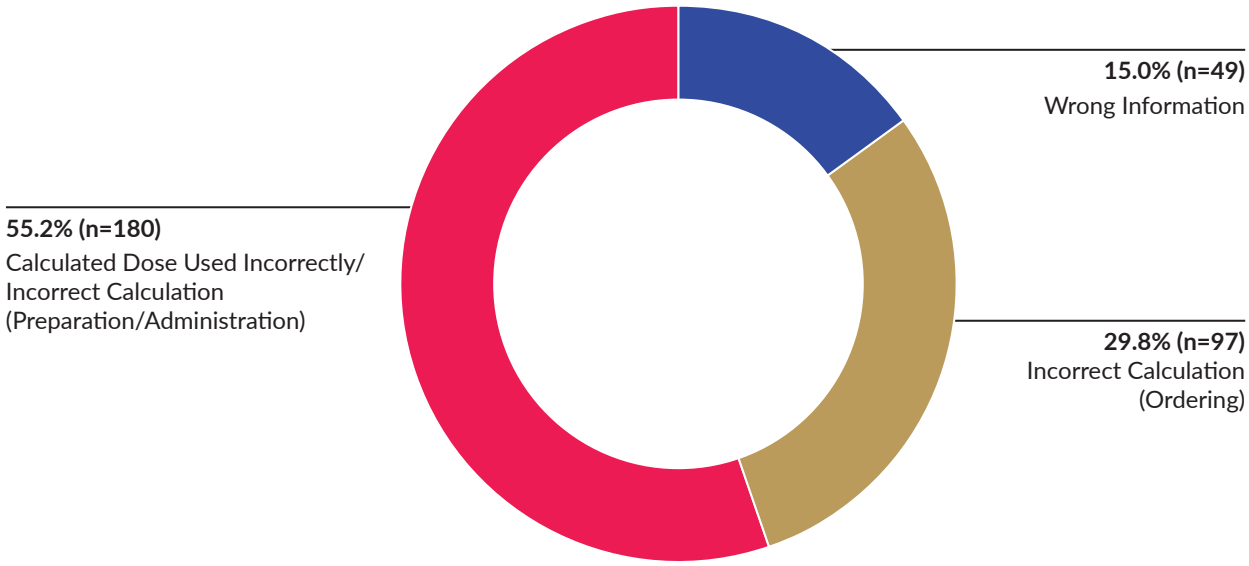


Figure 2. Dose Calculation Issue Type by Patient Age Category Identified in PA-PSRS Reports (N=326)

