The Art and Science of Infusion Nursing

Primary Intravenous Set Consumption Across 3 Branded Infusion Pumps

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ABSTRACT

This retrospective study of 6426 hip replacement, coronary artery bypass graft, and colectomy surgeries across 23 US hospitals found that intravenous (IV) set designs that can be interchanged for use both in gravity-fed and automated pump delivery systems are replaced less frequently than IV sets designed for use primarily by one delivery method. Semistructured interviews with nurses highlighted the impact of set design on nursing workflow when moving between gravity-fed and pump-based administration. Use of interchangeable, single-design IV sets across gravity and automated infusions minimizes disruptions to closed systems, may reduce nurses being distracted from patients' clinical needs when replacing sets, and may yield supply cost savings.

Key words: gravity infusion, hospital database, infusion pump, interchangeable IV set, IV set replacement, IV tubing, nurse workflow, patient safety, standard set technology

BACKGROUND

More than 51 million inpatient surgical procedures are performed annually in US hospitals.[1] An estimated 90% of all hospitalized patients receive one or more intravenous (IV) fluids.[2] Depending on the level of accuracy required, fluids may be delivered either by gravity or with the use of electromechanical infusion pumps. In North America, most infusions are delivered through infusion pumps. Volumetric pumps employ different designs and mechanisms to control fluid flow. Common designs include rollers that compress the IV tubing or sets of mechanical fingers that compress the tubing in sequence. An alternative design requires use of a cassette equipped with a flow regulator.

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These design differences dictate the use of manufacturer-dedicated administration sets (IV tubing) to ensure that pumps meet quality and performance specifications. Some pumps are designed to have a specific delimited section of tubing (also called pump segment) with integrated fitment mechanisms interacting with the compression mechanism. Other pumps require a specifically designed cassette to be introduced in the pump. In contrast, certain pumps do not have any design modifications entailing integration into the pump segment, and instead use straight standard tubing. Generally, designs that employ a fitment mechanism in a specific section of tubing, including those with a dedicated cassette, are not readily interchangeable (automated infusion to gravity-fed fluid delivery and vice versa) as designs in which sections of straight tubing can be inserted directly into the pump.

Some major US pump manufacturers offer different portfolios of administration sets (noninterchangeable sets) for gravity-fed delivery versus pump-based delivery. These noninterchangeable technologies have some recognized advantages and safety features, particularly in that they facilitate the administration set loading task that nurses perform. Pump sets with cassettes (Figure 1, Set A) or an integrated safety clamp fitment (Figure 1, Set B) require less training or mental workload to identify the tubing segment to be introduced into the pump than interchangeable, single set design technology. It could be assumed that the noninterchangeable sets are technically usable for gravity infusion, but it is counterintuitive to clinicians to select a set with cassette or fitment mechanisms if the therapy will be delivered through gravity; they tend to select standard straight tubing initially (eg, gravity set, Figure 1), especially if the therapy requires high flow rates or if they intend to use pressure infusion cuffs: "teardowns" (different administration set interchanges) may happen across different settings. In addition, cassette-based sets may lack roller clamps (nurses will need to use flow regulators on the cassette) to control flow when used outside the pump. All designs have free-flow protection features: cassettes have flow regulators that close automatically when the pump door is opened; the other design with a fitment segment has an integrated safety clamp, and the straight tubing interchangeable design has a keyed slide clamp that closes when it is inserted into a keyhole to open the pump door.

Interchangeable or single set design technology is an alternative to noninterchangeable technology. Interchangeable technology incorporates a single design of straight tubing that functions similarly in and out of the pump and, therefore, is readily interchangeable between gravity-fed and electromechanical fluid delivery (Figure 1, Set C); this technology uses a keyed slide clamp to open the pump door for channel access. A comparison of the types of primary IV sets that are used with 3 of the major pump brands used in the United States can be seen in Figure 1.

