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Comparative Safety, Efficiency, and Nursing Preference Among 3 Methods for Intravenous Push Medication Preparation: A Randomized Crossover Simulation Study

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Objective: The aim of this study was to compare total time for drug preparation, associated errors, and nurses' preferences among 3 different intravenous (IV) push medication methods.

Research Design: A randomized crossover simulation design was used to compare total time for drug preparation and incidence of medication preparation errors between BD Simplist (BDS), Carpuject (CJ), and traditional vial-and-syringe process (TVSP). Three medication preparation areas were created to mimic a hospital setting. Twenty-four critical care nurses were asked to prepare an IV dose of diphenhydramine, ketorolac, and morphine in random order using BDS, CJ, and TVSP, also in random order. Total time for the preparation of each drug was measured. Medication preparation errors were noted. At the start of the study, nurses were surveyed about their stress levels regarding aspects of IV push medications. At completion, nurses were asked to rank order from the most to the least preferred administration method.

Results: Mean time in seconds for drug preparation was significantly shorter ($P < 0.004$) with BDS (28.7; 95% confidence interval [CI], 23.3–34.2) and CJ (28.3; 95% CI, 23.1–33.5) compared with TVSP (65.8; 95% CI, 57.7–73.9). The time difference between BDS and CJ was not statistically significant. Medication preparation errors were significantly reduced with BDS compared with both CJ and TVSP (1.4% versus 77.8% versus 73.6%; $P < 0.001$). The BDS was ranked by nurses as the most preferred method.

Conclusions: The BD Simplist system for IV push medications may offer nurses an opportunity to reduce steps and reduce errors during medication preparation.

Key Words: prefilled syringes, intravenous push medication, randomized trial, nursing practice, medication safety

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Safe administration of intravenous (IV) push medications is an issue of growing concern in health care today.¹ The risks from many types of medication errors have been decreasing since the adoption of technological solutions such as computerized physician order entry and bar-coded medication administration, but significant risks remain with IV push medications because of the lack

of safety checks at the point of preparation and administration.^{2–4} Several at-risk practices have been identified, which potentially lead to adverse drug events such as unlabeled syringes, mislabeled syringes, syringe-to-syringe transfer, unnecessary dilution, and use of saline flush syringes to dilute IV medications.^{5–8} High nursing workload has been associated with adverse drug events^{9–13} and cited as a contributing factor for adverse drug events in human factor studies.¹⁴ Nursing workloads have increased because of decreased lengths of stay, implementation of electronic medical records, and increased use of technology.¹⁵ Increased workloads, higher patient volumes, and staff shortages have put greater demands on nurses for their time. When nurses are pressed for time, they are more likely to engage in at-risk practices when they believe the risks to themselves or their patients are negligible or justified. An IV push medication system that is engineered to be efficient and safe may be a benefit to busy nurses today.

A recommended strategy to eliminate risk points with IV push medications is to use manufacturer prefilled, ready-to-administer syringes.¹⁶ Prefilled syringe products, such as BDS (Simplist, BD Rx, Wilson, NC) and CJ (Carpuject, Hospira Inc, Lake Forest, IL), are now commercially available and may reduce nursing time and improve safety¹⁷; however, limited quantitative or qualitative information is available supporting these improvements in medication safety or efficiency.

A randomized crossover simulation study was conducted to compare total time for drug preparation and errors associated with BDS, CJ, and traditional vial and syringe preparation (TVSP).

The objectives were to measure differences in preparation time for these 3 methods of IV push medications and to quantify at-risk behaviors associated with the 3 methods along with the nurses' satisfaction and preferences for each of these processes.

METHODS

Study Design

In this study, a randomized crossover design was used to compare BDS and CJ to TVSP in a simulated nursing unit environment. It was determined that a simulation model was preferable to control for confounding variables such as interruptions, distractions, and other events that naturally occur in the clinical setting that could influence the study outcomes or make the end points difficult to interpret.

Study Population

Study participants were attendees of the 2015 National Teaching Institute of the American Association of Critical-Care Nurses (AACN), held on May 1 to 19, 2015, in San Diego, CA. The AACN is the largest specialty nursing organization in the world, with more than 100,000 members who care for acutely and critically ill patients. Invitations to participate in the study were sent by postcard to all conference registrants. The first 27

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respondents were selected to participate. The number (27) was selected to ensure that the desired sample size of 24 participants would be available on the day of the study. All participants were registered nurses with at least 3 years of experience and currently responsible for preparing and administering IV push medications in their employment. The subjects were not blinded to the sponsor of the study and were given an informed consent describing the study and compensation.