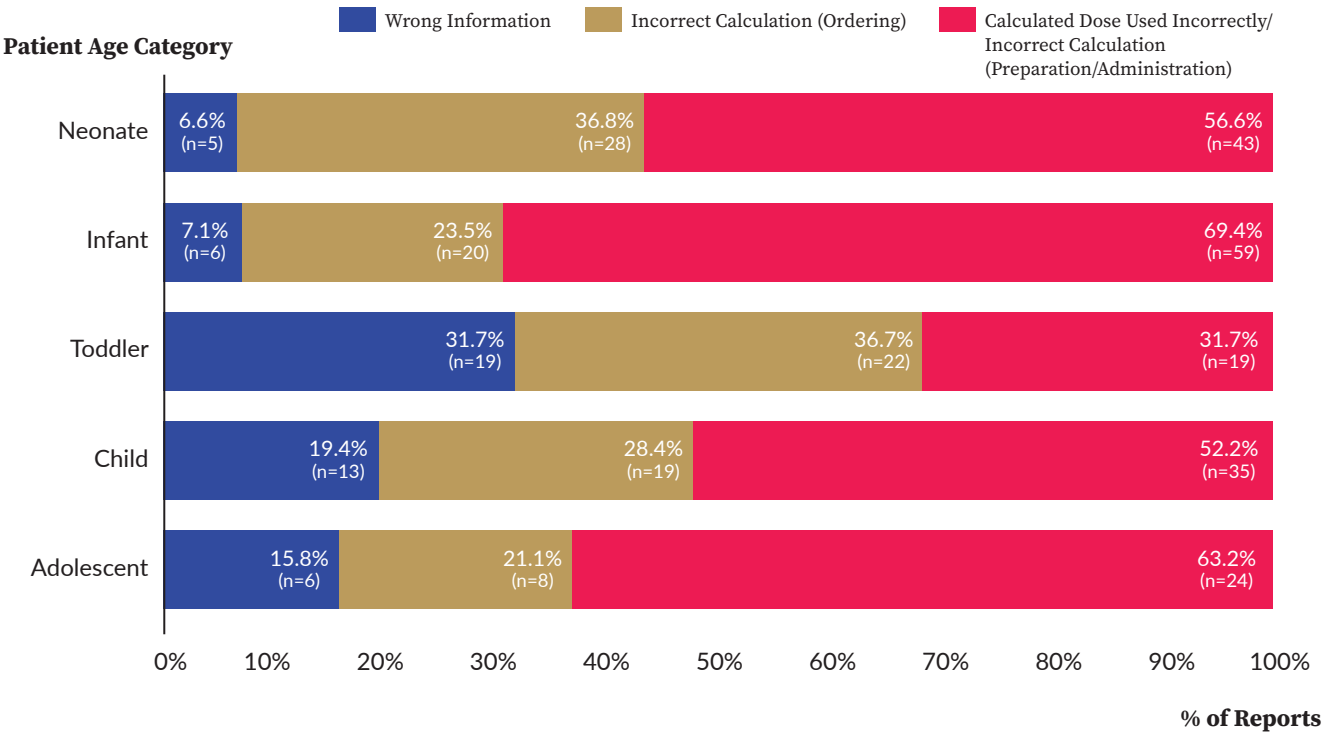
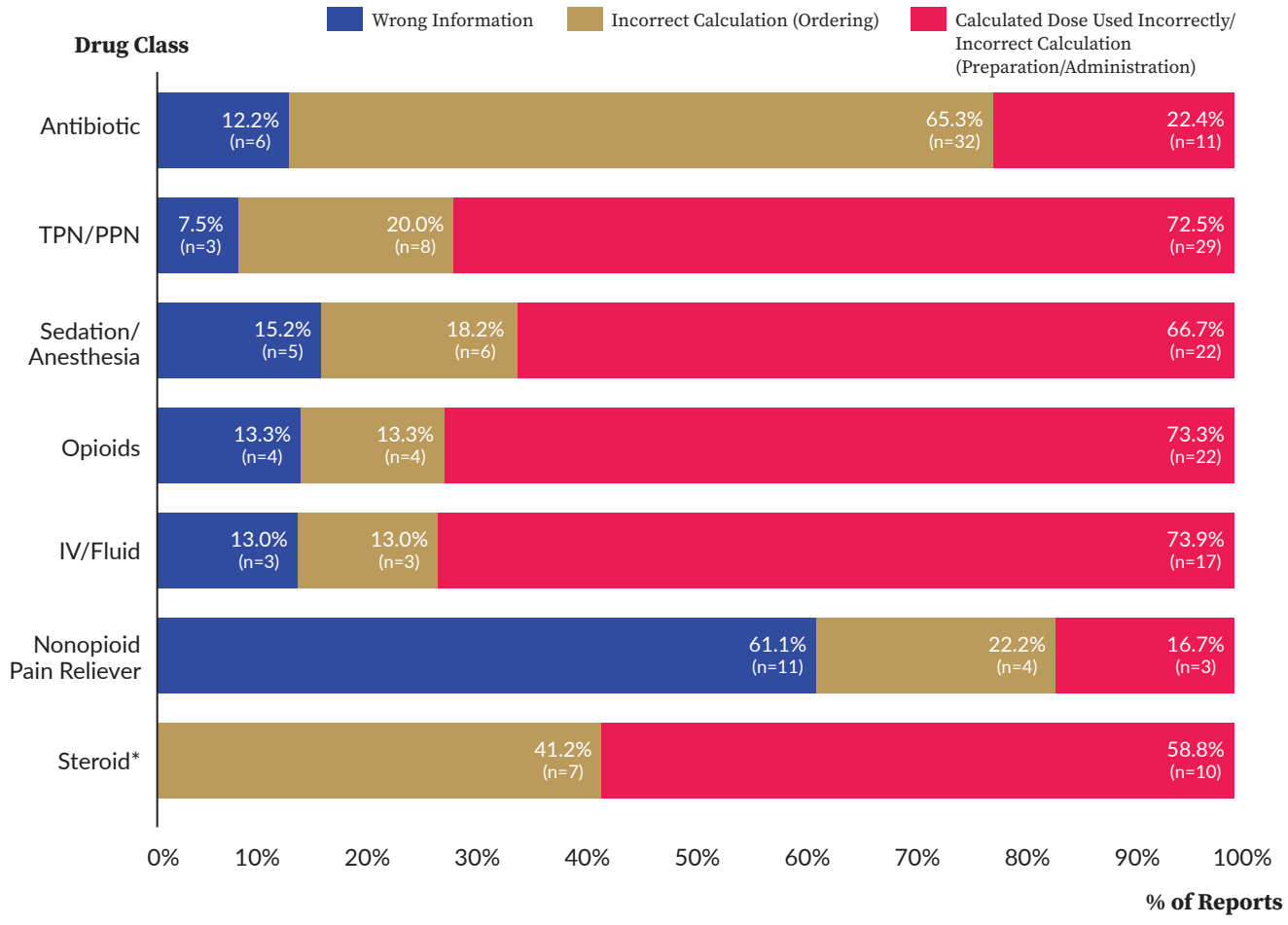


