

# Development of an algorithm using ultrasonography-assisted peripheral intravenous catheter placement for reducing catheter failure

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**SUMMARY** Up to 50% peripheral intravenous catheters (PIVs) are removed prematurely because of failures. Catheter failure (CF) leads to replacement and is a great concern for patients and medical staff. It is known that visualization of catheters and vessels with ultrasonography (US) during placement prevents CF. However, US is not a common technique for general nurses. In order to standardize US-assisted PIV placement techniques, an algorithm is needed. This study aimed to develop an algorithm using US-assisted PIV placement to reduce CF rate. Furthermore, to evaluate the effectiveness of the algorithm, CF rates were compared before and after intervention. A pretest-posttest study was performed. The intervention was PIV placement by 23 nurses undergoing training sessions for the algorithm. Intention to treat, per protocol analyses were applied. Logistic regression analysis was used for factor analysis. The CF rate in the pre-intervention group 35.2% (19/54) did not significantly differ from post-intervention group 33.6% (48/143) ( $p = 0.831$ ), yet significantly differ from complete algorithm-use group 8.7% (2/23;  $p = 0.017$ ). In factor analysis, compliance to the algorithm was significantly correlated with CF ( $p = 0.032$ ). The compliance rate was low 16.1% (23/143). Algorithm compliance reduced CF by confirming appropriate catheter tip position from the insertion to the securement phase. This algorithm effectively reduced CF, however, the compliance rate was unacceptable. In order to increase the compliance rate, modified algorithm and new visualizing technology is required.

**Keywords** Algorithm, incidence, intention to treat analysis, per protocol analysis, rate of compliance

## 1. Introduction

Peripheral intravenous catheters (PIVs) are used in > 60% of hospital inpatients (1). Approximately 30-50% of PIVs require removal due to complications prior to the completion of infusion therapy; this phenomenon is called catheter failure (CF) (2). CF is defined as "PIV that has been removed due to the signs and symptoms of catheter failure, but not for other reasons such as accidental dislodgement" (3). Catheter replacement can lead to distress and discomfort, substantially increasing clinical staff workloads and medical costs (4). CF is a serious problem for patients who undergo infusion therapy and clinical staff; thus, it should be prevented.

CF is affected by patient, chemical, and mechanical factors. Patient factors include age, female sex,

diabetes, cancer, infection, steroids, bedridden status, and malnutrition (3,5-8). Chemical factors include antibiotic use and hyperosmolar infusion (9,10). Infusion therapy standards of practice recommend the selection of a midline catheter or peripherally inserted central catheter depending on infusion therapy duration to reduce chemical effect.11 Mechanical factors are related to vessel wall irritation and include using too large a catheter for the vasculature, multiple punctures of the same site, and use of a stiff catheter (5,12,13).

Our previous study confirmed the efficacy of a care bundle which was focused on the above mechanical factors related to CF. The care bundle included the use of polyurethane material catheters, selection of a vessel with a diameter of approximately 3.3 times the diameter of the catheter, and adjustment of the catheter

tip position to prevent vessel wall irritation, using ultrasound guidance to confirm catheter tip position within the vessel. The study using the above care bundle revealed low incidence rate of CF, which was 11% in the intervention group versus 30% in the control group (14). This suggested that reducing mechanical irritation prevented CF substantially. Ultrasonography (US) operation was provided by one trained research nurse in that study. However, in current clinical settings, use of US is not a common technique for general nurses. The acquisition of new skills should be standardized; therefore, in the present study, we focused on developing an algorithm to standardize the teaching of US-assisted PIV placement skills.

Algorithms apply evidence to specific behaviors and rules to promote effective and appropriate medical care (15). Conventional algorithms for US-guided PIV insertion were developed to increase the insertion success rate in patients with difficult intravenous access (16,17). However, none of the previous algorithms prevents the incidence of CF. The algorithm developed for the present study, which enables clinical nurses to confirm the appropriateness of the catheter position from the insertion to the securement phase, might be required to decrease the incidence of CF.

The present study aimed to develop an algorithm that enables general nurses to acquire the US-assisted PIV placement skills to prevent CF. Furthermore, to evaluate the effectiveness of the algorithm, CF rates were compared before and after intervention.

## 2. Methods

### 2.1. Algorithm

The algorithm was developed to avoid mechanical stimulation and decrease the incidence of CF. The first step of the algorithm development process is verbalizing an outline of US-assisted PIV placement: infusion therapy (situation), patient (subject), catheter placement under US guidance (procedure), and tracking of adverse events and correspondence. The second step systematizing each of the above outline items. The final step is creating graphical representations of the items. Eventually, we developed the algorithm.

