SYSTEMS-LEVEL QUALITY IMPROVEMENT

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Tracking the Progress of Wireless Infusion Pump Drug Library Updates– A Data-Driven Analysis of Pump Update Delays

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Abstract

Modern smart infusion pumps are wirelessly connected to a network server for easy data communications. The two-way communication allows uploading of infusion data and downloading of drug library updates. We have discovered significant delays in library updates. This research aimed at studying the drug library update process of one vendor pump and the contributing factors of pump update delays. Our data included BD Alaris™ pump status and infusion reports of two hospital systems (92 and 80 days, respectively, in 2015). We analyzed drug library update progressions at the individual device and fleet levels. To complete a library update, a pump goes through two status transitions: from noncurrent to a new library pending, and from pending to current. On average it took five to nine days for 50% of a pump fleet to become current after a new drug library was disseminated. We confirmed factors that affect noncurrent-to-pending time to include time to first power-on and total power-on time. We also found that high pump utilization promotes shorter pending-to-current time. Two distinctive and important steps of a drug library update on Alaris™ pumps are pending a new library and completing the library installation. To avoid potential patient harm caused by infusion pumps without appropriate drug limits due to update delays, hospitals should monitor the progression of a drug library update on its pump fleet. Potential ways to improve drug library updates on a fleet of pumps include better technologies, improved pump user-interface design, and more staff training.

Introduction

An infusion pump is a widely used medical device to intravenously deliver fluids or drugs into a patient's body in controlled amounts. Functional failures in an infusion pump can have negative impact on patient safety [1]. "Smart" infusion pumps are those equipped with Dose Error Reduction Systems (DERS) with customized drug library and can alert the user when potential issues or problems occur during infusion programming or administration [1, 2]. Smart infusion pumps also record and store usage information, some in great detail, which can be used to improve infusion practice and patient safety [3]. Nowadays smart infusion pumps are widely used in the U.S., many with wireless communication capabilities for data uploading and downloading.

The Institute for Safe Medication Practices recommends that hospitals routinely review and revise their drug limit settings in the drug library to reflect changes in available infusion supplies, clinical practices, or patient populations [4]. Typically, a medication safety committee consisting of physicians, nurses, and pharmacists in a hospital system is in charge of reviewing and adjusting the drug limits in the library on a regular basis. The convenience of wirelessly disseminating a new drug library version from the network server to all pumps in the hospital was believed to guarantee the success of having drug library update installed on each pump in a timely manner without the need for human intervention [5].

Nonetheless, we have discovered that drug library updates on infusion pumps often do not happen very efficiently and

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prolonged delays of such update have been observed in various hospitals [6–8]. Our prior study showed significant drug library update delays occurred during a two-year period among 49 hospitals of 12 health systems, with delay medians ranging from 22 to 192 days [8]. The slow update was also identified to increase risk of use error during the early stage of implementing smart pumps [9]. This library update delay problem was quite disconcerting to us researchers and clinicians alike. Using an outdated drug library on an infusion pump could mean using incorrect or no drug limits when administering infusions which in turn may jeopardize patient safety.

The goal of this work was to evaluate the pump drug library update process and identify the potential contributing factors of pump update delays. This manuscript presents the findings from analyzing drug library updates on individual BD Alaris™ (Becton, Dickinson and Company, San Diego, CA) pumps in two hospital systems. We aimed to study the steps involved in completing a pump library update process, especially (1) whether the required steps contribute equally to the overall pump update delay, and (2) how pump usage impacts the completion of drug library updates.

Method

Data

The study dataset includes vendor provided infusion pump status and all infusion detail reports of two member hospital systems (hereafter, HS-A and HS-B) in the Regenstrief National Center for Medical Device Informatics (REMEDI) Infusion Pump community of practice, supported by the Regenstrief Center for Healthcare Engineering at Purdue University. The dataset contains five facilities: Facilities 1 to 4 of a multi-facility hospital system, HS-A, and a single facility hospital system, HS-B, (Facility 5). All of these facilities used Alaris™ pumps with manufacturer provided software packages. Our data consisted of HS-A's pump fleet from June 4, 2015 to September 3, 2015 (92 days), and HS-B's July 1 to September 18, 2015 (80 days). Both HS-A and HS-B went through three update cycles (i.e., library version releases) during its study period, and the average update cycle length (i.e., days between two consecutive releases) was 28 days.