Figure 3. Dose Calculation Issue Type by Drug Class Identified in PA-PSRS Reports (n=210)



*None of the reports that involved a steroid occurred as a result of using wrong information in the calculation.

ordering (65.3%) and nonopioid pain relievers were mostly associated with wrong information being used in the dose calculation (61.1%). All other drug classes analyzed were mostly associated with calculated doses not being properly used during preparation/administration or incorrect calculations during preparation/administration.

Technology Optimization Opportunities to Address Dose Calculation Issues

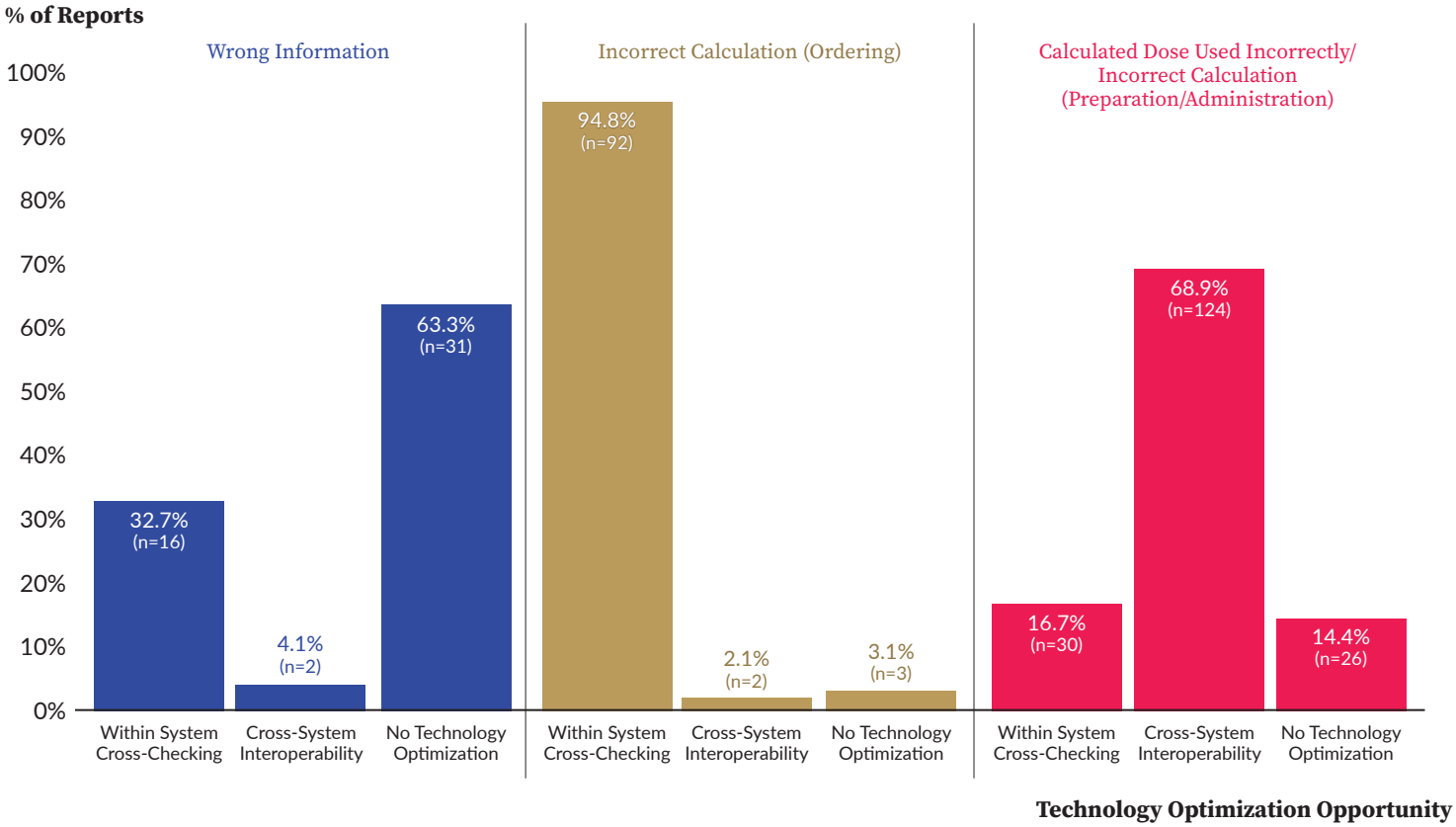
Technology optimizations could potentially have addressed 81.6% (266 of 326) of the dose calculation issues either via *within system cross-checking* (138 of 326, 42.3%) or improved *cross-system interoperability* between technologies (128 of 326, 39.3%). For the remaining 60 reports (18.4% of 326) in the sample, a clear way for technology to optimize the process could not be identified. **Figure 4** shows the frequency count of technology optimization opportunity by dose calculation issue type and where technology was not believed to be capable of optimizing the process. Percentages reflect the technology optimization opportunity relative to all reports within that dose calculation issue type. It was difficult to identify technology optimizations to address many of the dose calculation issues associated with wrong information (63.3%). *Within system cross-checking* would address the largest percent (94.8%) of incorrect calculations during ordering while *cross-system interoperability* would address 68.9% of the dose calculation issues associated with either the calculated dose not being properly used during preparation/administration or an incorrect calculation during preparation/administration.