Study Setting

The study was conducted in a hotel adjacent to the AACN meeting. Participants were checked into and exited the study via a small lobby area. Three hotel meeting rooms were set up to simulate a medication preparation area that would be typical of an acute care hospital. The rooms were labeled A (where medications were prepared using BDS), B (where medications were prepared using CJ), and C (where medications were prepared using TVSP). The setting also included a large meeting room with several tables used for participants to receive study instructions and to complete pre- and post-data collection and survey forms.

The simulated medication preparation stations were equipped with blue bins that held 3-, 5-, and 10-mL syringes; 18-gauge and 22-gauge needles; blunt-tip needles; filter needles; 10-mL pre-filled saline syringes (PFSs); 10-mL single-use saline vials; alcohol wipes; blank white adhesive labels; 1- and 2-in white silk tape; pens; pencils; marking pens; new (still in the bag) CJ holders; and plastic coffee straws. As this was a simulation study, no actual medications were used. Blank pre-filled syringes, cartridges, and vials were filled with saline and labeled according to usual conventions as of diphenhydramine 25 mg/mL (2 mL), ketorolac 30 mg/mL (1 mL), and morphine 2 mg/mL (1 mL). At each station, there were three 3 × 5 index cards, one for each of the simulated drugs, which participants shuffled to determine a random order of drug preparation. A simulated medication record was at each station. The purpose of the medication record was to inform the participant what dose of each drug to prepare. The diphenhydramine dose was intentionally set as one half of the total volume provided. Supply lists and photos were used to ensure that each station was exactly the same.

The simulation stations were monitored by a registered nurse to oversee the sequence of medication preparation and record the medication time and observations onto a data collection form. The monitors received detailed training on the study tools and remained in the same simulation station throughout the course of the study. The monitors were not permitted to interact with the participants unless there was a question about the simulation task.

Measures

The dependent variables in this study were (1) total time for drug preparation, (2) medication preparation errors, and (3) nurses satisfaction and preferences with 3 IV push medication systems. The time interval for each medication preparation began with gathering materials and medication to the final disposal of medication waste and was measured in seconds using a Sportline 226 Sport Timer stopwatch (Sportline, Elmsford, NY).

Medication preparation errors were predefined based on current safe practices for IV push medication preparation guidance from the Institute for Safe Medication Practice (ISMP).¹

Medication preparation errors included the following: withdrawal of drug from the CJ using a needle, dilution of the drug into a pre-filled flush syringe, failure to label the syringe, failure to swab the top of the vial, and misuse of the CJ. Misuse of the CJ was included to cover for innovative use of such items as coffee

straws, pens, syringe plungers, or cotton swabs to activate the CJ cartridge.

A prestudy questionnaire composed of 23 questions about components of IV push medication administration was used to gather information of the participants' level of stress with IV push medications. The tool used a simple 5-point scale with 1 indicating no stress and 5 indicating high stress. After the simulated medication preparations, the nurses completed a poststudy questionnaire that included participant demographics and practice-related questions. Participants were asked to rate their satisfaction with the 3 IV push medication systems from 1 as not at all satisfied to 5 as very satisfied. The nurses also ranked their preference for the 3 IV push medication systems and indicated which of the 3 systems they would recommend to their colleagues.

Procedure

After participants were provided information about the study and informed consent was documented, they underwent a brief session to review the BDS and CJ technologies, and then, each one completed a prestudy questionnaire. All participants confirmed existing familiarity with TVSP and CJ methods. Only 1 nurse was familiar with BDS. The 24 nurses were randomly assigned to a sequence of the 3 medication preparation rooms: A (where medications were prepared using BDS), B (where medications were prepared using CJ), and C (where medications were prepared using TVSP). Participants were given a card with the random order indicating which rooms (A, B, or C) to go to first, second, and third.

In each room, the participant was asked to prepare an IV dose of diphenhydramine 25 mg/mL, ketorolac 30 mg/mL, and morphine 2 mg/mL (in random order) using BDS, CJ, or TVSP. The participant was asked to shuffle the 3 index cards with drug names so that the sequence of drug preparation was randomly determined in each simulation scenario. When the first session of 3 medication preparations by 1 of the IV push methods was completed, participants progressed into the next room in their randomized sequence, and the simulation was continued. After the second session, participants went into the third scenario to complete the study.

