Nurse and Pharmacist Knowledge of Intravenous Smart Pump System Setup Requirements

Karen K. Giuliano and Jeannine W.C. Blake

Abstract

Objective: The primary purpose of this research was to describe nurse and pharmacist knowledge of setup requirements for intravenous (IV) smart pumps that require head height differentials for accurate fluid flow.

Methods: A secondary analysis of anonymous electronic survey data using a database of prerecruited clinicians was conducted. A survey was sent by email to 173 pharmacists and 960 nurses. The response rate for pharmacists was 58% (100 of 173), and the response rate for nurses was 52% (500 of 960). After removing respondents who did not provide direct care and who did not use a head height differential IV infusion system, the final sample for analysis was 186 nurses and 25 pharmacists.

Results: Overall, less than one-half of respondents (40%) were aware that manufacturer guidelines for positioning the primary infusion bag relative to the infusion pump were available. Slightly more (49.5%) were aware of the required head height differentials for secondary infusion. Only five respondents selected the correct primary head height, eight respondents selected the correct secondary head height, and one respondent selected both the correct primary and secondary head heights.

Conclusion: The results of this study identify a substantial lack of knowledge among frontline clinicians regarding manufacturer recommendations for accurate IV administration of primary and secondary infusions for head height differential infusion systems. Both increased clinician education and innovative technology solutions are needed to improve IV smart pump safety and usability.

Large-volume intravenous (IV) smart pumps are the most widely used infusion devices in U.S. acute care hospitals due to their versatility in administering both fluids and medications.[1,2] Recent data from U.S. acute care settings support an adoption rate of 99% for IV smart pumps with built-in dose error reduction software designed to mitigate medication administration errors.[3] Although data support that IV smart pumps can reduce medication administration errors, they have not eliminated error, including serious adverse drug events with high-alert medications.[4–10]

Secondary medication administration by large-volume IV smart pump is used extensively in U.S. acute care settings for administering IV medications ordered for one-time or intermittent dosing. The most commonly used method for secondary administration requires the primary continuous infusion to pause during the secondary infusion, then resume automatically after the secondary infusion is complete.[1,11–13] The secondary infusion delivery method typically is used for administration of antibiotics and electrolyte replacement therapy.[14]

Research has identified secondary medication infusions as particularly error prone.[12,14] Both the setup and usability of most IV smart pump systems are complex, vary among different IV smart pump types, and have numerous associated failure modes that are not easily detected at the point of care.[12] The majority of secondary medications are infused using the "head height differential" method, which requires a differential between the top of the fluid level in the primary and secondary fluid containers. These differentials generate the hydrostatic pressure required to close the primary tubing back-check valve and facilitate accurate secondary medication infusion (Figure 1).

IV smart pump systems from BD/Alaris, Baxter/Sigma, B. Braun, and Zyno use this

***Karen K. Giuliano**, PhD, RN, FAAN, is an associate professor (joint) in the Institute for Applied Life Sciences and College of Nursing at the University of Massachusetts Amherst. Email: kkgiuliano@umass.edu*
Corresponding author

***Jeannine W.C. Blake**, MS, RN, is a doctoral student in the Institute for Applied Life Sciences and College of Nursing at the University of Massachusetts Amherst. Email: jcondon@umass.edu*