Discussion

Using a task-analytic approach to analyze pediatric dose calculation issues, we identified that most of these issues were associated with calculated doses not being properly used during preparation/administration or incorrectly calculated doses during preparation/administration (55.2%), followed by incorrect calculations during ordering (29.8%), and then by issues associated with using the wrong information for the calculation in 15% of the reports. Using the wrong information for the calculation was more of an issue for toddlers (31.7%), children (19.4%), and adolescents (15.8%) compared to neonates (6.6%) and infants (7.1%) when looking at percentages relative to other dose calculation issues within a patient age category. The differences by drug class showed interesting patterns. Nonopioid pain relievers were associated with wrong information used in the calculation a majority of the time (61.1%) relative to other dose calculation issue types, while antibiotics were often associated with incorrect calculations during ordering (65.3%), and the other drug classes mostly had issues with drug preparation and administration.

Technology optimizations may be able to address many of the incorrect dose calculation issues during ordering and many of the issues during preparation/administration, which comprise most of the entire set of dose calculation issues analyzed. Dose calculation issues associated with wrong information, however, are more difficult to address with technology optimization. One clear pattern that emerged was that the majority of incorrect calculation issues during ordering could be addressed by better information cross-checking within a single health IT system, and

Figure 4. Technology Optimization Opportunity by Dose Calculation Issue Type Identified in PA-PSRS Reports (N=326)



these optimizations would likely be best implemented at the point of medication ordering/reviewing. For example, a feature such as checking a documented weight against the weight being used in a medication order could ensure that the correct information was being entered into calculations. A different pattern of technology optimizations exists for dose calculation issues during preparation/administration. *Cross-system interoperability* between different technologies, such as smart pumps and the electronic medication administration record (eMAR), could address many of these issues.

Recommended Technology Optimizations to Address Dose Calculation Issues

Following from our analysis, we provide specific recommendations for technology optimizations to address dose calculation issues. As a general principle, when designing technology to address safety issues, focusing on preventing a user from making the error by designing the error-prone step out of the workflow is the most effective approach.[21] Alerts should only be used when the approach of designing out errors is not possible. For example, it is more effective to design a medication ordering screen such that medication doses well above recommended dose guidelines are not presented rather than alerting a user when they select a dose outside the guideline ranges. When alerts are the only option to address a safety concern, the alerts should be designed with the end user in mind.[27] Specific recommendations based on our analyses and the work of others are provided below:

Preventing wrong information being used in the dose calculation (pre-ordering):

- Implement rules to cross-check currently documented weight/height against historical values, if available, and alert the provider if potentially abnormal increases or decreases (e.g., 25%) are input into the EHR.
- Implement rules to check current weight/height against normal ranges for the patient's age and alert the provider if a potentially abnormal value is being documented.
- Implement rules that do not allow impossible pediatric values to be entered into weight/height fields (e.g., 1000 kgs).
- Ensure technology interfaces consistently use the same units of measure, such as metric units. For example, when documenting weight ensure weight is always documented in kilograms or grams, as appropriate.