When participants completed all 3 simulated scenarios, each was asked to complete a poststudy questionnaire to capture both quantitative (e.g., product preferences, comfort level) and qualitative data (e.g., likes and dislikes with each system, concerns) related to the 3 systems of IV medication delivery. Upon completion of all the study requirements, the participants were dismissed and given a \$100 dollar gift card for their participation.

Sample Size and Statistical Considerations

The primary end point of the study was total time of IV drug preparation for each of the 3 systems. Secondary end points consisted of the number of medication preparation errors, nursing satisfaction, and product preferences. Twenty-four participants prepared 3 IV drug orders in each of the simulation rooms for a total of 9 orders per subject. The unit of analysis in this crossover study was a drug prepared via an IV syringe system (a dose). The final sample size was 72 drug preparations in each of the simulation groups yielding a total sample size of 216 doses. Therefore, 72 drug preparations in each group achieved 90% power to detect a difference of 60 seconds between the 2 experimental groups (BDS and CJ) and the TVSP control group. This was based on the assumption of SDs of 120 and 60 seconds at a significance level (α) of 0.017 using a 1-way analysis of variance (ANOVA) test.

Demographic data were presented descriptively as means, medians, or proportions. A univariate 1-way ANOVA test was

used to compare total time for drug preparation between groups. This was followed with a more robust comparison using multivariate mixed regression models with an adjustment for clustering on study participants. Independent variables were evaluated in the regression model and were retained using a backward elimination process with a preset α at 0.05. Respondent satisfaction and preferences were assessed using the Kruskal-Wallis test. Differences in errors between groups were compared using the χ^2 statistic. All of the statistical analyses were performed using Stata, release 11.0 (Stata Corp, College Station, TX).

RESULTS

Demographics

All 27 respondents presented for inclusion to the study. The first 24 nurses who had responded to the invitation were included in the study. The characteristics of the study participants are presented in Table 1. The mean age of study nurses was 50 years, and 11 (45.8%) of 24 had a bachelor's degree in nursing. Overall, the participants had practiced nursing for a mean of 23.7 years, and 14 (58%) of 24 were working in community hospitals ranging in size from less than 100 to more than 400 beds (Table 1). Of the 24 nurses, 15 (62.5%) were staff registered nurses (RNs), and 19 (79%) were currently working in an intensive care unit (ICU) setting. All respondents reported that they administered at least one IV medication per day, with 4 of the nurses giving more than 20 (16.7%). All study subjects indicated that TVSP was used in their practice settings, with CJ also being used by 17 (70.8%) of 24. However, BDS was used by only 1 nurse in her practice (Table 1).

More than three quarters (79.2%) of study participants reported that they had experienced near-miss events while administering IV push medications. A near-miss event is generally accepted to be an error that happened but was caught before it could harm the patient. Eight of the participants (33.3%) reported that they had experienced a needle stick injury while preparing IV push medications. Health care organizations are expected to use engineering controls to reduce needle stick injuries, including the elimination of needles where acceptable alternatives are available.¹⁸ Slightly more than one half (54.3%) of the participants rated their current system of IV push medication as satisfactory; no systems were rated as excellent (Table 1).

Stressors Associated With IV Push Medications

The administration of IV push medication may be associated with incremental stress. Based on a scale of 1 as no stress to 5 as high stress, participants rated the risk of using an unlabeled syringe as the most stressful component of IV push drug administration (mean, 3.88), followed closely by using a mislabeled syringe (3.33), missing supplies such as needles and syringes (2.96), missing the CJ holder (2.83), interruptions while preparing medications (2.79), and mislabeling a syringe (2.58) (Table 2).

Preparation Time

Study participants were asked to prepare 3 IV push drugs (in random order) in each of the 3 simulation rooms. The preparation time results are presented in Table 3. The results revealed that the mean time in seconds for IV drug preparation was significantly shorter ($P = 0.004$) with BDS (28.7; 95% confidence interval [CI], 23.3–34.2) and CJ (28.3; 95% CI, 23.1–33.5) compared with TVSP (65.8; 95% CI, 57.7–73.9). Outliers in any quantitative analysis can confound the estimation of a group mean. Therefore, total drug preparation times were also graphically presented as a