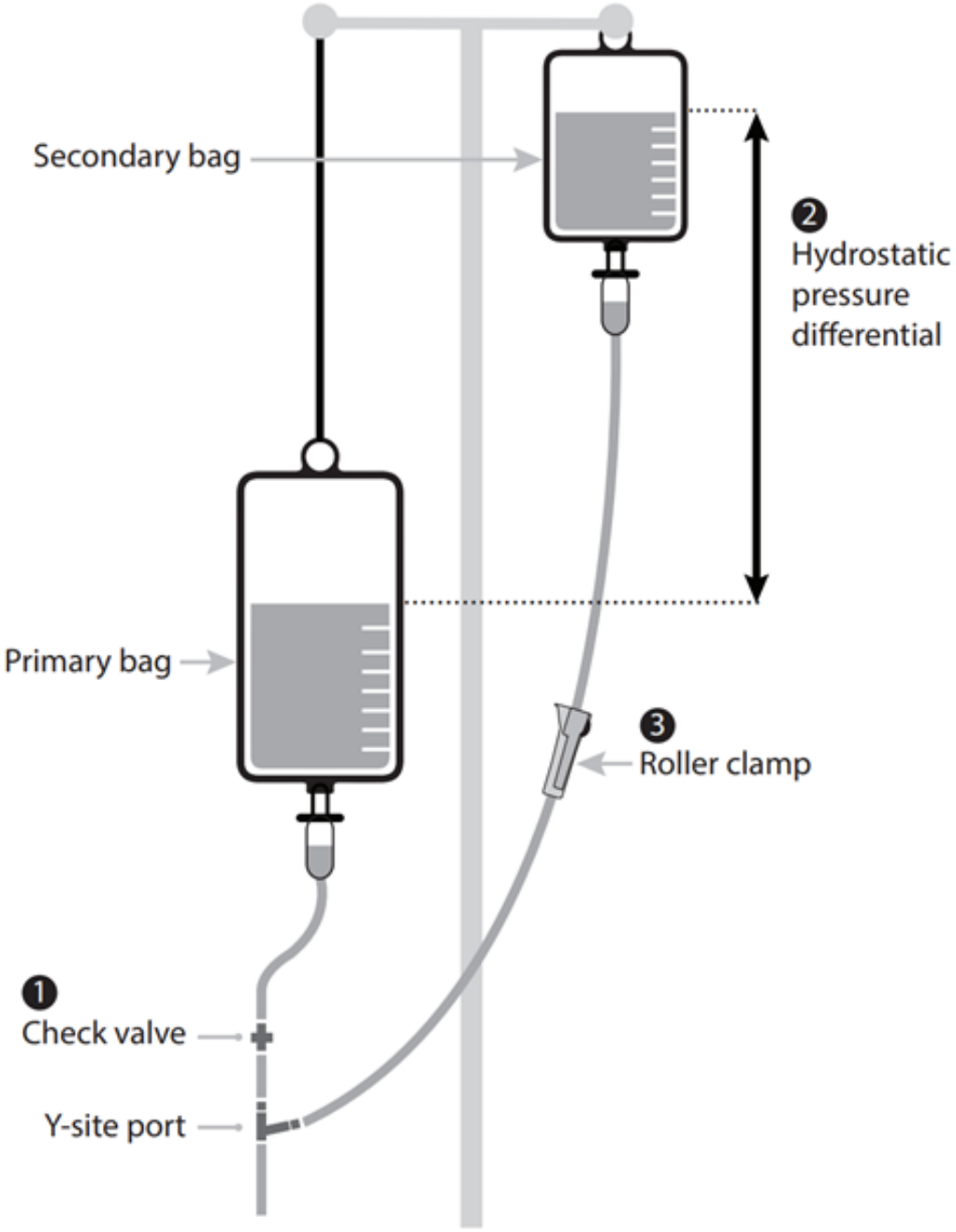

Figure 1. Required components for secondary medication infusion using the head height differential method. Used with permission from Karen K. Giuliano.

method, with each having specific head height differentials and setup requirements.[15–18] In contrast, a cassette pumping mechanism is used for other devices (e.g., manufactured by ICU Medical Plum and Ivenix) pumps. The user setup requirements for these cassette systems do not require a head height differential or back-check valve. Instead, when administering a secondary medication, the cassette provides a separate fluid path for secondary infusion, which is controlled independently from the primary infusion.

It is important for nurses to be educated regarding the setup requirements of the IV smart pump system they are using, in order to avoid potentially dangerous secondary medication error caused by inaccurate flow.

Objectives

The primary purpose of this research was to describe nurse and pharmacist knowledge of

setup requirements for IV smart pumps that require specific head height differentials. As head height differential systems account for approximately 85% of large-volume IV smart pumps in current clinical use, this is an issue of major clinical relevance.[19]

This research sought to (1) determine the overall distribution of IV smart pump types in the total sample, (2) collect descriptive data on IV smart pump clinical use experiences among nurses, (3) describe the general knowledge of direct care nurses and pharmacists regarding the setup requirements for head height differential infusion systems, and (4) describe nurses' knowledge of the primary and secondary medication setup requirements by IV smart pump type.

Methods

A secondary analysis of anonymous electronic survey data was conducted. The survey was conducted by a third-party research organization using an existing database of clinicians prerecruited to participate in survey research voluntarily on topics of interest. The survey, which took approximately 20 minutes to complete, was sent by email to 173 pharmacists between Oct. 30, 2019, and Nov. 10, 2019, and to 960 nurses between Dec. 13, 2019, and Jan. 13, 2020. The pharmacist response rate was 58% (100 of 173), and the nurse response rate was 52% (500 of 960). The honorarium of $40 for each completed survey likely resulted in the high response rate. All data provided to the authors were anonymous, and institutional review board approval obtained through IntegReview (Austin, TX) deemed the research to be exempt.

Procedure to Create Final Dataset for Analyses

1. The total anonymous dataset was obtained by the principal investigator (K.K.G.) in Excel format.
2. Descriptive analyses were conducted on the total sample of nurses (n = 500) and pharmacists (n = 100) to determine the distribution of IV smart pump types across the sample (Table 1).
3. All non–direct care nurses and pharmacists were removed from the sample, leaving a sample of 233 direct care nurses and 25 direct care pharmacists (Figure 2).

Smart Pump Type	No. Nurses	No. Pharmacists	Total No. (%)
BD Alaris/Carefusion	285	58	343 (57)
Baxter Sigma Spectrum	105	26	131 (22)
B. Braun (Infusomat Space, Horizon, or Outlook)	28	2	30 (5)
ICU Medical/Hospira Plum 360 or Plum A	82	14	96 (16)
Total	500	100	600 (100)

Table 1. Smart pump types for whole sample.

4. Clinicians using a cassette system also were removed, leaving only those clinicians using one of the three head height differential IV infusion systems for secondary medication administration for analysis (Figure 2). The final sample for analysis was 211 respondents (186 nurses and 25 pharmacists).
5. Descriptive analyses were conducted on three questions that asked about the IV smart pump clinical use experiences of nurses (Table 2).
6. Descriptive analyses were conducted using two questions that asked about

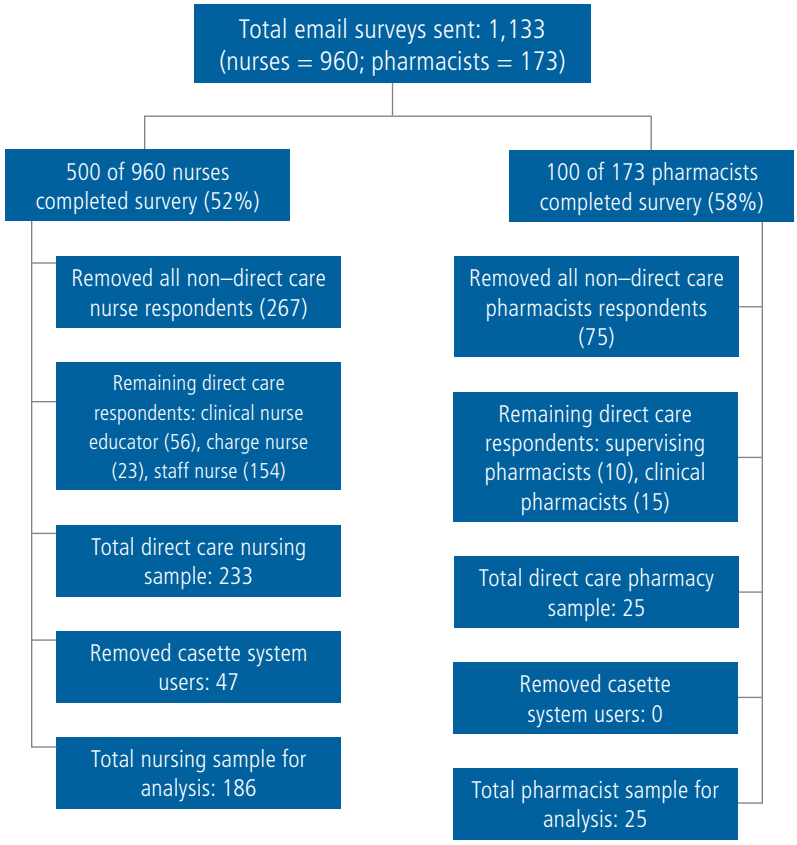

Figure 2. Final sample diagram flowchart.

Question*	Nurses No. (%)
(1) In general, how often does your current general infusion pump indicate it has completed a primary infusion but leaves a meaningful amount of fluid in the primary IV bag?	
Rarely, if ever	4 (4.2)
In 5–10% of primary infusions	49 (51.6)
In up to 20% of primary infusions	21 (22.1)
In up to 30% of primary infusions	21 (22.1)
Total	95 (100)
(2) Which of the following statements best captures your beliefs about the most common cause of fluid remaining in the primary IV bag?	
Pump delivers correct volume even with fluid left in bag, even though there may be fluid left in the bag (overfill)	49 (51.6)
Excess fluid means patient did not get full dose (pump malfunction)	17 (17.9)
Nurses probably misprogrammed pump	14 (14.7)
Not sure why	15 (15.8)
Total	95 (100)
(3) In general, when using your current pump, how often is the secondary infusion delivered too quickly, incompletely, or not at all?	
Rarely, if ever	93 (50)
In 5–10% of secondary infusions	65 (34.9)
In up to 20% of secondary infusions	17 (9.1)
In up to 30% of secondary infusions	11 (5.9)
Total	186 (100)

Table 2. Questions on intravenous (IV) smart pump clinical use experiences. *Data missing for some responses.

general knowledge of nurses and pharmacists regarding the setup requirements for head height differential infusion systems (Table 3).

7. Descriptive analyses were conducted to describe nurses' knowledge of the primary and secondary medication setup requirements by IV smart pump type (Table 4).

Results

The sample (n = 211) included a range of U.S. hospital types and sizes, with a wide range of geographic locations. Mean/median hospital bed size was 429/350 (SD 350; minimum, 100; maximum, 1,500). Approximately two-thirds of respondents were part of an integrated delivery network, and one-third were reported as independently owned. The nursing sample primarily identified as female (77%), with a mean age of 49 years (range 32–72) and a mean of 21 years (range 6–44)of experience. The pharmacist sample primarily identified as male (64%), with a mean age of 50 years (range 31–72) and a mean of 25 years (range 6–49) of experience.

Because of the differences in usability among the different IV smart pumps, research objective 1 was of interest. The distribution of IV smart pump types among the total number of survey respondents is shown in Table 1. The results showed that the most commonly used IV smart pump type is BD/Alaris (57%), followed by the Baxter Sigma Spectrum (22%), ICU Medical Plum Series (16%), and B. Braun (5%). The distribution of IV smart pump types in this

Question	Overall No. (%)	Nurses No. (%)	Pharmacists No. (%)
(1) There are times during patient care when the pump is not at the level of the patient's heart or insertion site. That does not have a meaningful impact on the accuracy of the volume the pump delivers.			
Strongly agree	52 (24.6)	46 (24.7)	6 (24)
Somewhat agree	71 (33.6)	62 (33)	9 (36)
Neither agree or disagree	43 (20.4)	36 (19.4)	7 (28)
Somewhat disagree	35 (16.6)	34 (18.3)	1 (4)
Strongly disagree	8 (3.8)	6 (3.2)	2 (8)
Don't know	2 (0.9)	2 (1.1)	0
Total	211 (100)	186 (100)	25 (100)
(2) Most current infusion pumps provide accurate infusions regardless of the distance between the height of the secondary bag and the height of the primary bag.			
Strongly agree	49 (23.2)	44 (23.7)	5 (20)
Somewhat agree	95 (45)	84 (45.2)	11 (44)
Neither agree or disagree	21 (10)	18 (9.7)	3 (12)
Somewhat disagree	30 (14.2)	27 (14.5)	3 (12)
Strongly disagree	13 (6.2)	12 (6.5)	1 (4)
Don't know	3 (1.4)	1 (0.5)	2 (8)
Total	211 (100)	186 (100)	25 (100)

Table 3. Nurse and pharmacist knowledge responses for basic head height differential infusion system setup.

sample was consistent with the distribution of IV smart pump types in the U.S. market, thus providing us a representative sample of large-volume IV smart pump users in U.S. healthcare.

Research objective 2 provided descriptive data on IV smart pump clinical use experiences among nurses. The majority of nurses delivering both primary and secondary medications had experienced numerous encounters of inaccurate IV medication administration. As summarized in Table 2, 96% of nurse respondents had experienced unexpected incomplete infusion of the primary bag, with 51% of nurses believing that the pump delivered the correct amount of primary fluid even when unexpected volume was left in the bag. Most commonly, their belief was attributed to overfill. For secondary infusions, 50% of nurse respondents had experienced unexpected incomplete infusion of the secondary medication bag.

Research objective 3 was to describe the general knowledge of direct care nurses and pharmacists regarding the setup requirements for head height differential infusion systems (Table 3). For question 1, only 12% of combined respondents understood the requirement for the infusion pump to be located at the level of the patient's heart or insertion site in order to deliver accurate medication flow. For question 2, 4% of the combined sample strongly disagreed with the incorrect statement, indicating that the vast majority of respondents (96%) did not understand the need for head height differentials to provide accurate secondary medication flow.

Research objective 4 described nurses' knowledge of the primary and secondary medication setup requirements by IV smart pump type (Table 4). Overall, less than one-half of respondents (40%) were aware that manufacturer guidelines for positioning the primary infusion bag relative to the infusion pump were available. Slightly more (49.5%) were aware of the required head height differentials. The frequency of responses for both primary and secondary recommendations was similar across all three IV smart pump types.

Of respondents who were aware of manufacturer recommendations, six (BD/Alaris, four; Baxter/Sigma, two) selected the correct primary head height recommendation, eight (BD/Alaris, five; Baxter/Sigma, three) selected the correct secondary head height requirements, and one (BD/Alaris) selected both the required primary and secondary head height requirements.

Discussion

The results of this study support a substantial lack of knowledge among frontline acute care nurses and pharmacists regarding manufacturer recommendations for accurate IV administration of primary and secondary infusions. These findings have major clinical implications. Even before considering the complexities of secondary infusion, the infusion of IV medications requires many complex steps, providing numerous opportunities for patient safety risk because of the rapid therapeutic effect of the IV administration route.[20,21]

The most common medications to be delivered via secondary infusion are antibiotics.[14] When antibiotic medications are not given at prescribed intervals or doses are not fully administered, subtherapeutic levels can result, causing a failure to kill or halt the growth of the infectious microorganism.[22] As implied by these findings and found in previous literature, delayed delivery of IV antibiotics as secondary infusions can occur as a result of IV smart pump system setup.[12,14,23] These findings highlight the potential for subtherapeutic dosing of secondary medications, most commonly antibiotics, which may go undetected.

Question	BD/Alaris No. (%)	Baxter No. (%)	B. Braun No. (%)	Overall No. (%)
n	116	54	16	186
(1) To the best of your knowledge, does the manufacturer of your pump recommend guidelines for the distance a primary IV bag should be hung above the pump?				
Yes	47 (40.5)	22 (40.7)	6 (38)	75 (40)
No	21 (18.1)	8 (14.8)	3 (19)	32 (17)
Don't know	48 (41.4)	24 (44.4)	7 (44)	79 (42)
Total	116 (100)	54 (100)	16 (100)	186 (100)
(2) To the best of your knowledge, does the manufacturer of your pump recommend guidelines for the height/distance for hanging a secondary IV bag above a primary IV bag?				
Yes	62 (53.4)	24 (40.7)	6 (37.5)	92 (49.5)
No	16 (13.8)	8 (14.8)	2 (12.5)	26 (14)
Don't know	38 (32.8)	22 (44.4)	8 (50)	68 (36.6)
Total	116 (100)	54 (100)	25 (100)	186 (100)

Table 4. Nurses' knowledge of the specific primary and secondary medication setup requirements based on intravenous (IV) smart pump type.

The issue of antibiotic resistance must also take a front seat when discussing incomplete antibiotic delivery. When microorganisms are exposed to antibiotic medication in a manner that does not cause full neutralization of the organism, selection pressure occurs, resulting in the development of a potentially dangerous resistance.[22] Although a clear link does not exist between secondary medication infusion practices and antibiotic resistance, the findings of this study indicate that current knowledge is insufficient and may be contributing to the emergence of multidrug-resistant organisms.

The second most commonly administered secondary medications are electrolyte replacements.[14] Electrolyte imbalance is common in many patients, including those who are elderly, postoperative, critically ill, and suffering from dehydration, infection, or malnutrition.[24,25] If electrolyte imbalance can be corrected quickly, especially in the critically ill, then the risk of a secondary injury and elevated risk of morbidity and mortality caused by sustained imbalance can be mitigated.[24,25]

Limitations

Although the findings of this study highlight a potentially important aspect of secondary medication administration safety, the major limitation is the use of secondary data collected from a third-party agency. Future study should include repeated data collection involving more detailed questions with the intention to more fully understand the thought processes, education experiences, and knowledge of nurses and pharmacists. Additional future study also should include laboratory measurement of the magnitude of inaccuracy related to secondary infusion head height differentials and pump height in relation to patients.

Conclusion

With an adoption rate of 99%, the use of IV smart pumps for medication administration is a widely accepted practice in U.S. acute care settings.[2] The findings of this study are representative of U.S. clinical practice as the majority of respondents reported using either the BD/Alaris and Baxter Sigma IV smart pumps, which require a head height differential setup for accurate fluid and medication infusion. Lack of knowledge and/or adherence to manufacturer-specified system setup requirements has the potential to decrease the efficacy of antibiotic administration and contribute to antibiotic resistance through subtherapeutic dosing due to inadvertent delay or omission. Delays in electrolyte replacement could lead to potentially dangerous secondary injury.

These results support the need for the implementation of both short- and long-term strategies to improve patient safety. In the short term, more education of frontline healthcare providers who use head height differential IV smart pump systems for secondary medication administration is needed. Over the long-term and consistent with Institute for Safe Medication Practices recommendations, the development of additional IV smart pumps systems and technologies that do not require a head height differential for accurate secondary medication administration is necessary.[3] With the high level of demand on nurse end-users at the at the point of care, innovative technology solutions designed using a human factors approach are needed to improve IV smart pump safety and usability in this important area of patient safety.

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