Preventing dose calculation issues during ordering:

- In general, taking the human component out of the calculation and relying on the technology to perform the calculation is an approach that will reduce the risk of human error.
- Enable automated calculations and automated population of patient weight and/or other relevant information that is already documented in the EHR.[28]
- Enable drug-dosing decision support that crossmatches drug dosing with other information already documented in the EHR such as weight, height, allergies, and diagnoses.[28]
- Implement rules within CPOE to make out-of-range doses (such as tenfold doses) not available to order.
- Activate drug dictionaries with pediatric-specific dose ranges and alerts.[28]

Preventing dose calculation issues during preparation/administration:

- Ensure pharmacy health IT software communicates with the medication ordering software to enable pharmacists to have easy access to the same data as the ordering provider.
- Utilize smart pumps and establish and maintain comprehensive drug library profiles for specific patient populations.
- When using smart pumps, establish guardrails to prevent users from entering medication doses out of range for specific medications and/or patients.
- Implement interoperability between smart pumps and the EHR to limit the number of calculations and programming done by clinicians at the bedside.[29]

A more comprehensive checklist of health IT safeguards, as well as test cases to assess whether a facility's EHR has these safeguards in place, is provided in **Appendix A**.

Additional Safety-Related Resources to Improve Healthcare Technologies

In addition to these recommendations, there are several other resources that healthcare facilities should consider for safer technology use and for using technology to prevent safety issues. These resources include:

SAFER Guides: The Safety Assurance Factors for EHR Resilience (SAFER) guides are self-assessment checklists that can serve as a proactive risk assessment tool to identify aspects of the health IT system that can be modified to improve safety.[30] SAFER guides are now being adopted by the Centers for Medicare & Medicaid Services and are available at https://www.healthit.gov/topic/safety/safer-guides.

Leapfrog Clinical Decision Support Tool: This tool is a survey-based instrument that can be used to assess CPOE safety through the completion of different test cases.[31] For example, the tool assesses a healthcare facility's CPOE for dose limits based on patient diagnosis and laboratory results. A clinician with experience using the healthcare facility's CPOE system completes the test cases that contain unsafe scenarios. Through this process, the facility can identify areas for CPOE optimization.

Human Factors Guides and Clinical Test Cases: The National Institute of Standards and Technology has developed a human factors guide to improve clinician interactions with the EHR specifically for pediatric settings.[32] The Pew Charitable Trusts and partners have developed clinical test cases, for both adults and pediatric patients, that can be used to assess the usability and safety of a healthcare facility's EHR.[33] These cases serve to identify specific areas for health IT optimization and can be used on any EHR vendor product.

Institute for Safe Medication Practices (ISMP) Guides and Resources: ISMP has several guidelines and tools that can be used by healthcare facilities to reduce dose calculation issues. These materials include guidelines for order sets, for electronic communication of medication information, and for safe implementation and use of smart pumps, as well as a variety of medication safety self-assessment tools.[34,35]

Limitations

Our analysis was limited to the information provided in the patient safety event report and we were not able to follow up with specific reporters or healthcare facilities for additional information about each described safety issue or about their local policies related to the medication process, such as facility-specific policies defining classification thresholds for adolescents and adults. Additionally, this study analyzed patient safety event reports submitted to PA-PSRS and may not be fully representative of experiences outside of Pennsylvania. The search strategy we used to identify dose calculation issue–related reports may not have identified all possible reports in the dataset. COVID-19 may have impacted the types of dose calculation issues reported and we were unable to identify whether patient safety reports were related to COVID-19. The identification of technology optimizations can be limited without knowing the specific customizations and configurations at each healthcare facility.

Conclusion

Analyzing pediatric dose calculation issues from a task-analytic perspective provides additional insight into how these issues persist after the adoption of technologies intended to improve safety. While many healthcare facilities have adopted health IT and other devices to support the medication process, these technologies are not always optimized to address dose calculation issues. Optimizing current technologies based on the recommendations provided from our analysis may serve to mitigate these dose-related safety issues.