TABLE 1. Characteristics of Nurse Study Participants and Practice Settings

Variable (range)	Study Group (n = 24)
Mean age	50.1 (29–63)
Nursing credentials	
ADN	12.5% (3)
BSN	45.8% (11)
Masters/PhD	54.2% (13)
CCRN	50.0% (12)
Mean year of university education	5.8 (0–17)
Means years of practice	23.7 (6–40)
Practice setting	
Community hospital	58.3% (14)
Teaching hospital	8.3% (2)
Rural hospital	33.3% (8)
No. beds	
<100	25.0% (6)
101–199	4.2% (1)
200–299	8.3% (2)
300–399	29.2% (7)
>400	33.3% (8)
Position	
Staff RN	62.5% (15)
Manager	12.5% (3)
CNS	12.5% (3)
Educator	8.3% (2)
Clinical coordinator	4.2% (1)
Patient type	
Medical ICU	16.7% (4)
Surgical ICU	37.5% (9)
CV ICU	16.7% (4)
Neurology ICU	4.2% (1)
Medical-surgical ICU	37.5% (9)
Step-down care/other	20.8% (5)
No. IVs given per day	
<5	29.2% (7)
5–10	37.5% (9)
11–15	12.5% (3)
16–20	4.2% (1)
>20	16.7% (4)
Current IV drug delivery systems	
TVSP	100% (24)
CJ	70.8% (17)
BDS	4.2% (1)
Experienced a near miss	79.2% (19)
Experienced a needle stick injury	33.3% (8)
Rating of current system	
Excellent	0.0% (0)
Good	25.0% (6)
Satisfactory	54.2% (13)
Poor	20.8% (5)
Satisfaction with current system (1 = not satisfied to 5 = satisfied)	4 (1–5)

ADN, Associate degree in Nursing; BDS, BD Simplist™; BSN, Bachelor of Science in Nursing; CCRN, Critical-Care Registered Nurse; CJ, Carpuject™; CNS, Clinical Nurse Specialist; ICU, intensive care unit; CV, cardiovascular; IV, intravenous; RN, registered nurse; TVSP, traditional vial-and-syringe preparation.

TABLE 2. Participant Stress Levels Associated With IV Push Medication Administration

Stress-Related Event (Range)	Mean Score*
Risk of using an unlabeled syringe	3.88
Giving unfamiliar medication	3.38
Using a mislabeled syringe	3.33
Missing supplies (e.g., syringes, needles)	2.96
Missing CJ Holder	2.83
Interruptions while doing medication preparations	2.79
Mislabeled a syringe	2.58
Giving high-alert medication	2.46
Time to find supplies	2.25
Having enough time to prepare the medication	2.21
Time to find the drug	2.21
Giving medication to critically ill patients	2.17
Prepping the correct dose	2.13
Keeping track of labels	2.13
Ensuring that the narcotic count is correct	2.08
Time to find labels	2.04
Administering meds to the correct patient	2.00
Correct drug potency	1.92
Entering the data into the medication record	1.92
Sterility issues	1.88
Giving IV narcotics	1.88
Prepping the correct medicine	1.83
Bar code scanning	1.83

*With no stress being 1 to high stress being 5.

median per group (Fig. 1). The findings were consistent in that BDS and CJ both had significantly lower median preparation times when compared with TVSP (23.2 and 20 versus 61.7 seconds). The time difference between BDS and CJ was not statistically significant ($P = 0.92$).

The analysis of total preparation time was continued with a multivariate analysis using mixed regression models for the continuous dependent variable, that is, total preparation time. In addition to the variable group (i.e., BDS versus CJ and BDS versus TVSP), other variables that were retained in the multivariate model were treatment setting, number of beds, type of nurse, and type of patients managed. All other respondent variables such as age and years of practice were eliminated from the model because they were not significantly associated with total preparation time. The types of IV drugs prepared (diphenhydramine versus ketorolac versus morphine) were also eliminated from the model because they had no impact on the total preparation time.

As initially indicated by the univariate 1-way ANOVA, the multivariate analysis confirmed that BDS and CJ had comparable

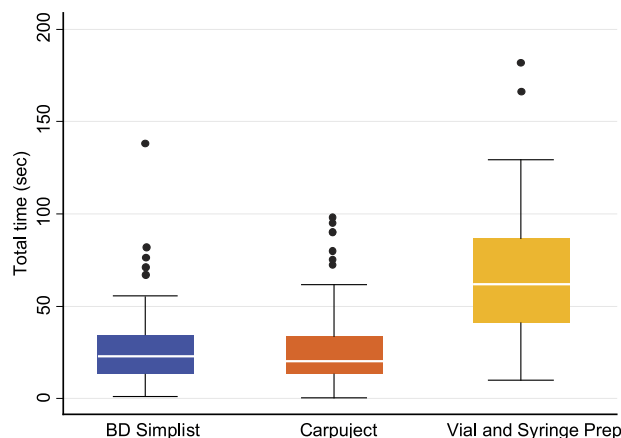


FIGURE 1. Total drug preparation times. Box plot of total median time for drug preparation. Estimates are presented as medians with the interquartile range. Outliers beyond the interquartile range are indicated as dots.