A literature review was conducted using MEDLINE and the Japan Medical Abstracts Society to identify evidence of the US-guided PIV placement technique.

The developed algorithm consisted of four additional points to land-mark insertion technique as follows: 1. Appropriate blood vessel: The clinical nurses succeed in selecting the vessel whose diameter was approximately 3.3 times the diameter of the catheter and storing the US images. 2. Appropriate insertion: The clinical nurses succeed in performing US-guided insertion when the target blood vessel was not palpable or visible with a tourniquet. 3. Needle in the blood

vessel: The clinical nurses need to verify that the needle is inside the blood vessel and adjust its position, as necessary. 4. Appropriate catheter tip position: The clinical nurses succeed in securing the catheter without any extra compression to the vessel wall and storing the US images (Figure 1).

We developed a training session for applying the algorithm. It is necessary for nurses to acquire the principle and basic knowledge of US, probe techniques, and US image interpretation. To acquire these knowledge and skills, workbook, e-learning, training lectures, and training practice were provided. After that, we confirmed that each of the nurses could use the algorithm in the objective structured clinical examination. During the training period, we provided the simulator and US devices to allow the nurses to practice at any time.

The algorithm and training session were developed under the supervision of an expert in fundamental nursing, an educator of nurse-designated procedures, and two certified dialysis nurses.

### 2.2. Study design and setting

This study was a pretest-posttest study and was undertaken in a surgical ward, in which the average daily number of PIV placement was high, at a large tertiary metropolitan hospital had 1228 beds in Tokyo, Japan

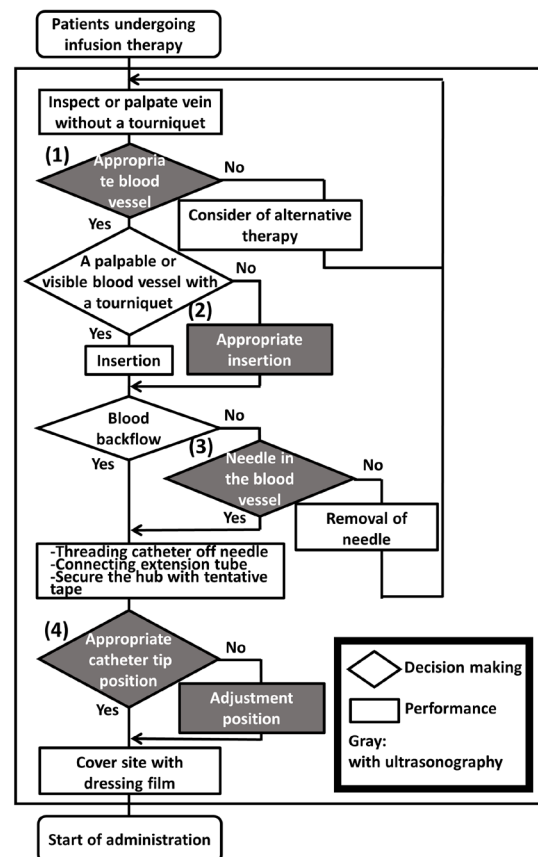


Figure 1. The algorithm using ultrasound-assisted peripheral intravenous catheter placement for reducing catheter failure.

between May 2018 and November 2018.

### 2.3. Participants

Nurses with > 1 year of experience with PIV placement in adults were eligible to enroll in the training session. Nurses without at least 6 months of continuous experience placing PIV in adults when this study started were excluded. Patients who underwent PIV therapy and had permission from their physician and nurses to participate were eligible to enroll. Patients who were < 20 years of age were excluded. Only PIVs which were inserted by nurses who had undergone the training on the algorithm for US-assisted PIV placement were analyzed.

### 2.4. Intervention

The intervention was PIV placement using the algorithm of the US-assisted PIV placement by the nurses who underwent the training session. This study included a 4-week pre-intervention period, a 4-week training period, a 10-week habituation period, and a 10-week post-intervention period. The tablet-type US device (SonoSite iViz, FUJIFILM SonoSite Inc., Bothell, US) equipped with liner-array transducers (6.4 MHz) was used to visualize the vessels and catheters.

### 2.5. Outcomes

The primary outcome was the cumulative incidence rate of CF, calculated as  $\{[\text{incidence of CF}]/[\text{total PIVs}]\} \times 100$  (%), and the incidence rate of CF, calculated as  $\{[\text{incidence of CF}]/[\text{total PIVs days}]\} \times 1,000$  (CF per 1000 catheter days). The incidence of CF was judged and recorded by the clinical nurse.