Notes

This study was approved by the MedStar Health Research Institute institutional review board.

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Appendix A—Pediatric Medication Dose Calculation Health Information Technology Safety Checklist and Test Cases

Purpose: Pediatric medication dose calculation issues can cause significant patient harm. This checklist is intended to help identify whether health information technology (health IT) safeguards for addressing certain sources of pediatric medication dose calculation issues are implemented in your facility's health IT systems.

The checklist is organized around medication pre-ordering, ordering, and administration stages. The checklist is intended to be used as a self-assessment tool and can be used in both inpatient and outpatient settings. Some recommendations may not be relevant to your healthcare facility and these can be omitted from your review process. For some checklist items, we have provided simple test cases to assist in your assessment of whether your health IT system has the checklist feature described. Tasks within each test case must be completed sequentially. When possible, we recommend using a team-based approach to completing this checklist with both clinical and technology expertise represented on the team.

Appendix A (continued).

Recommendation	Is the recommendation implemented? Yes	No	Associated Test Case Question
Pre-Order			
Patient weight should be documented in metric units only, specifically grams and kilograms, as appropriate.	☐	☐	Q1
Patient weight should be displayed in metric units only, specifically grams and kilograms, as appropriate.	☐	☐	N/A
Patient height should be documented in metric units only, specifically centimeters.	☐	☐	Q2
Patient height should be displayed in metric units only, specifically centimeters.	☐	☐	N/A
The health IT software should clearly indicate whether a field on the interface for the patient's weight is for actual weight or dosing weight.	☐	☐	N/A
When a patient's weight is documented, the health IT software should compare it to the patient's age and notify the user if the weight is not within range for the patient's age.	☐	☐	Q3
When a patient's height is documented, the health IT software should compare it to the patient's age and notify the user if the height is not within range for the patient's age.	☐	☐	Q4
When a patient's weight is documented, it should be compared to previously documented weights, if available, and the health IT software should compare and notify the user if there is a significant discrepancy.*	☐	☐	Q5
When a patient's height is documented, it should be compared to previously documented heights, if available, and the health IT software should compare and notify the user if there is a significant discepancy.*	☐	☐	Q6
When a patient's actual and dosing weights are documented, the health IT software should compare these weights to each other and notify the user if there is a significant discrepancy.*	☐	☐	Q7
Ordering			
When ordering/prescribing medications, the health IT software should represent all doses in metric units.	☐	☐	N/A
When ordering/prescribing medications, the health IT software should clearly indicate whether the patient's actual or dosing weight is being used.	☐	☐	N/A
Medication ordering/prescribing should be supported by medication order sets, especially for high-risk populations like newborns.	☐	☐	Q8
When ordering/prescribing medications, the health IT software should round the dose to the hundredths place (e.g., 0.05) for certain medications and populations.	☐	☐	Q9
When ordering/prescribing medications, the health IT software should provide a method to access up-to-date medication dosing information, such as drug dictionaries.	☐	☐	N/A
The pharmacy health IT software should interface with the ordering/prescribing health IT software to support pharmacist order verification.	☐	☐	N/A
When ordering/prescribing medications, the health IT software should limit the maximum dose that can be entered to appropriate ranges for the medication.	☐	☐	Q10
When ordering/prescribing medications, the health IT software should limit the daily maximum dose the patient can receive based on clinical guidelines.	☐	☐	Q11
When ordering/prescribing medications, the health IT software should limit the maximum dose the patient can receive within a specific time interval (e.g., per week, per month) based on clinical guidelines.	☐	☐	Q12
When ordering/prescribing medications, the health IT software should require documentation of weight prior to completion of the order.	☐	☐	Q13
When ordering/prescribing medications, the health IT software should require documentation of height prior to completion of the order.	☐	☐	Q14
When ordering/prescribing medications, the health IT software should limit the maximum dose the patient can receive within their lifetime (e.g., radiation, chemotherapy) based on clinical guidelines.	☐	☐	N/A
The health IT software should perform dose calculations for the user.	☐	☐	N/A
Administration			
When staff are administering medications, barcode medication administration (BCMA) should enable verification of drug dose.	☐	☐	N/A
When staff are administering medications, smart pumps with appropriate drug libraries should be available.	☐	☐	N/A
When staff are administering medications, the health IT software (e.g., electronic health record) should interface with smart pumps.	☐	☐	N/A

* The allowable discrepancy will vary by population and should be determined by the facility.