drug preparation times, and both were significantly lower than TVSP (Table 4). The multivariate analysis also revealed that study participants from rural hospitals took approximately 40.6 seconds longer to prepare an IV push medication, regardless of the IV push system when compared with their colleagues who work in community hospitals. In contrast, nurse participants who practice in teaching hospitals took 20.6 fewer seconds to prepare an IV drug relative to those who practice in a community hospital setting. Nurses who work in hospitals with 101 to 199 beds had faster preparation times than the participants from smaller and larger hospitals. The findings also revealed that staff RNs took less time (range, 11.2–16.4 seconds) to prepare an IV medication compared with other types of nurses. Lastly, the type of patients managed was significantly associated with total preparation time. When compared with respondents who worked in cardiovascular (CV) ICUs, neurology ICU nurses required, on average, 33.5 fewer seconds to prepare an IV push drug ($P < 0.001$). In contrast, nurses who worked in medical, medical-surgical, and surgical ICUs had significantly longer preparation times compared with CV ICU nurses (Table 4). Although some of these findings are statistically significant, they may not bear clinical relevance to the primary end points of this study.

Medication Preparation Errors

In the total sample size of 216 medications prepared, there were 110 errors recorded (50.9%). The percentage of medication errors was calculated by dividing the number of observed errors by the number of doses. The findings revealed that BDS was associated with significantly fewer errors during the overall preparation process compared with the CJ and TVSP (Table 5). There

TABLE 3. Summary of Total Time Between Groups

Outcome	BDS Group (n = 72)	CJ Group (n = 72)	TVSP Group (n = 72)
Mean (95% CI)	28.7 (23.3 to 34.2)	28.3* (23.1 to 33.5)	65.8** (57.7 to 73.9)
Median (range)	23.2 (0.9 to 138)	20.0 (7 to 98)	61.7 (10 to 182)

* $P = 0.92$ versus BDS
 ** $P = 0.004$ versus BDS

TABLE 4. Multivariate Analysis on Factors Associated with Total Preparation Time

Variable	Mean Difference in Preparation Time, Second	95% CI	P
Group (versus BDS)			
CJ versus BDS	-1.2	-15.1 to 12.7	0.86
TVSP versus BDS	26.7	9.5 to 43.4	0.004
Setting			
Rural versus community hospital	40.6	37.1 to 44.1	<0.001
Teaching versus community hospital	-20.5	-25.3 to -15.7	<0.001
No. beds			
200–299 versus 101–199	9.9	2.9 to 16.8	0.007
300–399 versus 101–199	25.4	20.3 to 30.4	<0.001
>400 versus 101–199	30.3	23.3 to 37.3	<0.001
≤100 versus 101–199	25.5	17.9 to 33.2	<0.001
Type of nurse			
Clinical coordinator versus CNS	-2.8	-16.8 to 11.2	0.69
Educator versus CNS	-5.1	-12.1 to 1.9	0.14
Manager versus CNS	-4.3	-13.6 to 5.1	0.35
Staff RN versus CNS	-16.4	-23.4 to -9.5	<0.001
Types of patients			
Medical ICU versus CV ICU	14.4	4.0 to 28.9	0.009
Medical surgical ICU versus CV ICU	13.8	3.7 to 24.0	0.009
Neurology ICU versus CV ICU	-33.5	-44.3 to -22.7	<0.001
Step-down unit	3.5	-6.6 to 13.6	0.48
Surgical ICU versus CV ICU	37.6	27.0 to 48.2	<0.001
Constant	15.3		
Adjusted R ²	0.34		

Adjusted R² is the proportion of variability in the dependent variable that is accounted for by the model; dependent variable is the total preparation time.