The secondary outcome was compliance to the algorithm. Compliance was assessed in accordance with 1. and 4. of the algorithm by one researcher as follows: the first point was 1. Appropriate blood vessel: We confirmed the blood vessels on the obtained images met the accomplishment threshold; and 4. Appropriate catheter tip position: We confirmed the positions on the obtained images met the accomplishment threshold.

### 2.6. Variables

Nurse characteristics (pre-intervention). We collected the following data about the nurses using a questionnaire: sex, age, years of experience, number of PIV insertions per week, experience level (beginner: < 100; intermediate: 100-800; expert: > 800) (18), experience with US-guided PIV placement, and academic background.

Patient and catheter characteristics (pre- and post-intervention). We collected the following data from the patients' medical records:

1) Patient factors: age, sex, body mass index (BMI),

presence or absence of organ cancer and/or diabetes, oral medicine (antimicrobials, steroids, anticoagulants, and antiplatelets), ambulatory status (KANGODO III and IV), blood examination (C-reactive protein [mg/dL], albumin [g/dL], and platelet [ $10^4/\mu\text{L}$ ]).

2) Medication factors: infusion (hyperosmolality, antibiotic, lipid emulsion, anticoagulant). We collected the following data with observing PIV placement at the bedside.

3) Mechanical factors: material of PIV (Teflon: Surshield Surflo II, Terumo Corporation, Tokyo, Japan; polyurethane: Surflo V3 Plus, Terumo Corporation), PIV lock period, insertion site (forearm, upper arm, hand, cubital fossa), and first-attempt success rate.

### 2.7. Sample size

Sample sizes were calculated for a comparison test of two proportions: A sample size of 51 PIVs per group conferred 80% power and a two-sided  $p$  value of 0.05, to detect an effect size of 25% in the CF rates between the pre- and post-intervention groups. The effect size was determined according to a previous study (17). The number of nurses who would undergo the algorithm training and could perform the insertion were unknown prior to the commencement of the study. For that reason, we doubled our intended sample size, for a total of 102 PIVs. Furthermore, we expected attrition rates of 70%; thus, 140 PIVs was the final calculated sample size.

### 2.8. Statistical analyses

We performed both the intention to treat (ITT) analysis and per protocol (PP) analysis. Pre- and post-intervention groups were compared in the ITT analysis. For the PP analysis, we compared the pre-intervention group and the complete algorithm-use group. The complete algorithm-use group accomplished both 1. and 4. in the algorithm.

In the univariate model, Fisher's exact test or the chi-square test was used to examine the categorical data, while Student's  $t$  test or the Mann-Whitney  $U$  test was selected to examine continuous data. The incidence rates of CF per 1000 PIV days were tested with Log-rank test. Logistic regression was used to calculate odds ratios (ORs) and 95% confidence intervals (CIs) after controlling simultaneously for potential confounders of CF. The final multivariate model was built with the variables at  $p$  values of < 0.15 and were tested for multicollinearity. The covariates were simultaneously introduced in accordance with a previous study or empirically selected if correlation was indicated.

The statistical analysis was performed using IBM SPSS Statistics ver. 23 (SPSS Inc., Chicago, IL, USA) and EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan).  $P$  values < 0.05 were considered statistically significant.

2.9. Ethical considerations

This study received approval from the Research Ethics Committee of the Faculty of Medicine, The University of Tokyo (No. 11832-(3)). The participants were informed about the study aim and processes, and written informed consent was obtained from each participant. The participants were free to withdraw consent and discontinue participating at any time.

3. Results

3.1. Participant flow

Twenty-five nurses were recruited as participants. Two nurses withdrew consent; thus, 23 nurses were analyzed. Ninety one percent were female. The mean age and nursing experience year were 26 years (interquartile range (IQR), 24-28) and four years (IQR, 2-6) respectively. The mean number of PIV placement per week was 2 (IQR, 1-3). Half of the participants had

intermediate-level experience. None had experience in US-guided PIV placement.

In the pre-intervention group, 54 PIVs were analyzed. In the post-intervention group, 143 PIVs were inserted by clinical nurses who completed algorithm training; these were analyzed as the post-intervention group (Figure 2).

3.2. Incidence of CF and algorithm compliance

3.2.1. Intention-to-treat analysis

The incidence of CF rate as the primary outcome was 35.2% (19/54) in the pre-intervention and 33.6% (48/143) in the post-intervention group. There was no significant intergroup difference in CF ( $p = 0.831$ ). The incidence of CF from the intention-to-treat analysis was 99.9 per 1,000 PIV days compared with 146.7 per 1,000 PIV days in the pre-intervention group ( $p = 0.214$ ; Table 1).