The *infusion pump status report* is a snapshot of the information and status of the entire pump fleet in the pump network server, available in the infusion pump system management software tool. It contains recordings of each pump's model, serial number, name of the activated drug library version, name and ID of the drug library version the pump is using, transfer timestamp of the drug library version on the pump, name and ID of the pending drug library version (if there is

one waiting to be installed) on the pump, last pump-server communication timestamp, and care unit/profile last observed. We asked our pharmacist collaborators to share such pump status report daily so we can track the status change of each pump and the patterns of the change. The *all infusion detail report* contains information of each infusion event including time stamp, care unit, the serial number of the pump from which the infusion was delivered and the drug library version the pump used at the time. This report can be generated using the pump manufacturer's web-based software application.

Pump hardware, software and pump server software versions

At the time of data collection in 2015, both HS-A and HS-B were using Alaris™ pump model 8015. In addition, based on vendor provided information, both hospital systems were using pump server software 3.3.1, and pump software version 9.12.

Definition and performance measures

To properly measure pump update performance, we defined the following: (1) an update cycle is the lapse of days between two consecutive library version releases or updates, (2) by comparing the drug library versions of each pump and the latest system release as stated in the status reports we classified each pump into one of three following statuses on each reporting day:
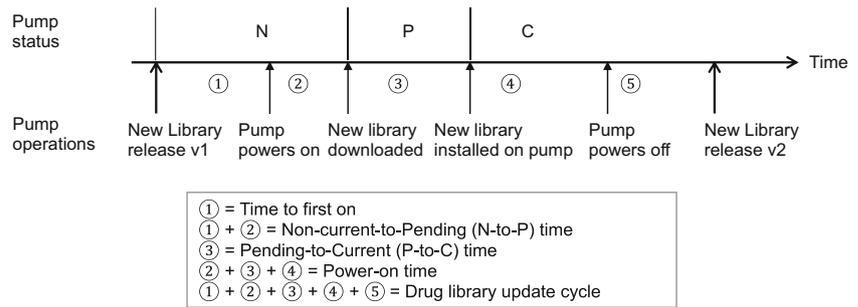
- Current (C): the pump was using the latest release of the drug library.
- Pending (P): the pump was not using the latest release of the drug library which, however, had been downloaded to the pump pending installation.
- Noncurrent (N): the pump was not using the latest release of the drug library nor did it have the latest release of the drug library pending on the pump.

Figure 1 is a pictorial representation of the various definitions outlined in this section.

The pump's serial number was used to identify each individual pump in our dataset. Based on the pump status report and all infusion detail report, each individual pump was tracked throughout the update cycles on those days when we received reports. We also defined the following: First, the time a pump changed its status was the earliest time observable to us in the pump status report or all infusion detail report; second, only pumps that were ever powered on during this period, and used in an update cycle were included in the analyses.

The Alaris™ pump is designed to download the disseminated drug library via Wi-Fi only while it is turned on, and that it completes installing the pending drug library only after the

Fig. 1 Definitions of pump status transitions and drug library update performance measures

① = Time to first on
① + ② = Non-current-to-Pending (N-to-P) time
③ = Pending-to-Current (P-to-C) time
② + ③ + ④ = Power-on time
① + ② + ③ + ④ + ⑤ = Drug library update cycle

user selects "New Patient" at the pump start-up page [10]. Therefore, we defined two distinctive steps in the update process: (1) download of the latest drug library onto a pump such that the pump transitions from noncurrent to pending (N-to-P), and (2) a human's manual initiation of the library update via the pump software such that the pump transitions from Pending to Current (P-to-C). A specific rule was applied regarding the P-to-C step. If a pump never became Pending in an update cycle (i.e., the pump was noncurrent throughout the whole cycle), we excluded it from the analysis of the P-to-C step, simply because it was not meaningful to calculate the duration of P-to-C when a pump never reached the pending status.

We defined two measures related to pump-server communications: the total *power-on time* and *time to first on* of a pump during the N-to-P step. *Power-on time* of any given pump is calculated by summing up the time duration of pump in use in all infusion records, while the *time to first on* is the time when a pump is turned on for the first time since the latest library release.

Statistical methods

To test the difference in each of the two steps of the drug library update process on the pump, we used ANOVA and Tukey tests for each pair of the facilities. In addition, Pearson correlation test was applied to factors contributing to Noncurrent-to-Pending (N-to-P) time.

Results

Pump fleet update performance

In each update cycle, only pumps that were used were included in this analysis (Table 1). In each facility, on average it took at least five days for 50% of the pumps to become "Current" and at least two weeks before 80% of all pumps in use became up-to-date. Most of the facilities did not complete update 90% of their total pumps in use within an update cycle. On average more than 84% of the pumps in use had become "Current" by the end of the update cycle. The number of pumps in use was determined by counting all unique pumps in the all infusion data. The last column in Table 1 shows the average total number of pumps accounted for in each facility per cycle based on the pump status reports. This census pump count varies for Facilities 1 to 4 from cycle to cycle due to pump movement among facilities, while remaining constant for Facility 5.

Pump update performance and comparison

ANOVA test was applied to the individual N-to-P and P-to-C steps. Statistically significant differences exist in both N-to-P and P-to-C durations among the five facilities (Table 2). Tukey tests of N-to-P and P-to-C were conducted for each pair of the facilities (Table 2). As *p*-values indicate, in step N-to-P, no statistically significant difference exists among Facilities 1, 2, 3 and 4 (HS-A), but a strong statistical difference exists

Table 1 Comparison of the pump update progressions for 3 update cycles

Facility	Mean (SD) duration until x of pumps in use became "Current" (day)[a]						Mean (SD) pump update performance measure per cycle		
	x = 50%	x = 60%	x = 70%	x = 80%	x = 85%	x = 90%	Max. % of pump in use updated	Number of pumps in use	Census # of pumps in fleet
1	5.0 (0.5)	7.2 (1.1)	10.2 (3.4)	15.9 (4.9)	N/A	N/A	89 (5)	182 (5)	219 (5)
2	5.3 (0.6)	7.0 (0.6)	9.2 (1.1)	13.2 (2.2)	16.8 (3.4)	22.4 (4.2)	95 (3)	189 (4)	236 (14)
3	5.3 (0.5)	6.7 (0.9)	10.2 (3.2)	15.2 (4.2)	22.3 (7.2)	N/A	91 (5)	295 (21)	384 (12)
4	8.0 (0.3)	10.9 (0.4)	14.8 (0.9)	20.7 (0.7)	24.5 (2.1)	N/A	92 (3)	85 (6)	149 (4)
5	9.0 (1.0)	11.6 (1.8)	15.8 (3.0)	21.9 (4.4)	N/A	N/A	84 (3)	468 (30)	686 (0)

[a] N/A indicates at least one measure was unavailable in any of the 3 update cycles for the facility

between each of Facilities 1, 2, 3 (HS-A) and Facility 5 (HS-B). In step P-to-C, Facilities 1, 2 and 3 show statistically significant differences while comparing to Facility 5. There are also statistically significant differences in P-to-C duration of Facilities 2 and 4, and Facilities 3 and 4 of HS-A.

Potential factors of pump update performance

Factors of time to pending or N-to-P

By design, after a new library release an Alaris™ pump may wirelessly download the new library file when it is powered on. Thus it's reasonable to assume the longer the pump stays on, the higher the likelihood it will transition from N to P (i.e., shorter N-to-P time). Table 3 shows the Pearson correlation tests of these two factors on the average time delay a pump transitions from N to P. The results are consistent across all five facilities: *time to first on* is positively correlated to N-to-P, and total *power-on time* is negatively correlated to N-to-P. Since the results of Facilities 1 to 4 are very similar, we elected to show the correlations of these two measures for Facilities 3 and 5 in Figs. 2 and 3, respectively. Ideally N-to-P should be close to zero after the pump is turned on for the first time after the latest library release, i.e., all points in these two figures should fall on the 45-degree line. Compared to Facility 5, Facility 3 apparently had more delays downloading the latest library to the pumps.

Factors of pending-to-current (P-to-C)

As mentioned above, the P-to-C transition requires the operator to power cycle the pump and then select "New Patient" on the start-up screen to complete the installation of the new library. Since our data did not contain the instances that such action was taken, we deemed individual infusion starts as potential pump status transition times. Moreover, our dataset did not contain patient identifiers, thus, we aggregated consecutive infusions on the same pump that were no more than 12 h apart as a way to differentiate those more likely for different patients, thus were likely opportunities for a user to select "New Patient" on the pump start-up.

We applied this 12-h rule to aggregate the number of infusions in P-to-C for each pump in each cycle and divided the number of distinctive infusions by the length of P-to-C. This "number of infusions per day" may also be viewed as a pump utilization measure. Figures 4 and 5 demonstrate the association of P-to-C and such pump utilization in HS-A and HS-B, respectively. In both figures, it shows that the more frequently a pump was used for infusion, the shorter the P-to-C time. On the contrary, it was more likely to prolong the P-to-C time as the number of infusions per day (x-axis) decreased. In Fig. 5, the data points are grouped based on the counted number of infusions and show similar patterns as those of HS-A in Fig. 4.

Discussion

The pump update delay problem is widespread as we previously discovered [7, 8]. It occurs in various hospitals and care

Table 2 ANOVA and Comparisons of time delays in each step among Facilities 1 to 5

N-to-P (day)

ANOVA Test			
df	Sum Sq	Mean Sq	*p*
4	929	232.14	≈0
Facility		Tukey Test	
Mean (SD)			
1	2	*t*	*p*
4.3 (7.7)	4.4 (7.0)	−0.3	0.99
	3		
	4.7 (8.2)	−0.9	0.87
	4		
	5.3 (8.2)	−1.7	0.36
	5		
	5.5 (7.2)	−3.2	0.01
2	3	*t*	*p*
4.4 (7.0)	4.7 (8.2)	−0.6	0.97
	4		
	5.3 (8.2)	−1.5	0.52
	5		
	5.5 (7.2)	−3.1	0.03
3	4	*t*	*p*
4.7 (8.2)	5.3 (8.2)	−1.1	0.75
	5		
	5.5 (7.2)	−2.5	0.08
4	5	*t*	*p*
5.3 (8.2)	5.5 (7.2)	−0.3	0.99

P-to-C (day)

ANOVA Test			
df	Sum Sq	Mean Sq	*p*
4	3280	820.1	≈0
Facility		Tukey Test	
Mean (SD)			
1	2	*t*	*p*
4.9 (7.4)	3.9 (6.2)	2.4	0.13
	3		
	4.2 (6.6)	1.6	0.47
	4		
	6.3 (7.9)	−2.3	0.08
	5		
	6.1 (7.3)	−3.3	0.01
2	3	*t*	*p*
3.9 (6.2)	4.2 (6.6)	−1.1	0.87
	4		
	6.3 (7.9)	−4.2	≈0
	5		
	6.1 (7.3)	−7	≈0
3	4	*t*	*p*
4.2 (6.6)	6.3 (7.9)	−3.6	≈0
	5		
	6.1 (7.3)	−6.3	≈0
4	5	*t*	*p*
6.3 (7.9)	6.1 (7.3)	0.2	0.99

Table 3 Pearson correlation test of Factors Time-to-First-On and Total power-on-time vs. N-to-P (time to pending)

Variable	Facility 1		Facility 2		Facility 3		Facility 4		Facility 5	
	r	p	r	p	r	p	r	p	r	p
Time to first on	0.59	0.00	0.63	0.00	0.61	0.00	0.75	0.00	0.98	0.00
Total power-on time	−0.13	0.03	−0.16	0.00	−0.25	0.00	−0.23	0.02	−0.40	0.00

r is the Pearson Correlation Coefficient

units we investigated, and the same problem was also discovered in other vendor pumps such as the MedNet Plum A + ™ smart pumps [11]. The Alaris™ pump in this study was designed to include a two-step update process in which the complete and timely update of a new drug library requires both reliable pump-server communication and proper human initiation of the new library file installation.

Update performance across facilities

Table 1 shows that it took more than 13 days for 80% of the pumps in use to be updated after a new drug library was activated. Facility 2 is the only one that 90% of pumps in use became most up-to-date. Moreover, the percentage improvement on pump updates in each facility slowed down as time went by: on average it took 2.2 days to improve from 50% to 60%, 3.4 days from 60% to 70%, and 5.3 days from 70% to 80%.

Even though at least 85% of the pumps in use became up-to-date by the end of an update cycle (Column 8 in Table 1),

17% to 43% of the pumps were never in use (but listed in the report). Since the specific design of the library update process of Alaris™ pump is that if a pump is not turned on or in use, it cannot download the pending new drug library or complete the installation of the new library on the pump, i.e., it cannot become "Pending" nor can it transition from pending to current. This was indicative of the impact of pump usage on the library update progress, and that led to our subsequent analysis of pump usage pattern.

Steps N-to-P and P-to-C

Our analysis showed, in most cases, no significant difference existed between the average times for a pump to complete the two update steps. In other words, the N-to-P and P-to-C steps contributed equally to the overall delay in pump library update. In addition, Table 2 shows that the average N-to-P time was statistically different when comparing that of Facilities 1, 2, 3 of HS-A to that of Facility 5 at the significance level of $\alpha = 0.05$, while no significant difference existed among the
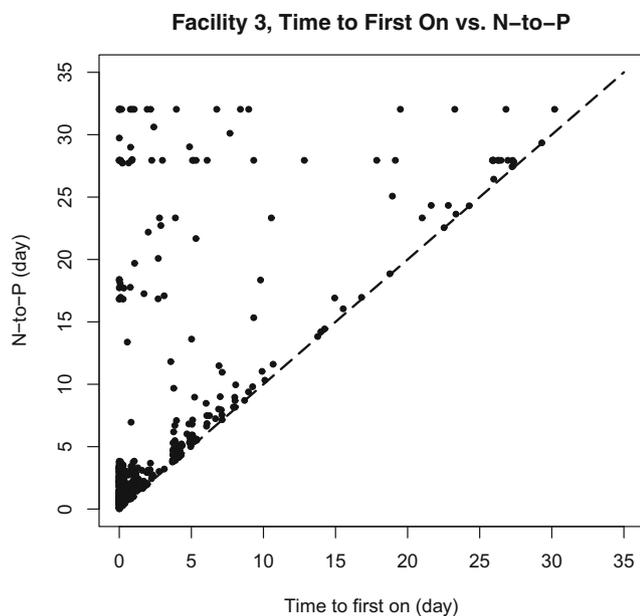

Fig. 2 Scatter plot of time to first on and N-to-P time for Facility 3. The dashed 45-degree line represents the immediate download of the new drug library file (i.e., the ideal case)
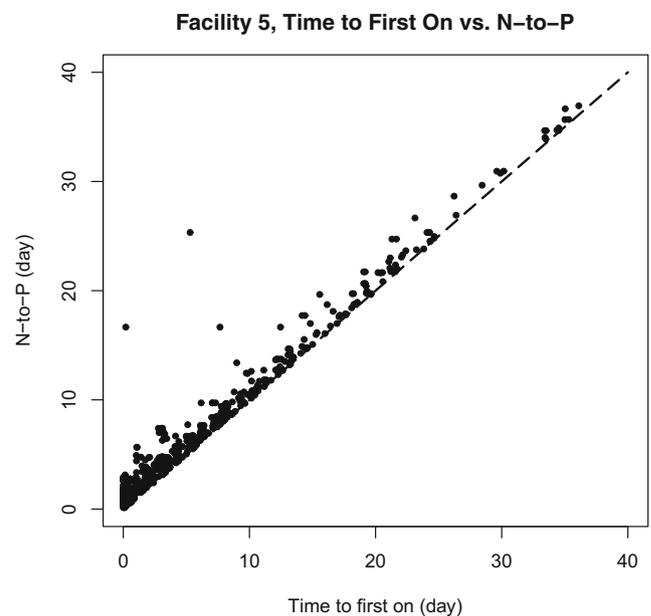

Fig. 3 Scatter plot of time to first on and N-to-P time for Facility 5. The dashed 45-degree line represents the immediate download of the new drug library file (i.e., the ideal case)
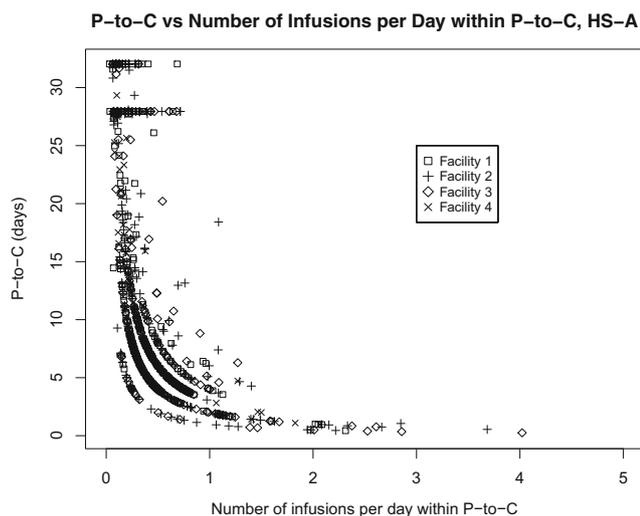
Fig. 4 Scatter plot of number of infusions per day vs. P-to-C time for facilities in HS-A

average N-to-P times of the HS-A facilities. On the other hand, the P-to-C result showed that the within-system differences did exist in HS-A. This implies that pump users in the various facilities within HS-A may have different pump update practices.

Another interesting observation from Figs. 2 and 3 on N-to-P is that the pumps in Facility 5 became pending as soon as they were turned on. In contrast, a higher percentage of pumps in Facility 3 (i.e., those in the upper-left side of the 45-degree dashed line) took longer time to become pending after the new library was released (Fig. 2). The difference between these two facilities of two hospital systems may be due to the difference in the network technologies, hardware age, WiFi coverage, etc. Clearly what we observed in Facility 5 was closer to ideal (Fig. 3).
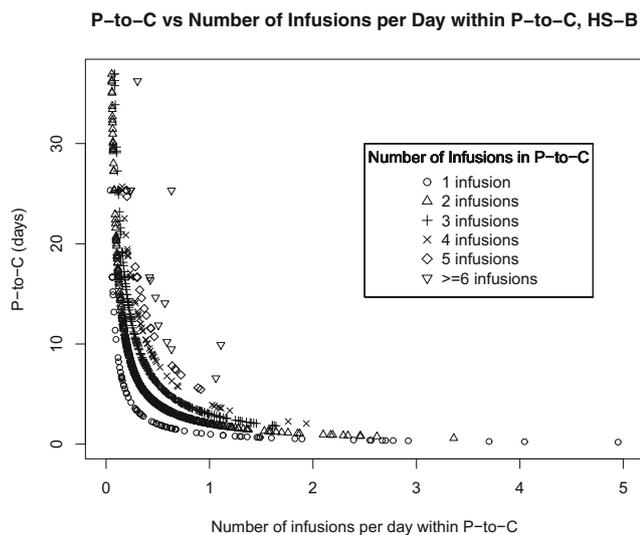

Fig. 5 Scatter plot of number of infusions per day vs. P-to-C time for HS-B

The impact of the pump usage pattern

Due to the two-step update process, we hypothesized that pump utilization would have significant and negative impact on the delay for a pump to transition from N-to-P and P-to-C. Pump usage can be measured in terms of the time a pump is turned on and how frequent infusions are administered by the pump. Table 3 clearly shows that the first time a pump was turned on after a new library release was positively correlated to N-to-P, and the total power-on time was negatively correlated to N-to-P. This means that the sooner a pump was turned on after a library release the sooner it downloaded the pending library file, and that the more a pump was in use the less time it took to become Pending (Figs. 4 and 5). In other words, the more frequently a pump was started for infusions, the quicker it became Current from the Pending status.

Our results support the hypothesis that pump utilization has a significant impact on the completion of drug library updates on individual pumps. Moreover, since a new pump library release is not done on a daily basis (e.g., it may be monthly, bi-monthly or, commonly, quarterly), without proper user training or effective indication on the pump user-interface, updating the library on a pump can easily be neglected or forgotten by the pump user.

Limitation of the study

The limitations of this study include the following: (1) our collected data were from pump status reports of only selected days during the study period (Facilities 1 to 4: 40% and Facility 5: 50% of the days), (2) we assumed the data were accurate accounts of actual events, and (3) the pump data naturally did not capture the human behavior and workflows pertinent to updating the drug library on a pump.

Conclusion

We used infusion pump data to identify two distinctive steps of an infusion pump library update, pending a new library and completing the library installation on the BD Alaris™ pump. Both steps contributed equally to the overall delay of the drug library update. Potential factors contributing to the long update process include pump utilization, WiFi coverage, and pump users' awareness of and knowledge on how to initiate the installation of a new drug library. In addition, the overall workflow designed to update these infusion pumps may not be ideal or well aligned with nursing staff's task priority [7]. To avoid potential harm caused by infusion pumps not guarded by appropriate drug limits, it is prudent that hospitals monitor the progression of a drug library update on its pump fleet. Potentially, an upgrade of the wireless

communication and pump technologies combined with more staff training and user-interface reminder for the pump update could facilitate and greatly improve the effectiveness of pump drug library updates.

Compliance with ethical standards

Conflict of interest   The authors declare that they have no conflict of interest.

Ethical approval   This article does not contain any studies with human participants or animals performed by any of the authors.

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