BDS, BD Simplist™; CI, confidence interval; CJ, Carpuject™; CNS, Clinical Nurse Specialist; CV, cardiovascular; ICU, intensive care unit; TVSP, traditional vial and syringe preparation.

was only 1 preparation error observed of the 72 medication preparations (1.4%) in the BDS group compared with 56 (77.8%) in the CJ group and 53 (73.6%) in the TVSP group ($P < 0.001$). Furthermore, 30% of the doses in the CJ group and 7% of the TVSP doses had 2 preparation errors. ($P < 0.001$) compared with none in the BDS group. The most frequent error for CJ was withdrawing the medication from the cartridge with a needle (32, 44%), and the most frequent error for TVSP was not labeling the syringe (41, 57%). The single error for BDS was one dose diluted into a PFS.

Nursing Preference

Upon completion of all 3 simulations, respondents were asked to complete a poststudy questionnaire to rate each of the 3 IV push systems. The nurses rated BDS highest for satisfaction, preference, and recommendation to their hospitals for adoption over CJ and TVSP. The rank score (1 being most preferred to 3 being least preferred) revealed that BDS had a median rank of 1, followed by TVSP and CJ, with median rank scores of 2 and 3, respectively ($P < 0.001$) (Fig. 2). All 24 nurses (100%) agreed or strongly agreed that prefilled bar-coded, needle-free syringes

would improve patient safety, make their jobs easier, and reduce their stress of medication preparation.

DISCUSSION

Three methods of IV push medication were studied to compare preparation time, preparation errors, nursing satisfaction, and nursing preference with the 3 systems. Intravenous drug preparation is a critical step in the medication administration phase. Approximately one third of all adverse drug events can be linked back to the administration phase of the medication use process.¹⁹ Intravenous medications carry a higher risk to the patient because of the speed of response, narrow therapeutic index for IV medications, and limited ability to reverse any adverse effects once administered.¹ Harm from IV medications errors has been reported to be 5 times greater than from non-IV doses of medications.⁴ In response to the need for greater safety, commercially available technologies, such as BDS and CJ, have been introduced to enhance the ease of use and minimize the potential for error. The current study attempts to evaluate these technologies in a simulated hospital environment to assess the efficiency and safety of these products.

Time to Prepare IV Push Medications

A primary end point of our study was to compare the total preparation time for 3 different methods of IV push medications. The manufacturer-prefilled syringes took significantly less time to prepare than TVSP ($P = 0.004$). This is not surprising because there are many more steps in the process for TVSP. Based on product design, we expected that the BDS product would take less preparation time. We were surprised to find that the difference in total time for CJ and BDS was not significant. This might be explained by the fact that only 1 participant had any familiarity with the BDS device. Both prefilled syringes saved nearly 30 seconds of time per dose. Although not clinically significant on a per-dose basis, when viewed by the number of doses given per day (as stated by our participants in Table 1), this could translate to upwards of 10 minutes of recovered nursing time per day.

Medication Preparation Errors

The other main objective of the study was to compare the errors for the 3 different methods of IV push medications. A total of 216 doses of IV push medications were prepared. The study was designed to look for 5 predefined types of errors and one "other" and included the following: withdrawal of drug from the CJ using a needle, dilution of the drug into a prefilled flush syringe, failure to label the syringe, failure to swab the top of the vial, and misuse of the CJ. Misuse of the CJ was included to cover for innovative use of such items as coffee straws, pens, syringe plungers, or cotton swabs to activate the CJ cartridge.

The most frequent error for CJ was withdrawing the medication from the cartridge with a needle (32, 44%). The practice of withdrawing the medication from the CJ cartridge with a needle makes the system similar to the TVSP method. The reasons why nurses use the CJ cartridge like a vial are many including the lack of cartridge holder, unclean cartridge holders, difficulties using the holders (such as slippage or unable to see markings), and the desire to dilute the medication before administration.⁵ Using the CJ cartridge as a single-dose or multidose vial is a known unsafe practice.⁵ Recently published guidelines from the ISMP on safe practices for adult IV push medications clearly state that the risks from this practice include contamination, dosing errors, and wrong medication errors.¹ The percentage of CJ doses that were withdrawn from the cartridge in our study may be lower than actual clinical practice because the participants were given an ample supply of clean, unused CJ holders in the simulations.

TABLE 5. Documented Errors During the Simulation Study

	BDS n = 72, n (%)	CJ n = 72, n (%)	TVSP n = 72, n (%)	Overall N = 216
Error 1: Withdrew CJ with needle	0 (0)	32 (44)	0 (0)	32 (15)
Error 2: Diluted into PFS	1 (1.4)	0 (0)	1 (1.4)	2 (1)
Error 3: Did not label	0 (0)	22 (31)	41 (57)	63 (29)
Error 4: Did not swab	0 (0)	0 (0)	0 (0)	0 (0)
Error 5: Misused CJ other than withdraw with needle	0 (0)	0 (0)	0 (0)	0 (0)
Error 6: Other	0 (0)	2 (2.8)	11 (15.3)	13 (6)
Total errors	1 (1.4)*	56 (77.8)	53 (73.6)	110 (51)
Error 6: Detail				
Dilution			5	
Taped vial to syringe			6	
Labeled after finish		2	0	

*The differences in errors rates between the BDS and the other 2 groups were statistically significant ($P < 0.001$).
 $P < 0.001$ for BDS versus CJ and BDS versus TVSP.

The most frequent error for TVSP was not labeling the syringe (41, 57%). When the participants withdrew the medication from the CJ cartridge with a needle, this created a new opportunity (or risk point) as an unlabeled syringe. It is important to note that in our study, after withdrawing the medication from the CJ cartridge with a needle, 22 (31%) of these doses were not labeled by the participants. When taken as a whole, 63 (29%) of the 216 doses were not labeled.

The instructions for the study participants emphasized that the simulation stations were meant to mimic a medication preparation room on a nursing unit and not at a patient bedside. Unless the medication is prepared for immediate administration, the recommended safety practice is to label the syringe.²⁰ The simulation stations included blank labels and white tape as options for labeling as well as markers and pens, which provided an opportunity for the participants to label the syringes; yet, nearly one third of the total doses were unlabeled. This is an interesting finding when the stressors associated with IV push medications are considered. The participants in the study rated the risk of using an unlabeled syringe as the most stressful component of IV push drug administration followed closely by using a mislabeled syringe, missing supplies such as needles and syringes, missing the CJ holder,

interruptions while preparing medications, and mislabeling a syringe. Many of these stressors are mitigated by using a prefilled labeled syringe. The use of a prefilled syringe that requires no assembly is an example of prevention through design.²¹ Policies, training, and manipulation of the environment are less successful strategies to mitigate risk of medication error. Eliminating the risks by correct use of a system such as BDS improves the likelihood of reducing errors. Using a prefilled syringe as intended by the manufacturer ensures that the medication is labeled throughout the medication use process and eliminates the risk point of mislabeled or unlabeled syringes.

The use of a PFS to dilute medications was another predefined error.²² Adding medication to a PFS is an unsafe practice because the syringe is labeled for saline and not the added medication, creating a mislabeled syringe. The markings on the PFS syringe are not as accurate as regular syringe and could lead to the administration of an incorrect dose.²³ Syringe-to-syringe transfer of medications may also lead to microbial contamination.¹ In our study, only 2 doses of medication were diluted into a PFS, and 6 other doses were diluted using saline from a single-use vial. The study monitors noted that there were several comments by the study participants stating that after they had prepared the medications (regardless of

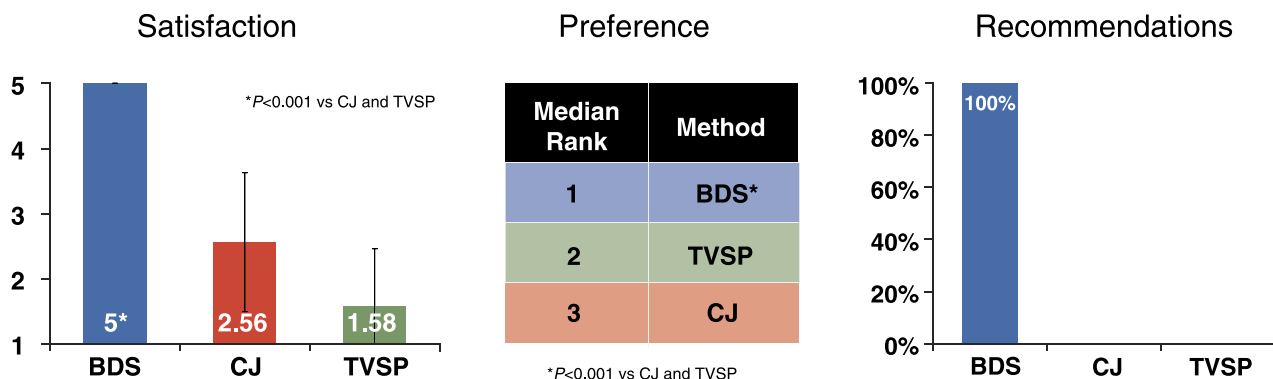


FIGURE 2. Ranking satisfaction, preference, and recommendation for adoption. Product poststudy satisfaction and preference. At the completion of all 3 simulations, respondents were asked to complete a poststudy questionnaire evaluating the following: satisfaction, where participants rated their satisfaction from 1 being not at all satisfied to 5 being very satisfied (data are mean \pm SD); preference where participants were asked to rank the 3 IV push systems; and recommendation where they were asked, "Which systems would you recommend to your colleagues (select all that apply)?" and participants unanimously recommended BDS. None recommended CJ or TVSP.