There were significant differences in patient characteristics, catheter usage, and catheter characteristics,

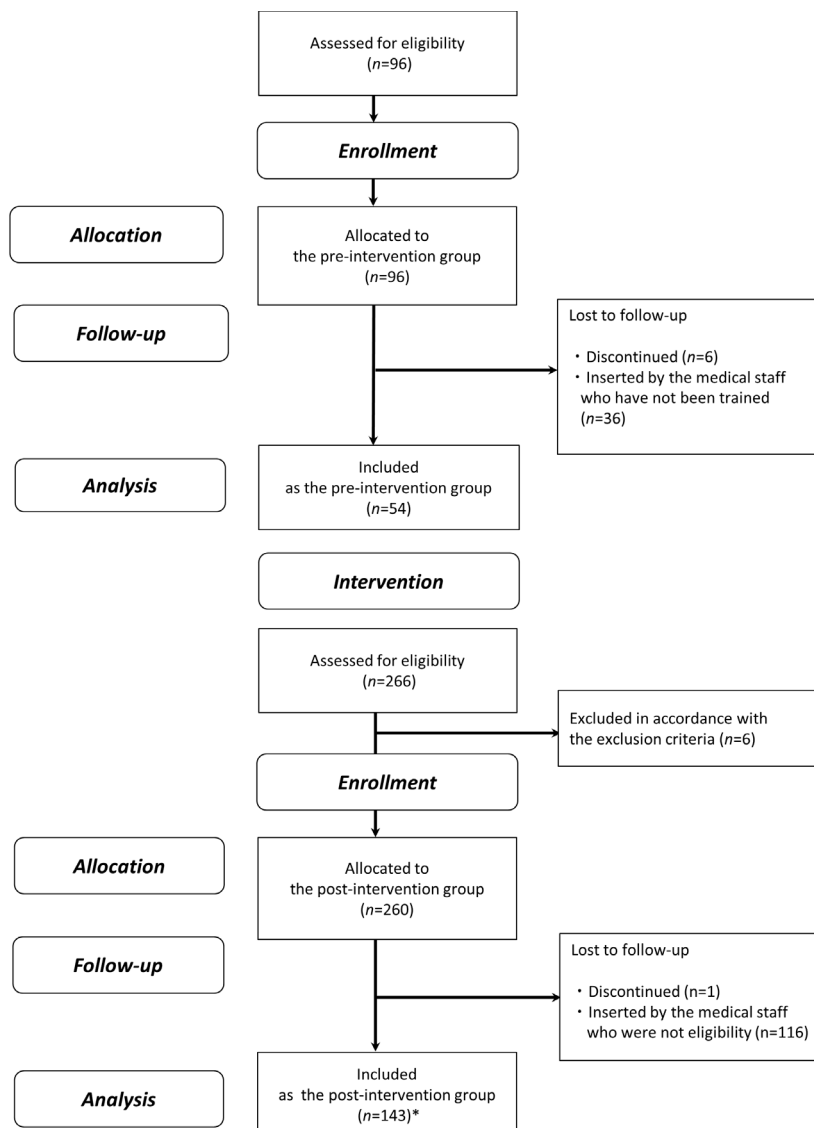


Figure 2. Catheter flowchart after the recruitment.

as follows: BMI ( $p = 0.014$ ), organ cancer ( $p = 0.003$ ), platelet count ( $p = 0.025$ ), multiple entry in each group ( $p = 0.034$ ), infusion, lipid emulsion ( $p = 0.019$ ), experience level ( $p < 0.001$ ), and polyurethane catheter ( $p < 0.001$ ; Table 2).

### 3.2.2. Per-protocol analysis

There were two groups in the PP analysis set as follows: pre-intervention group and complete algorithm-use group. The incidence of CF rate as the primary outcome was 35.2% (19/54) in the pre-

intervention group and 8.7% (2/23) in complete algorithm-use group. The intergroup difference was significant ( $p = 0.017$ ). The incidence of CF in the per-protocol analysis was 24.4 per 1,000 days compared with 146.7 per 1,000 days in the pre-intervention group ( $p = 0.010$ ; Table 1).

