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Untangling Infusion Confusion: A Comparative Evaluation of Interventions in a Simulated Intensive Care Setting

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Objectives: Assess interventions' impact on preventing IV infusion identification and disconnection mix-ups.

Design: Experimental study with repeated measures design.

Setting: High fidelity simulated adult ICU.

Subjects: Forty critical care nurses.

Interventions: Participants had to correctly identify infusions and disconnect an infusion in four different conditions: baseline (current practice); line labels/organizers; smart pump; and light-linking system.

Measurements and Main Results: Participants identified infusions with significantly fewer errors when using line labels/organizers (0; 0%) than in the baseline (12; 7.7%) and smart pump conditions (10; 6.4%) ($p < 0.01$). The light-linking system did not significantly affect identification errors (5; 3.2%) compared with the other conditions. Participants were significantly faster identifying infusions when using line labels/organizers (0:31) than in the baseline (1:20), smart pump (1:29), and light-linking (1:22) conditions ($p < 0.001$). When disconnecting an infusion, there was no significant difference in errors between conditions, but participants were significantly slower when using the smart pump than all other conditions ($p < 0.001$).

Conclusions: The results suggest that line labels/organizers may increase infusion identification accuracy and efficiency. (*Crit Care Med* 2019; 47:e597–e601)

Key Words: drug labeling; human factors engineering; infusion pumps; infusions, intravenous; medication error; patient safety

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When a patient is receiving multiple IV infusions, the various components (bags, tubing, and pumps) often become entwined at the bedside (referred to as "spaghetti syndrome") (1). Also, infusions look similar and there is a lack of information along an infusion pathway. Consequently, whenever an infusion change is required (e.g., rate change, disconnection), a clinician must reconcile the bag with the associated tubing, pump, and patient access port. Given this complicated setup, infusion mix-up errors (e.g., adjust rate on wrong pump) and delays have occurred (2, 3), which is particularly concerning in emergency situations (1) and has resulted in patient harm and death (4).

Kane-Gill et al (5) showed that higher number of drugs being infused IV translates into greater likelihood of having an adverse drug event. A review by the Pennsylvania Patient Safety Authority of IV infusion incidents reported from 2004

to 2013 found that infusion mix-ups errors were the most common error (22.6%; $n = 205$), of which 92% involved high-alert drugs (e.g., heparin, insulin) (4). In 2010 the Association for the Advancement of Medical Instrumentation and the U.S. Food and Drug Administration issued an urgent call to action to improve the management of multiple infusions (6), and ECRI Institute rated infusion mix-ups as one of the top 10 health technology hazards for 2015 (7).

Current strategies to reduce infusion mix-ups are limited, with infusion setups varying between clinicians, units, and hospitals (4, 8). Although interventions have been proposed (1–4, 8–11), they have not been empirically evaluated except for a study that demonstrated that infusion labels improved timely infusion identification (2). Thus, further empirical assessment of interventions is required to identify effective risk-mitigation strategies. Without this knowledge, we will not be able to respond to the urgent calls to improve the safety of administering multiple infusions, and mix-up errors will continue. To this end, as part of a larger study (12), we evaluated the impact of three interventions on the accuracy and speed of infusion identification and disconnection.

MATERIALS AND METHODS

Participants

Forty ICU nurses were recruited from a Toronto hospital, where institutional Research Ethics Board approval was obtained; participants consented in writing.

Design

The experiment was a repeated measures design. Each nurse completed two tasks (identify and disconnect infusions) under four conditions: baseline (current practice), line labels/organizers, smart pump, and light-linking system. The order of tasks and interventions was counterbalanced such that equal numbers of nurses completed tasks and interventions in different orders to control for order/carryover effects (e.g., fatigue effect, practice effect).

Location/Apparatus

The experiment was conducted in a high-fidelity simulated ICU with four patients (manikins), each receiving 11 continuous infusions (represents a high acuity patient based on previous project phases [13]). Each patient was receiving two infusions through a peripheral catheter and nine through a central venous triple-lumen catheter (distal port had a plain IV catheter for "as-needed" medication administration, the medial and proximal ports each had four infusions connected using multiport connectors). To mimic common practice at the participating institution, inotropic/vasopressor-related medications and sedative/narcotic medications were grouped on the proximal and medial access ports, respectively. Each nurse performed tasks within a highly realistic but controlled setting, allowing observations and errors to occur that would be impractical and unsafe in an actual ICU.

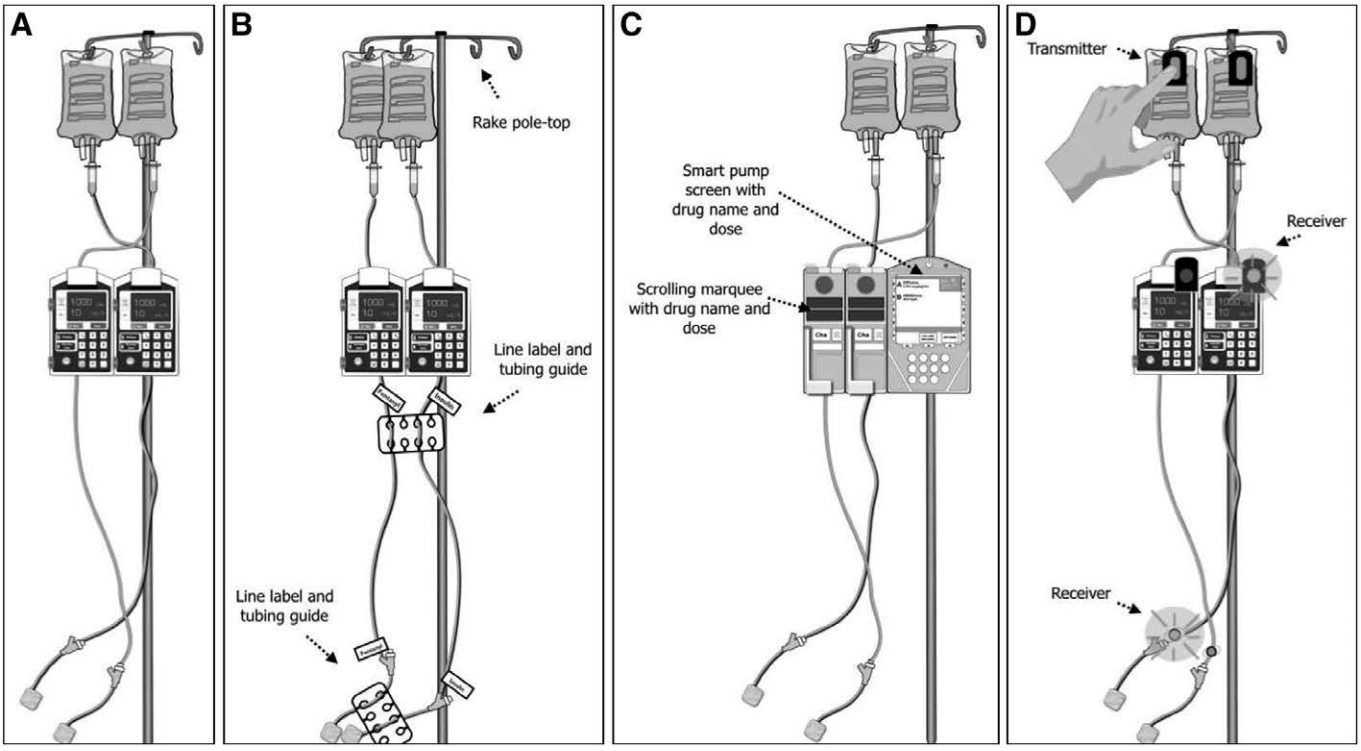

Figure 1. Infusion setup by experimental condition. Each patient/mannequin had 11 continuous IV infusions, but only two infusions are shown above for simplicity. **A**, Baseline (no intervention). **B**, Line labels/organizers condition: rake pole-top; pre-printed wrap-around content line labels 8 cm below the pump and directly above the lowest injection port on the tubing; and tubing guides immediately below the pump and lowest injection port. **C**, Smart pump condition: drug name and dose displayed on central programming unit and scrolled on each channel. **D**, Light-linking system condition: when a participant pushed the button on the bag, a wireless signal was transmitted to receivers on the corresponding pump and the distal end of the IV tubing, causing green lights to flash for 7 s. Figure adapted with permission from Health Quality Ontario. Adaptations are themselves works protected by copyright. So in order to publish this adaptation, authorization must be obtained both from the owner of the copyright in the original work and from the owner of copyright in the translation or adaptation.

Conditions

Baseline. The setup replicated standard equipment currently used in the ICU from which participants were recruited (**Fig. 1*A***). Eleven nonsmart pumps (Graseby 3000; Smiths Medical, Minneapolis, MN) were attached to two IV poles (pole 1: six pumps, two rows, three pumps/row; pole 2: five pumps, two rows, two and three pumps/row) and placed on the same side of the bed. No line labels/organizers were used (except for medication labels on bags). IV bags were hung on four-hook star pole-tops (Pryor Products, Oceanside, CA). Tubing above and below the pump was interweaved using a standard setup.

In the intervention conditions, infusions were set up as in the baseline condition with the following exceptions:

Line Labels/Organizers. Labels/organizers have been recommended to augment information along the infusion pathway and reduce physical complexity (e.g., align components, separate tubing) (2–4, 8, 10, 11) (**Fig. 1*B***). This intervention was a bundle of three components: 1) Pre-printed wrap-around labels (custom-made white labels with black text with the drug/fluid name on either side of the flap) were placed on each infusion 8 cm below the pump and another directly above the lowest injection port on the tubing; 2) Tubing organizers/guides (modified Nurse Buddy II, custom made by Verafied Medical Innovations LLC, American Canyon, CA) grouped infusions by access port: proximal, distal, and medial for central and peripheral catheters. The guide colors matched those of central catheter access ports (white, blue, brown) and a green guide was used for the peripheral catheter. The guides were immediately below the pump and lowest injection port and prevented tubing tangles; and 3) Another organizer, a rake pole-top (two rows of four hooks by Pryor Products, CA), was used to align the bags to the corresponding pump below (preventing tubing tangles above the pump).

Smart Pump (i.e., a pump with dose error reduction software which checks programmed variables against limits in a customized hospital drug library; **Fig. 1*C***) have been recommended because infusion identifiers (e.g., drug name) are displayed on the pump screen, unlike nonsmart pumps (10). The smart pump used in this study (Alaris system; Becton Dickinson/Carefusion, San Diego, CA) displayed the drug name and dose being delivered on the central programming unit (alternated with the volume to be infused) and on each pump's channel (attached to the programming unit).

Light-Linking System. Pump designers have suggested illuminating the infusion pathway (on demand) to automate line-tracing (12) (**Fig. 1*D***). Since a light-linking system was not commercially available, three prototype components were developed and added per infusion. Pushing a button on the bag transmitted a wireless signal to receivers on the corresponding pump and distal end of the tubing, causing both to flash a green light for 7 seconds. Although these components were reusable, they were developed to test the idea of illuminating the infusion pathway (with the intent of embedding them in the tubing and/or pump if effective).

Procedure

Participants completed scenarios individually. After receiving intervention training, participants were oriented to the patients by an actor playing the role of a charge nurse, and completed the following tasks (embedded with other patient-care tasks):

1) Infusion identification: verbally identify the access port to which an infusion was connected (trace from bag to port) and identify the three other infusions connected to the same access port (trace from port up to bag ×3).
2) Infusion disconnection: identify and stop the pump (trace from bag to pump) and disconnect tubing from patient (trace from pump to port).

After participants completed all tasks in a scenario, they were trained on the next intervention, and the procedure repeated for all four conditions.

Metrics and Analysis

In an observation room, researchers recorded errors and task time (per participant and condition). There were a maximum of four potential identification errors (identify wrong access port and wrong three infusions connected to

TABLE 1. Participant Characteristics

Characteristic	Frequency, $n = 39$[a], n (%)
Role	
Staff nurse	39 (100)
Sex	
Female	37 (95)
Male	2 (5)
Age range, yr	
18–29	8 (21)
30–39	14 (36)
40–49	8 (21)
50–64	9 (23)
Years of critical care experience, yr	
< 1	3 (8)
1–3	3 (8)
4–10	18 (46)
> 10	15 (38)
Average shift(s) per week	
< 1	1 (3)
1–2	0 (0)
3–4	21 (54)
> 4	17 (44)

[a]$n = 39$.
One participant's data were not collected due to a technical failure.
Percentages may appear inexact due to rounding.

the access port) and a maximum of two potential disconnection errors (stop and disconnect the wrong pump and tubing). Infusion identification (errors, time) and disconnection (errors, time) tasks were analyzed in four separate (intervention type) repeated measures analysis of variances ($\alpha = 0.05$). Post hoc pairwise comparisons were conducted using Bonferroni correction.

RESULTS

Participants (demographics in **Table 1**) made significantly fewer identification errors when using the line labels/organizers (0%) than in the baseline (7.7%) and smart pump (6.4%) conditions ($F = 4.33$; $p < 0.01$; **Table 2**). The light-linking system (3.2%) did not significantly affect errors compared with the other conditions because it could not be initiated at the access port; consequently, participants resorted to manual line-tracing when tracing up from the access port. Participants were also significantly faster at identifying infusions with the line labels/organizers than all other conditions (Table 2).

Only one error was made in the disconnection task, so there was no significant difference in disconnection errors between conditions (Table 2). Participants were significantly slower at disconnecting an infusion when using the smart pump than all other conditions because of transitional issues with using the new technology (e.g., confusion on how to turn off the pump).

DISCUSSION

Our study is the first to empirically compare the effectiveness of different interventions to minimize infusion mix-ups and demonstrate that line labels/organizers have the double benefit of decreasing infusion identification time and errors. Our results support previous findings that as follows: infusion mix-ups occur (2–4); line labels improve timely infusion identification (2); and nurses self-report that infusion organizers decrease time to untangle infusions (11). This research should serve as motivation to standardize the use of labels/organizers when a patient is receiving multiple infusions—a seemingly obvious gap in current standards.

Our findings suggest that line labels/organizers improve infusion safety by augmenting visual communication along the pathway (e.g., infusion contents, access port) and organization

TABLE 2. Mix-Up Errors and Task Time by Experimental Condition

	Mix-Up Errors ($n = 39$[a])				Mean Task Time ($n = 39$[a])	
	Identification Task (Maximum Four Errors Per Participant)		Disconnection Task (Maximum Two Errors Per Participant)			
Condition	Mean % Errors Per Participant (SD)	Description of Errors	Mean % Errors Per Participant (SD)	Description of Errors	Identification Task mm:ss (SD)	Disconnection Task mm:ss (SD)
Baseline	7.7 (15.3)	Twelve errors were made by 10 participants: one misidentified access port; 11 misidentified infusions	0.0 (—)		01:20 (00:38)	00:27 (00:15)
Line labels/ organizers	0.0[b] (—)		0.0 (—)		00:31[c] (00:22)	00:31 (00:19)
Smart pump	6.4 (11.1)	Ten errors were made by 10 participants: two misidentified access ports; eight misidentified infusions	1.3 (—)	One error across all participants; one wrong infusion disconnected	01:29 (00:44)	00:49[d] (00:23)
Light-linking system	3.2 (8.5)	Five errors were made by five participants: zero misidentified access port; five misidentified infusions	0.0 (—)		01:22 (00:36)	00:32 (00:21)
Statistics	$F(3, 114) = 4.33$; $p < 0.01$		Not significant		$F(3, 144) = 11.64$; $p < 0.001$	$F(3, 114) = 27.40$; $p < 0.001$

[a]Thirty-nine participants; one (of 40) participant was excluded because they could not complete the tasks with the light-linking system because of technical difficulties.

[b]Line labels/organizers condition was significantly different compared with the baseline and smart pump conditions (identification task errors).

[c]Line labels/organizers condition was significantly different compared with all other conditions (identification task time).

[d]Smart pump condition was significantly different than all other conditions (disconnection task time).

Dashes indicate that an SD couldn't be calculated.

(e.g., align bags to pumps, minimize tangles). Line labels/organizers should be applied even when using smart pumps since these pumps alone did not improve infusion identification. Although line labels/organizers require resources at setup, our findings show they improve infusion identification efficiency, shifting the resource burden to a time before urgent or emergent actions are required (e.g., titration during a code). These findings strengthen existing evidence (2, 11) and recommendations to use labels/organizers (2–4, 8, 10, 11) and provide design details to support their uptake and impact (e.g., label design, number/placements). Future work should focus on creating standard practices and implementation guidance to avoid known challenges (e.g., compliance, stocking labels) (8, 13–15) or potential new errors not evaluated in this study (e.g., label wrong line). However, it is important to stress that since label/organizers do not eliminate the potential for errors, other risk-mitigation practices (e.g., tracing infusion pathways before making changes and after staff hand-off) must still be promoted.

Manufacturer efforts to embed the principles of clear visual identifiers and infusion organization into infusion system design are urgently needed. This will further reduce the burden on clinicians to reconcile discrete infusion components (e.g., bag, pump, tubing) and use add-on components, like labels/organizers, since components may be better associated to begin with (e.g., perceptual markers, physical proximity).

Limitations of our study include that this was a simulated adult ICU with specific setups (e.g., patient receiving 11 infusions, interventions in ideal configuration) and a small sample of nurses from one hospital, which may limit generalizability. Since labels/organizers were evaluated together, it is not possible to isolate their individual effects (labels, guides, pole-top).

CONCLUSIONS

The results suggest that line labels/organizers may increase infusion identification accuracy and efficiency and yet there is no standard practice regarding their use.

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