method), they would further dilute for administration, suggesting that the frequency of dilution may be higher in a clinical setting. This is consistent with the findings of the ISMP survey on dilution practices reported in June 2014, which indicated that 83% of respondents dilute some IV medications before administration.⁸ The respondents mentioned that they were more likely to dilute a medication given via a peripheral venous access device versus a central venous access catheter. The nurses in our study were drawn from a pool of critical care nurses. Patients in critical care areas are more likely to have central venous access catheters; thus, these nurses may be less inclined to dilute the medications used in our study.

The Centers for Disease Control and Prevention recommends that the rubber septum on a vial be disinfected with an alcohol swab before inserting the needle to withdraw medication.²⁴ This is important because the cap on the vial is intended to protect the septum from damage, but is not sterile. There were no instances observed where the nurses failed to swab the vials.

We included an error type for misuse of the CJ device. Anecdotal reports described instances in which nurses activated the CJ prefilled cartridge by pushing the plunger with a coffee straw, cotton swab, writing pen, or the plunger from another syringe. The simulation stations included coffee straws, cotton swabs, pens, and syringes. There were no instances where nurses used these novel approaches. This may be in part due to the fact that clean CJ cartridge holders that were still in the bag were made available at each simulation station.

Finally, we monitored for other types of errors common to the process of preparing IV push medications for administration. We observed 6 instances where nurses taped the vial to the syringe as a method of labeling. This practice is not acceptable because the vial and tape can obscure the syringe markings and/or get dislodged from the syringe. There was one case where the nurse labeled 2 syringes after drawing up the 2 medications, instead of preparing and labeling separately. No other at-risk behaviors were observed.

In summary, there were a total of 110 errors made when 216 doses of IV push medications were prepared in a simulated setting. When the study participants were presented with a new IV push medication method, there was a statistically significant decrease in the rate of errors, which may suggest that the product design enhances patient safety.

Nursing Preferences

The nursing feedback from the poststudy questionnaire indicated that the BDS device had the highest level of satisfaction and preference by the study participants. Decisions for purchasing medications have traditionally been under the supervision of the Pharmacy Department. Nursing input is typically included in the nonmedication/supply purchasing decisions but not always with purchase of medication devices. As new devices/methods for IV push medication administration are introduced, it is important to gain nursing insight for product preferences especially when it impacts nursing efficiency and patient safety. The information from this study should be considered when organizations are selecting an IV push medication system.

Frequently, drug acquisition cost is the primary determinant for drug purchases. As new medication delivery devices are introduced, it is incumbent on the organization to consider the total costs of using each device, including the financial impact of improved patient safety. The incremental cost associated with preventable adverse drug events has been estimated to be as high as \$5857 dollars per case.²⁵ Incorporating patient safety into purchasing decisions is an excellent way for health care organizations to integrate the culture of patient safety into decisions made away from the bedside.

This study has limitations. The study participants were intentionally drawn from the attendees at the AACN meeting because of their frequent use of IV push medications. We acknowledge that the results may not be the same if the participants were drawn from a different subset of nursing. The results of this study may not be generalizable across all settings because there is variability in nursing practices for IV push medication administration. A simulation model was used intentionally to capture as continuous a process as possible for the preparation time portion of the study. These preparation times would not be applicable to a real clinical setting. The observed medication errors were not unlike those that would occur in a clinical setting, which could be magnified by the influence of such events as interruptions and distractions. Further research should be conducted to validate the findings in this study. There was the potential for the Hawthorne effect on performance because subjects were aware that their IV medication preparation practices were being evaluated.

CONCLUSIONS

The findings of this study suggest that it is possible to gain efficiencies (save time) in medication administration while reducing risks to patients from medication-related adverse events. When nurses are pressed for time, distracted, or interrupted, patient safety is often compromised. The BDS system for IV push medications may offer nurses an opportunity to save time, reduce errors, and improve nursing satisfaction during medication administration. Nursing preferences as well as the safety profiles of IV push medication systems should be factored into pharmacy drug purchasing decisions.

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