Appendix A (continued).

Test Case 1: Pre-Order

To be completed by: *Nursing Staff*
Test Patient Parameters: *Age- 2 months, Sex- Male, Weight- NOT ENTERED, Height- NOT ENTERED*

		Yes	No	Unsure
Task 1.1:	Document the patient's **actual weight** as 20 lbs.			
	Q1. Does the electronic health record (EHR) prevent you from entering the patient's **actual weight** in a unit other than kg?	☐	☐	☐
Task 1.2:	Document the patient's **height** as 2 ft and 7 in.			
	Q2. Does the EHR prevent you from entering the patient's **height** in a unit other than cm?	☐	☐	☐
Task 1.3:	Document the patient's **actual weight** as 9 kg.			
	Q3. Does the EHR notify you that the **actual weight** is out of range for the patient's age?	☐	☐	☐
Task 1.4:	Document patient's **height** as 80 cm.			
	Q4. Does the EHR notify you that the **height** is out of range for the patient's age?	☐	☐	☐
Task 1.5: Task 1.6: Task 1.7:	Document patient's **actual weight** as 4.5 kg. Document patient's **height** as 55 cm. Document patient's **actual weight** as 6.5 kg.			
	Q5. Does the EHR notify you that the **actual weight** entered is substantially different than the previously documented **actual weight**?	☐	☐	☐
Task 1.8:	Document patient's **height** as 63 cm.			
	Q6. Does the EHR notify you that the **height** entered is substantially different than the previously documented **height**?	☐	☐	☐
Task 1.9: Task 1.10:	Document patient's **actual weight** as 4.5 kg. Document patient's **dosing weight** as 6.5 kg.			
	Q7. Does the EHR notify you that the **dosing weight** entered is substantially different than the **actual weight**?	☐	☐	☐

Notes:

Test Case 2: Ordering

To be completed by: *Ordering Provider*
Test Patient Parameters: *Age- Between 7 and 30 days old*, Sex- Female, Weight- 3.410 kg, Height- 52 cm, Allergies- No Known Allergies (NKA)*

		Yes	No	Unsure
Task 2.1:	Search for **antibiotics for newborns** (gentamicin and ampicillin).			
	Q8. Does the EHR provide an order set for **antibiotics for newborns** (gentamicin and ampicillin)?	☐	☐	☐
Task 2.2:	Order **indomethacin** with a dose of **0.682 mg.** *(Note: please enter this dose exactly.)*			
	Q9. Does the EHR round the dose to the **hundredth place** (e.g., 0.68)?	☐	☐	☐
Task 2.3:	Order **acetaminophen, 68 mg, one time.**			
	Q10. Does the EHR notify you that this **single** dose is out of range for the patient?	☐	☐	☐
Task 2.4: Task 2.5:	Delete previous acetaminophen order. Order **acetaminophen, 52 mg, every 4 hours.**			
	Q11. Does the EHR notify you that the **daily** dose is out of range?	☐	☐	☐
Task 2.6:	Delete previous acetaminophen order.			

*Remember patient age must be between 7 and 30 days old during testing so consider the time between creating the patient and completing the use cases.

Notes:

Appendix A (continued).

Test Case 3: Ordering

To be completed by: *Ordering Provider*
Test Patient Parameters: *Age- 6 years, Sex- Female, Weight- 20 kg, Height- 110 cm, Allergies- No Known Allergies (NKA)*

		Yes	No	Unsure
Task 3.1:	Order **Botox, 120 units, every 6 weeks.**			
	Q12. Does the EHR notify you that the **weekly** dose is out of range?	☐	☐	☐
Task 3.2:	Delete the order for Botox.			

Notes:

Test Case 4: Ordering

To be completed by: *Ordering Provider*
Test Patient Parameters: *Age- 3 years, Sex- Male, Weight- NOT ENTERED, Height- NOT ENTERED, Allergies- No Known Allergies (NKA)*

		Yes	No	Unsure
Task 4.1:	Order **ibuprofen, 50 mg, one time.**			
	Q13. Does the EHR prevent you from signing the medication until the patient's **weight** is entered?	☐	☐	☐
	Q14. Does the EHR prevent you from signing the medication until the patient's **height** is entered?	☐	☐	☐
Task 4.2:	Delete the order for ibuprofen.			

Notes: