Designing and evaluating an automated intravenous dosage medication calculation tool for reducing the time of stat medication administration in a pediatric emergency department

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ABSTRACT

Background: Urgent medications are regularly prescribed using the term “stat”, which indicates that the medication should be administered within 30 min after it is ordered. However, many hospitals struggle to reliably administer stat medications within 30 min after they are ordered. This study involved developing and evaluating an automated intravenous dosage medication calculation tool (AIVDMCT) for reducing the time between the order and administration of stat medications to children at a pediatric emergency department (PED) in Saudi Arabia.

Methods: This prospective observational study evaluated data from before (June–December 2016) and after (June–December 2017) the AIVDMCT was implemented for high-risk medications in our PED. Patients were considered eligible if they were <14 years old, weighed <40 kg, and required stat intravenous (IV) medications at the PED of our tertiary care hospital.

Results: Implementation of the AIVDMCT significantly reduced the intervals between the time of order (TO) and the time of preparation (TP) (average time: 8.05 ± 3.42 min) and between the TP and the time of administration (TA) (average time: 3.74 ± 1.70 min). Furthermore, the interval from the TO to the TA was significantly reduced after the AIVDMCT was implemented (average time: 11.79 ± 4.48 min, P < 0.001).

Conclusion: The AIVDMCT was associated with a significant reduction in the interval from the TO to the TA. This increased the proportion of stat medications that were delivered within the 30-min target window.

1. Introduction

Patients who present to the pediatric emergency department (PED) have a high risk of medication errors, with rates of up to 5.7 medication errors per 100 orders [1]. The most common type of medication error in the PED is overdose [1]. The risk of these errors is high in the emergency department (ED), as there is a need to rapidly administer the medication after preparation using the ED's floor stock and under the stress of critical situations.

Urgent medical treatments are regularly prescribed in the PED and other hospital wards using the term “stat”, which is derived comes from the Latin word “statim” for “immediately”. This prescription term is intended to speed up orders that are required immediately, and stat medication orders should be administered within 30 min after the time they are ordered [2]. However, numerous hospitals struggle to reliably administer stat medications in <30 min, despite the fact that delayed medication administration can prolong the patient recovery time, prolong the hospital stay, and even harm the patient [3]. Prompt administration of urgent medications is important for high-quality care, as delayed administration of anti-microbial agents is associated with increased mortality among sepsis patients and children with epilepticus [4, 5]. Nursing practice for drug ordering and delivery is typically divided into five stages: prescribing, transcribing, dispensing, administration, and monitoring, which must be observed carefully when nurses...
administer any type of drug [1]. Errors can occur during the steps for prescribing the medication, reading the prescription, dispensing the medication, administering the medication, and controlling the drug(s) [6].

The current practice at our tertiary care hospital focuses on nine “rights”: the right patient, the right drug, the right route, the right dose and strength, the right time and in relation to meals, the right documentation, the right product label/integrity/purity/expiry date, the right to education/explanation, and the right to refuse treatment. All of these parameters must be documented and communicated to the physician. Every medication order written by physicians is reviewed by an assigned nurse for appropriateness and clarification regarding the safe medication dose using our institution’s drug formulary [Figure 1]. However, the calculations are performed manually by the nurses before the medication is administered to the patient, and this is tracked using a paperwork-based system for physician orders that is administered by nurses and other healthcare workers. This system is prone to calculation errors or delays in the administration of medication to the patient, which can be associated with different harms. Moreover, requesting, dispensing, and administering medications, as well as monitoring the treatment process, are becoming increasingly challenging processes for pediatric patients [6, 7]. Several strategies have been proposed to prevent and reduce medication errors, which target staff training, communicating information regarding new drugs, making pharmacology books available in the ward, medication-error analysis, computerized provider-order entry systems, automated dispensing cabinets, barcoded systems, medication reconciliation processes, and proper labeling of syringes according to the International Organization for Standardization guidelines [1, 6, 8]. These measures can be used to prevent medication errors and thus increase the quality of care and patient safety [6].

The present study aimed to develop and evaluate an automated intravenous dosage medication calculation tool (AIVDMCT) for reducing the interval from the time of order to the time of administration among children who were treated at a tertiary hospital’s PED in Riyadh, Saudi Arabia.

2. Methods

2.1. Study setting and design

This prospective observational study was performed at the PED of a tertiary care hospital in Riyadh, Saudi Arabia. This institution includes four hospitals and four medical centers, which expect to treat >19,171 inpatients annually and >238,404 patients at the outpatient department and EDs. The PED had 26 beds to provide acute care and critical care to an average of 1,913 patients per month. The present study focused on the prescription of high-risk intravenous medications in the PED, which were defined as antibiotics, antiepileptic drugs, intravenous electrolyte

![Diagram of medication administration process]

Figure 1. Barriers to timely medication administration.
replacement, frusemide, labetalol, mannitol, steroids, atropine, adenosine, insulin, morphine, fentanyl, milrinone, and inotropes.

This study evaluated an AIVDMCT that was designed to reduce the time from the order to administration of stat medications in the PED. The study flowchart and medication guidelines were reviewed, monitored, and renewed annually by a senior pharmacist and a registered nurse [Figure 1]. The tool considered patient demographic data, generic medication names, vial or ampule strength, physician dosage order, and dilution instructions with the rate of infusion for the nurses. Data were collected for pediatric patients (≤14 years old, body weight of ≤40 kg) who were prescribed high-risk medications in the PED during June–December 2016 (before the AIVDMCT was implemented) and during June–December 2017 (after the AIVDMCT was implemented). The study was approved by our institutional review board [Figure 2].

2.2. Study intervention

The AIVDMCT and a review guideline system were developed by a quality improvement (QI) core team, which included pediatric consultant physicians, registered pediatric nurses, senior pharmacists, and a Microsoft Excel expert engineer. The pediatric consultant physicians, senior pharmacists, and registered pediatric nurses were involved to ensure that the information was collected accurately and reflected important safety considerations. The pediatric consultant physicians and senior pharmacists defined the standard medication doses, and the pharmacists and nurses standardized the medication preparation and administration procedures.

The tool was developed based on an Excel spreadsheet for cardiopulmonary resuscitation, which includes the stat and infusion medications, as well as dosage calculations for weights of 1–40 kg [Figure 3]. At
the end of 2017, the QI core team developed the AIVDMCT using a secured Excel spreadsheet to record the safe and proper medication administration processes, which included dosage calculations, preparation processes, and appropriate administration times for pediatric patients with body weights of 1–40 kg. The standard formulas were used from our tertiary hospital-approved medication guidelines, with oversight from the pharmacy team and conversion into the automated tool by the Microsoft Excel engineer.

The AIVDMCT system included the medical record number (MRN), patient name, patient age, patient weight, generic medication name, vial or ampule strength, physician dosage order, and dilution instructions with rate of infusion for the nurses [Figure 2]. The AIVDMCT system was installed on all computers in the PED, which allowed the nurses to enter the patient's MRN and weight in kg, as well as the name of the medication and the physician-ordered medication dosage. The system automatically generates a list of medication options with the calculated intravenous dosage based on the drug strength and patient weight. The nurses were encouraged to contact the pharmacist to ensure that all patients received the correct medication, especially if the patient had a condition that might alter the medication dose or administration (e.g., allergies, medical disorders, abnormal laboratory test results, or other conditions). When the medication was approved by the pharmacy, one nurse prepared the medication and a second nurse performed manual checks to confirm the medication calculations. The first nurse then confirmed the patient's identity based on their first, middle, and last names, as well as the MRN. When the patient's identity has been confirmed, the medication is administered using the proper technique [Figure 1]. A team of nurses and pharmacists was assembled to follow the medication processes from

![Figure 3. A spreadsheet based on body weight that includes the STAT and infusion medication doses.](image-url)
the order to the administration, which identified barriers to timely medication administration. The nursing staff were also educated regarding the AIVDMCT and how to properly use that system.

The following information was collected for each medication order: medication name, date ordered, time of order (TO) by the physician, and time of preparation (TP) and time of administration (TA) by the nurses. This information was collected into an Excel spreadsheet to evaluate these times before and after the implementation of the AIVDMCT. The TO was defined as the time at which the physician placed the medication order. The TP was defined as the time that the nurse entered the order into the AIVDMCT and retrieved the medication from the PED floor stock or the pharmacy. The TA was defined as the time at which the patient received the medication. All medication orders were prospectively reviewed by the QI core team before and after the AIVDMCT was implemented, and a physician was consulted for cases that required further clarification. The QI core team collected data from the patient’s electronic medical records on a monthly basis during June–December 2016 (before the AIVDMCT was implemented) and during June–December 2017 (after the AIVDMCT was implemented). Data were not collected for other months during the study period because of staffing issues at the time.

2.3. Procedures and evaluations

This study involved several steps. First, the study was conceived after a brief literature review. Second, a study flowchart was created for the project proposal. Third, we performed a comprehensive literature review before creating the AIVDMCT system and collecting and analyzing the data. Patient anonymity was preserved at all steps, with the patients' names and MRNs stored in a safe and secure location. Raw data were treated with strict confidentiality and only used for research purposes.

A self-administered questionnaire was developed by the QI core team to evaluate the AIVDMCT. Before the questionnaire was distributed, the questioner was pre-tested and validated. Pilot study was done among 40 nurses. Minor modifications were made, which were intended to minimize ambiguity and to enhance clarity and simplicity. The questionnaire required an average of 10–15 min to complete, and was randomly sent to pediatric registered nurses who worked in the PED and provided informed consent to participate in the survey.

Each nurse received the questionnaire along with a cover letter explaining the project. The questionnaire focused on 12 statements regarding the AIVDMCT, which were scored based on a 5-point Likert scale (strongly agree, agree, undecided, disagree, and strongly disagree).

The questionnaire statements were: “the AIVDMCT is easy to use”, “I feel confident that I am not harming the patient via medication errors”, “the AIVDMCT covers the most commonly used medications in my department”, “the AIVDMCT is based on the KFMC drug formulary and/or PALS guidelines”, “the awareness session provided a positive learning environment”, “the tool fulfilled the expectations from the previous cardiopulmonary resuscitation sheet”, “I am overall satisfied with the AIVDMCT”, and “I recommend the AIVDMCT to the Children Specialized Hospital or pediatric critical care areas”.

The primary statistical test included a descriptive analysis of the survey questions. All continuous variables such as TO - TP, TP - TA and TO – TA expressed as Mean ± S.D. Paired sample t-test was applied to determine the mean significant differences pre and post observations of TO – TP, TP – TA and TO – TA. P – value less than 0.05 consider as statistically significant. All data entered and analyzed through Statistical Package for Social Sciences 25 (SPSS Inc., Chicago, IL, USA).

3. Results

The present study evaluated data from 328 eligible cases, including 164 cases from the pre-implementation period (June–December 2016) and the 164 cases from the post-implementation period (June–December 2017) [Table 1 and Figure 4]. During the pre-implementation period, the average interval from the TO to the TP was 31.52 ± 16.38 min and the average interval from the TP to the TA was 7.98 ± 6.39 min. The overall

| Table 1. Before and after implementation of the automated intravenous dosage medication calculation tool according to calendar. |
|---|---|---|
| TO-TP | Automated intravenous dosage medication calculation tool | P-value |
| | Before 2016 (n = 164) | After 2017 (n = 164) | |
| June | 30.49 ± 17.22 | 7 ± 2.53 | <0.001 |
| July | 29.38 ± 18.31 | 5.33 ± 1.05 | <0.001 |
| August | 25.61 ± 12.37 | 9.91 ± 3.87 | <0.001 |
| September | 35.5 ± 17.54 | 11.55 ± 2.5 | <0.001 |
| October | 38.33 ± 12.95 | 9.83 ± 2.55 | <0.001 |
| November | 42.33 ± 21.12 | 7.73 ± 2.96 | <0.001 |
| December | 26.82 ± 7.8 | 4.82 ± 0.73 | <0.001 |
| TP-TA | | | |
| June | 8.7 ± 5.59 | 3.03 ± 1.52 | <0.001 |
| July | 7.83 ± 5.02 | 2.96 ± 0.55 | <0.001 |
| August | 7.33 ± 10.67 | 3.82 ± 2.11 | 0.080 |
| September | 7.25 ± 3.49 | 5.1 ± 2.29 | 0.016 |
| October | 7.78 ± 4.73 | 4.33 ± 1.24 | 0.015 |
| November | 10.33 ± 5.5 | 4.73 ± 0.96 | <0.001 |
| December | 6.82 ± 2.83 | 3.12 ± 0.49 | 0.002 |
| TO-TA | | | |
| June | 39.19 ± 20.37 | 10.03 ± 3.18 | <0.001 |
| July | 37.21 ± 21.08 | 8.29 ± 1.43 | <0.001 |
| August | 32.94 ± 18.83 | 13.73 ± 5.31 | <0.001 |
| September | 42.75 ± 18.47 | 16.65 ± 4.03 | <0.001 |
| October | 46.11 ± 15.43 | 14.17 ± 2.9 | <0.001 |
| November | 53.33 ± 21.44 | 12.47 ± 3.14 | <0.001 |
| December | 33.65 ± 9.77 | 7.94 ± 0.9 | <0.001 |

Results are shown in minutes (mean ± standard deviation).

TO: time of order, TP: time of preparation, TA: time of administration.
time from order to administration was 39.55 ± 19.34 min during the pre-
implementation period [Table 2 and Figure 4]. During the post-
implementation period, significantly reduced intervals were observed
for TO to TP (average time: 8.05 ± 3.42 min) and for TP to TA (average
time: 3.74 ± 1.70 min). Moreover, there was a significant reduction in
the interval from TO to TA (average time: 11.79 ± 4.48 min, P < 0.001)
[Table 2 and Figure 5]. The nurses’ feedback regarding the ADIVMCT
revealed 100% satisfaction that they were avoiding patient harm, saving
time in critically ill or deteriorating cases, and that the tool was user-
friendly and secure.

4. Discussion

The present study revealed that implementation of the AIVDMCT was
associated with a significant reduction in the average time from TO to TA
(from 39.55 ± 19.34 min to 11.79 ± 4.48 min), with an increased propor-
tion of stat medications that were administered within the target
window.

Although the overuse of stat orders is well-documented, few studies
have evaluated the turnaround times that hospitals can achieve for
administering stat medication orders [3, 9]. The present study revealed
that an AIVDMCT system was associated with a significant reduction in
the time from medication order to administration, with average times of
<30 min. A similar study at the neonatal intensive care unit of the Cin-
cinnati Children’s Hospital Medical Center revealed a potential reduction
in the medication administration time from 256 min to 35 min after
implementing an automated medication administration system [10]. In
addition, a study at Aramco Johns Hopkins in Saudi Arabia revealed a
decrease in the time needed to deliver stat medications (from 59.7 min to
40.7 min) after the implementation of multiple systems, which included
structured communication, an electronic inbox for stat medication orders
sent by nurses to the pharmacy, and the use of a pink envelope for
delivering stat medication orders [2]. Another study at the Kimball
Medical Center in New Jersey revealed that the median time needed to
process non-physician-entered orders was significantly less than that
needed for physician-entered orders (27 min vs. 34 min) [11]. However,
another study from the United States revealed that “ward bay wall
charts” for documenting and communicating stat medications actually
increased the median time to administration (from 94 min to 146 min, a
55% increase), which was associated with delayed medication delivery
and poorer communication [3]. Despite the limited number of studies,
those findings may help guide the determination of medication error
severity, and may be useful for educating physicians regarding innova-
tive methods that can be used to confirm the correct and safe dosages for
their patients.

5. Conclusion

The present study revealed that the AIVDMCT was associated with a
significant reduction in the interval from the TO to the TA, which
increased the proportion of stat medications that were administered in
the target window. In our center, the AIVDMCT is complemented by
other systems that can help reduce the time to medication administra-
tion, such as computerized provider-order entry systems, automated
dispensing cabinets, barcoding systems, and medication reconciliation.
Hospitals that have undesirably long times to medication administration
should consider whether implementing these strategies can help reduce
their medication administration times.

5.1. Recommendations

We recommend that hospitals and emergency staff members identify
and address any modifiable variables that could lead to delays in the
administration of these often life-saving medications. It is also critical
that institutions create and promote awareness regarding ways to reduce
medication errors through multiple strategies, which can include
medication-error analysis, automated dispensing cabinets, barcoding
systems, medication reconciliation, standardizing medication-use pro-
cesses, and education for emergency department nurses, physicians, and
clinical pharmacists. It may also be prudent to incorporate patient
The present study has several limitations. First, we did not have access to data regarding patient outcomes, which would be needed to determine whether reducing the time to administration of stat medications was associated with improved outcomes. Second, we did not collect data regarding orders that were designated as stat but were later excluded. Third, staffing limitations resulted in some data not being collected during several months in the study period. Fourth, we were not able to control for all variables that might have influenced the turnaround time for stat medications during the study period. Therefore, the present study cannot definitively demonstrate that there was a causal relationship between implementing the AIVDMCT system and reducing the time to stat medication administration.

5.2. Limitations

The present study has several limitations. First, we did not have access to data regarding patient outcomes, which would be needed to determine whether reducing the time to administration of stat medications was associated with improved outcomes. Second, we did not collect data regarding orders that were designated as stat but were later excluded. Third, staffing limitations resulted in some data not being collected during several months in the study period. Fourth, we were not able to control for all variables that might have influenced the turnaround time for stat medications during the study period. Therefore, the present study cannot definitively demonstrate that there was a causal relationship between implementing the AIVDMCT system and reducing the time to stat medication administration.

Declarations

Author contribution statement

Y. Algoraini: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

N. Hakeem and A. Azzalrahman: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

M. AlShatatrat, M. Abudawass, R. Rehana, D. Laderas, N. AlCazar and I. AlHarfi: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Table 2. Overall analysis of times from before and after the AIVDMCT implementation.

| Variables | Before 2016 (n = 164) | After 2017 (n = 164) | P-value |
|-----------|-----------------------|----------------------|---------|
| TO-TP     | 31.52 ± 16.38         | 8.05 ± 3.42          | <0.001  |
| TP-TA     | 7.98 ± 6.39           | 3.74 ± 1.70          | <0.001  |
| TO-TA     | 39.55 ± 19.34         | 11.79 ± 4.48         | <0.001  |

Results are shown in minutes (mean ± standard deviation). TO: time of order, TP: time of preparation, TA: time of administration.

Figure 5. Analysis of timings before and after implementation of the automated intravenous dosage medication calculation tool. Data are shown in minutes. TO: time of order, TP: time of preparation, TA: time of administration.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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