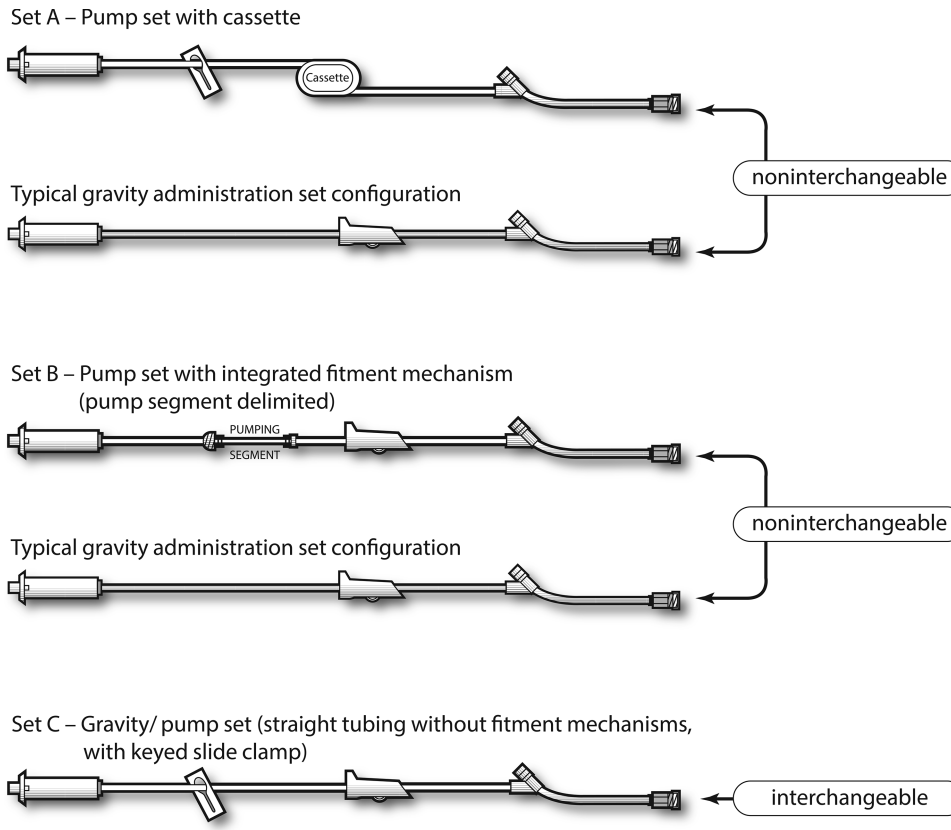

Figure 1 Schematic of primary nonspecialty administration sets designed for different infusion systems illustrating interchangeable and noninterchangeable set designs. Images shown are for illustration only and may differ from the actual products.

When separate gravity sets are used in place of a noninterchangeable set design and procedures require shifting from gravity-fed to pump-fed IV administration, nurses must tear down the administration set to accommodate the shift. While IV therapy set teardowns occur across the continuum of patient care, shifts from gravity to pump administration tend to be more frequent in the preoperative holding area, operating room, postoperative recovery unit, and both the critical care and noncritical care areas that receive postoperative patients. Using a primary IV set with a single set design that is readily interchangeable between gravity and infusion pump fluid administration could result in greater efficiency in nursing workflow because the same set can be used both within and outside of an infusion pump.

Using a single set design might also reduce the frequency of administration set replacement, which may minimize the potential of introducing contaminants when a closed IV access system is opened. For example, a recent Cochrane review reported the results of 5000 subjects in 16 randomized or controlled clinical trials that compared the implications of different replacement times for administration sets.[3] The reviewers reported that infrequent set replacement (every 4 days/96 hours unless used to deliver lipids, blood, or blood products) was found to reduce the rate of bloodstream infection; however, they were unable to make any conclusions about the impact of replacement interval on costs because none of the included trials reported cost data. The authors also concluded that high-quality evidence directing optimal set replacement times is lacking. The Replacement after Standard Versus Prolonged use trial (the RSVP trial) aims to address this evidence gap by comparing set replacement at 4 and 7 days in 6554 adult and pediatric subjects.[4] Research to date has focused on the impact of set replacement times on infection rates, but has not examined whether set design may influence replacement time or how replacements may impact inpatient care workflow for nurses or translate into real-world practice.

Because no increase in bloodstream infections was reported in published studies,[5] current Centers for Disease Control and Prevention (CDC) guidelines recommend that continuously used IV administration sets be replaced no sooner than every 96 hours but at least every 7 days, with the exception of sets used to administer blood, fat emulsions, or propofol.[6,7] These recommendations supplanted the 2002 CDC guidelines, which called for set replacement no more frequently than every 72 hours, and are consistent with conclusions of the 2013 Cochrane review.[3,8] However, questions remain about optimal set replacement time.

The study objective was to identify whether primary IV set replacement rates varied between pumps using interchangeable administration sets compared with those using noninterchangeable administration sets. This objective was investigated by comparing the number of primary administration sets used among 3 different pump designs (1 with interchangeable sets and 2 with noninterchangeable sets) across 3 common procedures[9] performed at US hospitals: coronary artery bypass grafts (CABGs) (US stays in 2012: 20 900); colectomy (US stays in 2012: 305 900); and total and partial hip replacements (US stays in 2012: 468 000).

To better understand the impact of set changes on nursing workload and nursing protocol, as well as implications for patient care, the main analysis was supplemented with anonymized interviews with practicing nurses familiar with at least 1 of the 3 pump types and caring for patients receiving at least 1 of the 3 procedure types.

METHODS

Quantitative Study

A retrospective, observational cohort study of primary set use among 3 different brands of IV administration pumps in patients undergoing CABG, colectomy, or hip replacement, with at least 1 overnight stay, was conducted between 2011 and 2013, inclusive. The study was limited to primary sets, both nonspecialty sets (gravity and pump sets) and specialty sets (blood, nitroglycerin, and lipid sets). The 3 branded pump sets compared were as follows: Set A represents those used with the Plum A+ infusion system (Hospira Infusion Systems, now part of ICU Medical, Inc; Lake Forest, IL), a cassette-based technology multi-infusion pump; Set B are those used with the Alaris pump (CareFusion, a BD company; San Diego, CA), which has a delimited tubing segment with an integrated safety clamp fitment mechanism; and Set C are those used with the SIGMA Spectrum infusion system (Baxter Healthcare Corporation; Deerfield, IL), which has straight tubing with a keyed slide clamp, without any integrated fitment mechanism.

Data source

The Premier hospital database was used to identify hospital discharge data including procedure performed, billed supplies and services, and deidentified patient demographics and disease state. The database covers more than 565 million patient encounters, or 1 in every 5 discharges in the United States, from 700 hospitals, clinics, and ambulatory surgery centers.[10]

Eligibility criteria

Study eligibility was assessed at the patient and institution level. Eligible patients had 1 of the 3 following surgical procedures as identified by International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-CM-9) procedural code[11]: CABG (36.11-36.16), colectomy (45.73 and 45.75), or hip replacement (81.51 and 81.52). Patients were aged 18 years or older and had a minimum inpatient stay of 1 day after the surgical procedure. Inclusion criteria required a patient hospital stay to have at least 1 charge for a primary (nonspecialty) administration set that could be used with 1 of the 3 major brands of infusion pumps. To focus on simple procedures and typical utilization, as

well as to minimize potential for any skewing from extreme cases, outliers in length of stay (LOS) >14 days, the highest and lowest 1% of the number of sets used per stay, and the highest and lowest 1% of the number of primary sets used were excluded.

Hospital eligibility included ≥100 hospital beds, with ≥30 procedures of any 1 of the 3 included types performed between 2011 and 2013 inclusive. At least 80% of admissions must have had an identifiable brand of infusion pump; primary use of a single, identifiable brand of infusion pump; and a minimum median ratio of 0.25 standard primary sets used per inpatient day (reflecting the most recent CDC guidelines for set changes every 96 hours[6]) across the years of the study. Because the study objective was to compare set replacement rates of the interchangeable or noninterchangeable primary sets used with specific pumps, eligible hospital stays were restricted to use of a single brand of pump as suggested by associated set use across at least 95% of patient discharges. Large variation in the number of IV sets used across calendar years was hypothesized to be associated with data quality issues. Therefore, eligible hospitals were required to have a standardized difference in the ratio of sets consumed per inpatient day between consecutive calendar years of 0.2 or less.

Data Analysis

All analyses were conducted using SAS version 9.2 (SAS Institute Inc; Cary, NC). A univariate model was constructed to compare set use among vendors. A multivariate model (a generalized linear mixed model with hospital as a random effect and patient-level variables as fixed effects) was constructed to account for confounding variables, including age; gender; race; insurance type; emergency versus scheduled admission; discharge status; Charlson Comorbidity Index (CCI); severity (as calculated by the All Patient Refined [APR] Diagnosis Related Groups [DRG], a US clinical model widely used for adjusting data for severity of illness and risk of mortality [3M Health Information Systems; Salt Lake City, UT]); day of surgery after hospital admission; teaching versus nonteaching hospital; hospitalization LOS; primary procedure; and procedure year. The random intercepts model included the hospital as a random effect. Forward stepwise selection was used to determine the significance and entry of variables into the model ($P \leq .20$).

A total of 3 sensitivity analyses were conducted. First, the patient selection criterion regarding the median set utilization to LOS ratio was changed from 0.25 (corresponding to set replacement every 96 hours) to 0.33 (every 72 hours) to account for the earlier CDC guidelines in place at the start of the study period. Second, the hospital selection criterion regarding the standardized difference between set utilization in consecutive years was calculated using the mean ratio values and standard deviation, and varied from 0.2 in the base model to 0.3 in the sensitivity analysis. A final sensitivity analysis compared set replacement for the interchangeable set technology (Set C) with set utilization for the 2 noninterchangeable set technologies combined (Set A and Set B).

Qualitative Study

Double-blinded, semistructured, 1-hour telephone interviews were conducted to capture nursing workflow associated with IV fluid administration during the perioperative period. A convenience sample of 3 nurses was recruited by a third party, and a unique identification number was assigned to participants to ensure anonymity. To minimize interviewer bias, all interviews were conducted by telephone by an independent researcher, and the audio was recorded after receiving the participant's permission, both in advance upon recruitment and confirmed orally during the interview. Neither study authors nor sponsor personnel were present during the interviews. Two independent researchers reviewed the audio recordings of the 3 interviews and identified key themes. The study questionnaire, consent forms, interview structure, and qualitative study design were reviewed and approved by an external institutional review board (Solutions IRB) in advance of participant recruitment.

Eligible nurses had at least 5 years of experience working with large-volume infusion pumps in an inpatient hospital setting, had worked at their current hospital for at least 1 year, currently worked at least 32 hours per week, and currently were in a role managing IV lines in postsurgical patient care. Nurses were required to have experience with at least 1 of the surgical types and 1 of the pump types included in the quantitative study so that all 3 infusion pump types were represented. Hospitals where they worked were required to have between 250 and 700 beds, to perform all 3 surgery types, and to use at least 1 of the 3 pump types included in the quantitative study. All nurses interviewed consented before participation.

RESULTS

Quantitative Study

Data selection

Of the 791 hospitals and 131 143 300 procedures (2011-2013) in the database, 23 hospitals and 6426 procedures met the eligibility criteria (Table 1). After applying the eligibility criteria to qualifying hospitals, approximately 98% of procedures were excluded. Most exclusions occurred at the hospital level, resulting in 50% of the 405 qualifying hospitals not meeting study inclusion criteria because of insufficient specificity of the set charge description recorded in the Premier hospital database to allow for association of an IV set charge with a particular brand of infusion pump. Primary administration set use by IV pump type for the 3 procedures was analyzed separately, resulting in 2354 CABG procedures among 14 providers, 3408 hip replacements among 19 providers, and 664 colectomies among 13 providers. The

TABLE 1

Attrition Table (Procedure Selection Criteria)[a]

Step	Criteria: Consort Diagram Steps Applied	Number of Admissions	(%) of Previous	Number of Providers
0	Premier Data Universe (inpatient and outpatient) 2011-2013	131 143 300	—	791
1	Starting count of CABG, colectomy, and hip replacement patients	294 812	100%	516
2	Remove providers with <100 beds, outpatient admissions, and admissions with age <18	284 911	96.6%	417
3	Remove providers unable to demonstrate a minimum aggregate procedure count of 30 across any 1 of the specified procedure groups	284 239	99.8%	390
4	Remove providers without itemized infusion set charges within Premier database (total of 397 147 charge transactions identified)	103 152	36.3%	330
5	Remove providers and associated admissions in which brand of infusion pump could not be identified from associated charge descriptions (total of 83 284 charge transactions remain)	33 031	32.0%	127
6	Exclude providers and associated admissions in which manufacturer cannot be associated with highest volume primary infusion set(s) consumed	25 833	78.2%	97
7	Exclude admission with more than 1 primary set vendor	24 219	93.8%	97
8	Exclude admissions exceeding 14 days in length	21 563	89.0%	97
9	Exclude admissions with extreme set utilization counts for associated LOS	20 987	97.3%	97
10	Exclude providers and associated admissions with median set to LOS ratio < 0.25	19 209	91.5%	76
11	Exclude providers in which >20% of admissions have primary set charges which cannot be associated with a vendor	11 599	60.4%	42
12	Exclude calendar years for included providers in which more than 1 primary set vendor was used for >5% of admissions	10 187	87.8%	38
13	Exclude providers and associated admissions in which year-over-year standardized difference for ratio of sets consumed to LOS exceeds 20%	6556	64.4%	26
14	Exclude providers and associated admission by surgical procedures for years in which minimum 10 admissions with associated procedures not identified	Varies by procedure type		
14a	CABG cohort	2354		14
14b	Hip replacement cohort	3408		19
14c	Colectomy cohort	664		13

Abbreviations: CABG, coronary artery bypass graft; LOS, length of stay.

[a]For the retrospective study, the final sample meeting the study eligibility criteria included 23 hospitals (providers) and 6426 separate procedures.

distribution of included hospitals and procedures across the 3 study years and across each procedure and pump type is provided in the online supplemental materials (see Supplemental Digital Content Table 1 online at http://links.lww.com/JIN/A87, which shows the number of procedures and providers meeting study eligibility criteria).

Differences in baseline patient characteristics among hospitals using specific pump brands for CABG, colectomy, and hip replacement procedures included age, race, marital status, payer type, CCI, severity as represented by APR DRG, and route of admission ($P < .05$ for all). Additional differences included discharge destination (CABG and colectomy), CCI and LOS (CABG and hip replacement), hospital geographic location (CABG only), and hospital bed count (hip replacement only), $P < .05$ for all (see Supplemental Digital Content Tables 2a, 2b, and 2c online at http://links.lww.com/JIN/A88, http://links.lww.com/JIN/A89, and http://links.lww.com/JIN/A90, respectively: 2a shows differences in baseline characteristics among coronary bypass patients; 2b shows differences in baseline characteristics among colectomy

patients; and 2c shows differences in baseline characteristics among hip replacement patients). Multivariate statistical models were used to control for these differences in baseline patient and hospital conditions.

Outcomes

Univariate model rate ratios comparing Set A or Set B versus Set C varied between 1.277 and 2.305 (95% confidence interval [CI], 1.166-2.634; $P < .0001$-$.017$), suggesting that, on average, hospitals using pumps requiring either of the 2 noninterchangeable set designs (Set A or Set B) consumed more sets per day than hospitals using the pump with interchangeable set technology (Set C). The multivariate model provided similar results for all 3 surgery types, with point estimates for sets used for Set A or Set B versus Set C ranging between 1.244 and 2.226 (95% CI, 1.143-2.544; $P \leq .0001$ for all; Figure 2). While each of the 3 multivariate sensitivity analyses resulted in slightly different point estimates, the direction of the results remained unchanged, and estimates remained statistically significant. Rate ratios in the 3 sensitivity analyses comparing set utilization for Set A and/or Set B versus Set C ranged between 1.113 and 2.215 ($P < .0001$-$.025$; 95% CI, 1.043-2.265), suggesting that hospitals using the interchangeable single set design of Set C experienced fewer set changes than those using noninterchangeable set technology.

Qualitative Study

The nurses participating in the interviews had between 18 and 25 years of nursing experience. Between them, they had worked with all 3 pumps included in the retrospective study, and each had experience caring for patients undergoing at least 1 of the 3 procedure types of interest. Their reported experience with interchangeable versus noninterchangeable administration sets mirrored the results of the retrospective study. All nurses spoke of their hospital staff using gravity-fed fluid delivery during surgery. The nurse working in an institution that stocked only an interchangeable set design described the ease of transferring from gravity flow during surgery to pump-regulated IV delivery in postoperative care. When asked about single set use compared with changing sets, she said it "would be confusing" and "more stressful" to have to use different set designs. The other nurses spoke of the level of effort required to change noninterchangeable sets, particularly when the patient had multiple sets of tubing, a common occurrence. These changes required "lots of effort," entailing "changing the tubing, hand-priming it, hanging it, programming the pump and confirming that it's working, if it works the first time."

The nurses interviewed talked about IV set changes between gravity and pump administration being exacerbated by complications from identifying the line to be changed among multiple lines and from pump alarms associated with air in the tubing, both common situations for some nurses. One nurse described her hospital as currently running "lean" inventory management with the result that new sets may not be close at hand. Although they estimated that the actual time to change a single set was between "a couple of minutes" and "4 to 5 minutes," the nurses noted that most patients have multiple IV lines, which compounds the time required for changes, and that the concentration required to change tubing was a distraction from patient care. Depending on the location of the patient's bed in the postsurgical unit, the nurse might have to cross a room to a supply closet to obtain the new tubing sets, then focus on the tubing and pump while changing the sets and sometimes be unable to see the patient. The nurses identified a concern that taking their "eyes off the patient" could cause them to miss early signs of a deteriorating condition at the critical time after surgery. This was especially an issue when caring for multiple patients simultaneously, as is typically the case: "Usually we try to stand between them but you still have to look away." These nurses were concerned that time spent on tubing changes might pose a risk to patient safety. They also described patients who were fragile or whose IV access was "precarious," and mentioned the risk of dislodging the IV catheter during a set change. The nurses described the speed with which clinical status can change, saying that "any patient can come in as a normal elective case, then turn around and be a total disaster."

When asked whether there are benefits to standardization of 1 type of primary set that can be used in both gravity

Comparison Sets	Procedures (n)‡	95% Confidence Interval*	
		Lower limits	Upper limit
CABG – Set A	996	1.143	1.354
CABG – Set B	252	1.949	2.544
COL – Set A	1538	1.362	1.810
COL – Set B	153	1.250	1.844
HIP – Set A	84	1.565	1.784
HIP – Set B	523	1.166	1.385

*Set C procedure totals: coronary artery bypass graft = 1205; colectomy = 328; hip replacement = 1347.

*p<0.0001

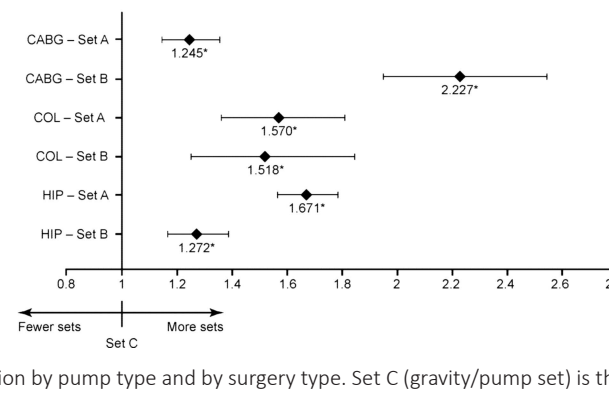

Figure 2 Rate ratio of primary administration set utilization by pump type and by surgery type. Set C (gravity/pump set) is the reference group with a rate ratio value of 1.0. Diamonds indicate rate ratios, and bars indicate 95% confidence interval limits. All rate ratios have a *P* value < .001. *Abbreviations: CABG, coronary artery bypass graft; COL, colectomy; HIP, hip replacement.*

mode as well as on an IV pump, 1 nurse working at a hospital using noninterchangeable set technology stated that this would "absolutely save a lot of extra scurrying and doing things at once. If you didn't have to change [sets], it wouldn't be just time-saving, but also you wouldn't have to take your eyes away from the patient. It would be nice if everything was compatible and you could just hang a new bag." Another nurse expressed a similar thought: "If sets are standardized, there is less risk."

DISCUSSION

This study of primary set utilization in real-world practice describing more than 6000 commonly performed surgical procedures is the first to examine whether differences in administration set design (interchangeable versus noninterchangeable sets) are associated with set replacement rates in inpatient care settings. The study is also unique in that it integrates a nursing perspective to gain insight into the implications of IV set replacement on workflow along the continuum of perioperative patient care.

The retrospective quantitative study found that interchangeable IV administration sets in hospitals using Set C, with its straight-line tubing with a keyed slide clamp, were replaced less frequently than noninterchangeable sets in hospitals using pumps requiring cassette-based technology (Set A) or those using pumps with sets having an integrated safety clamp fitment (Set B). This difference in replacement rates was found for all 3 surgery types. Hip replacement procedures are generally of lower complexity and result in shorter LOS than the other 2 surgery types. Nevertheless, set utilization during hip replacement also showed lower replacement rates for institutions using interchangeable rather than noninterchangeable sets, as was the case during more complex CABG and colectomy procedures. These findings were robust to adjusting the model for confounding variables as well as to 3 different sensitivity analyses: increasing the mean set utilization to LOS ratio from 0.25 (replacement every 96 hours) to 0.33 (replacement every 72 hours) as a procedure selection criterion, increasing the mean difference in set quantity to LOS ratio in consecutive years from 0.2 to 0.3 in hospital selection, and combining set replacement rates for Set A and Set B (both being noninterchangeable) for comparison with Set C (interchangeable set technology).

Interviews with 3 practicing nurses provided real-world context for the data analysis. The nurses described the varying fluid and drug requirements of surgery and the postanesthesia care unit, noting that optimal care requires different IV flow rates at different points in the patient journey. The interviewed nurses spoke of the high flow rates used during surgery and the preference to use gravity flow to achieve those rates. In their experience, many of the fluids used in postsurgical care, particularly blood and certain drugs, have specific delivery requirements that require a pump, as discussed in published reports.[12] The nurses characterized the impact of set changes on nursing workflow as taking their attention away from direct patient observation. The nurses interviewed expressed concern about set changes as a distraction from patient care that could possibly affect patient safety. Surprisingly to the research team, given the CDC guidelines on set replacement[6] and published evidence showing that reductions in opening closed IV systems minimizes the possibility of infection risk,[4,5] none of the 3 nurses interviewed mentioned possible exposure to infection when the system was opened during IV set changes.

The research findings illustrate issues around nursing workflow, which are particularly relevant as shortages of nursing staff and implications for patient care have been the subject of many studies and some legislation. Insufficient nursing staff has been shown to correlate with patient mortality, medication errors, and hospital readmission rates, and studies have acknowledged the role of multiple variables in determining effective staffing models.[13] Establishing efficiencies in nursing workflow may free up time for nurses to focus attention on their patients' clinical status. The differences in the rate of set changes identified in the quantitative study may result in relevant benefits for patient care, for nursing workflow efficiencies, and potentially for cost savings when a single design of sets is used throughout a patient's continuum of care.

Study Limitations

Study limitations of the quantitative analysis include those associated with the data, selection criteria, and study design. First, the quantitative data represented only those hospitals participating in the Premier hospital database, which were generally medium-sized (100-499 beds), were less likely to be teaching hospitals, and were not representative of all regions of the country. Also, the available study variables were limited to information collected in the study database. Only 3 surgery types were examined, and cases thought to represent extreme outliers were censored; thus, the study did not account for set utilization during difficult cases requiring longer stays or other surgery types. Unique procedures were included in the retrospective study, but they did not necessarily represent unique patients. Finally, neither supply nor labor costs for set replacement were investigated in this study.

Second, after applying the eligibility criteria to qualifying hospitals, approximately 98% of procedures were excluded. The largest exclusions occurred at the hospital level, resulting in 50% of the 405 qualifying hospitals not meeting study inclusion criteria because of insufficient specificity of the listed IV set charge description to allow for association of an IV set charge with a particular brand of infusion pump. The study selection criteria resulted in small sample sizes for some of the institutions, pump types, and/or procedures. For example, the maximum number of institutions meeting eligibility criteria per individual procedure type and year was 7 (Supplemental Table 1; http://links.lww.com/JIN/A87).

Further, in 2013 only 1 hospital contributed data for use of Set B (integrated safety clamp fitment set) in CABG, and in 2011, 1 hospital reported using Set B for colectomy. The results for Set B should be interpreted with caution for respective years. It is possible that some hospitals, such as those with a large volume of qualifying procedures, may have a disproportionate impact on the results. It is unknown how excluding nonqualifying providers from the study (due either to omission from the Premier hospital database or to study eligibility criteria) affected the study results.

Third, because selection of hospitals into the quantitative study was not randomized, selection bias may exist. Variables not included in the database (eg, nurse experience, patient clinical data, and unknown confounders that can only properly be addressed in randomized controlled trials) were not included in the analysis. Also of note is that the analysis used a single value for set replacement rate; however, CDC guidelines on set replacement changed during the study period. To address this, analyses using both the older (replacement no more often than 72 hours or 0.33 sets/day) and the new guidelines (96 hours or 0.25 sets/day) were run, which separately maintained statistical significance and the same directionality in the results. The limitations of a retrospective study design and the restrictive inclusion criteria required to select hospitals in which recorded set use appears to be reflective of actual consumption resulted in a small sample. Given our relatively small sample size, the magnitude of the difference in the frequency of set replacement among infusion pump brands identified in this study is subject to large standard error and should not be considered representative or definitive of set replacement frequency. Despite the limitations of the quantitative analysis, the results consistently show that sets with interchangeable technology were replaced less frequently than those that were noninterchangeable, resulting in both fewer set changes and fewer primary IV sets consumed in hospitals using pumps with interchangeable set technology than in hospitals using pumps with noninterchangeable technology.

Limitations of the qualitative study include a small sample of 3 nurses; however, the interviews were not intended to be representative but, rather, case studies to provide a view into nursing workflow in environments where either interchangeable or noninterchangeable set technology was used during the continuum of perioperative care. Although nurses were screened both for experience with different pump types and the surgeries examined in the retrospective study, they were not equally experienced in all the workflows associated with each of the 3 surgical procedures in the quantitative study, in working with both interchangeable and noninterchangeable pump set technology, or in providing care at multiple points of patient contact across the inpatient journey.

Study Implications

The financial implications of the study results for hospital costs are not well understood. Raad et al[14] studied hospitalized oncology patients and concluded that extending replacement from 72 to 96 hours in the 84% of patients who did not require blood products, parenteral nutrition, or interleukin-2 would save $700 000 (2001 US dollars) annually in a single hospital. Lai[15] calculated a single institution's savings of extending replacements from every 3 days to every 4 days to be over $60 000 (1998 US dollars). Rickard et al[16] estimated savings of up to $200 (2004 US dollars) per set based on the costs of administration sets alone. None of these studies considered the contribution of savings in nursing time, a theme identified in the qualitative interviews, and none controlled for interchangeable versus noninterchangeable sets as in both the quantitative analyses and the nurse interviews.

Greater efficiency through using a single set design of IV sets may streamline patient flow among departments and allow for smoother transitions between gravity and pump IV fluid administration. These efficiencies may save staff time, reduce training needs, maintain closed systems, reduce touch contamination, and ultimately result in cost savings through reduced inventory stemming from fewer sets used per LOS, through fewer openings of closed IV systems, and from fewer interruptions in nursing workflow. Such efficiencies, coupled with the additional nursing attention available for direct patient observation and care, may also support the safe staffing initiatives under way in hospitals across the United States.[13] Additional real-world studies of the frequency of set replacement for different pump types and the implications for patient management and nursing workflow are needed to inform clinical practice.

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