There were significant differences in patient and catheter characteristics between the pre-intervention group and complete algorithm-use group as follows: BMI ( $p = 0.043$ ), organ cancer ( $p = 0.015$ ), oral medicine, steroids ( $p = 0.022$ ), albumin ( $p = 0.017$ ), infusion of antibiotics ( $p = 0.024$ ), infusion of lipid

**Table 1. Incidence of catheter failure in intention-to-treat and per-protocol analyses**

Items	Catheter failure	$p$ Value <sup>a</sup>	Per 1000 catheter days	$p$ Value <sup>b</sup>
Pre-intervention ( $n = 54$ )	19 (35.2%)	0.831	146.7	0.214
Post-intervention ( $n = 143$ )	48 (33.6%)		99.9	
Pre-intervention ( $n = 54$ )	19 (35.2%)	0.017*	146.7	0.010*
Complete algorithm-use in post-intervention ( $n = 23$ )	2 (8.7%)		24.4	

<sup>a</sup>Pearson's chi-square test, <sup>b</sup>Log-rank test; \* $p < 0.05$ .

**Table 2. Patients and catheters characteristics in the intention-to-treat and per protocol analyses**

Items	Pre-intervention	Post-intervention		Complete algorithm-use in post-intervention	
Characteristics	( $n = 54$ )	( $n = 143$ )	$p$ Value <sup>†</sup>	( $n = 23$ )	$p$ Value <sup>††</sup>
<b>Patient factor</b>					
Male	35 (65%)	98 (69%)	0.619	16 (70%)	0.687
Age, median (IQR)	68 (60-78)	70 (66-77)	0.135	69 (57-75)	0.872
BMI, median (IQR)	21 (18-23)	23 (20-26)	0.014*	24 (3.4) <sup>d</sup>	0.043*
Diabetes	12 (22%)	43 (30%)	0.273	4 (17%)	0.442
Organ cancer	35 (65%)	59 (41%)	0.003*	8 (35%)	0.015*
<b>Oral medicine</b>					
Antimicrobials	12 (22%)	24 (17%)	0.378	2 (8.7%)	0.138
Steroids	2 (3.7%)	19 (13%)	0.052	5 (22%)	0.022*
Anticoagulants and antiplatelets	12 (22%)	49 (34%)	0.103	10 (44%)	0.059
Ambulatory status (KANGODO III and IV)	34 (63%)	109 (76%)	0.063	19 (80%)	0.088
<b>Blood examination</b>					
C-reactive protein [mg/dL], median (IQR)	1.5 (0.2-4.0)	3.1 (0.2-4.7)	0.574	0.5 (0.1-2.6)	0.476
Albumin [g/dL], median (IQR)	3.2 (0.6) <sup>d</sup>	3.3 (0.6) <sup>a,d</sup>	0.945	3.6 (0.6) <sup>c,d</sup>	0.017*
Platelets [ $10^4/\mu\text{L}$ ], median (IQR)	22 (18-28)	25 (19-32)	0.025*	19 (17-30)	0.798
Multiple entry in each group	17 (32%)	69 (48%)	0.034*	4 (26%)	0.204
<b>Chemical factor</b>					
<b>Infusion</b>					
Hyperosmolality	20 (37%)	36 (25%)	0.100	4 (17%)	0.088
Antimicrobials	18 (33%)	46 (32%)	0.876	2 (8.7%)	0.024*
Lipid emulsion	0	12 (8.4%)	0.019*	3 (13%)	0.024*
Anticoagulants	7 (13%)	28 (20%)	0.278	9 (39%)	0.015*
<b>Technical factor</b>					
Experience level			0.096		0.403
Beginner [ $<100$ catheters]	5 (9.3%)	12 (8.4%)		2 (8.7%)	
Intermediate [ $100-800$ catheters]	20 (37%)	77 (54%)		9 (39%)	
Expert [ $>800$ catheters]	29 (54%)	54 (38%)		12 (52%)	
First attempt success	36 (67%)	91 (67%) <sup>b</sup>	0.974	17 (74%)	0.530
<b>Mechanical factor</b>					
Insertion in the forearm	50 (93%)	132 (97%) <sup>b</sup>	0.162	23 (100%)	0.234
Polyurethane catheter	0	80 (57%) <sup>b</sup>	$< 0.001^*$	17 (74%)	$< 0.001^*$
Catheter lock period, median (IQR)	10 (0-11)	18 (0-14)	0.482	0 (0-19)	0.346

$t$  test or Mann-Whitney  $U$  test, Pearson chi-square test or Fisher's exact test; IQR = interquartile range; <sup>a</sup> $n = 142$ . <sup>b</sup> $n = 136$ . <sup>c</sup> $n = 22$ . <sup>d</sup>mean (SD); \* $p < 0.05$ ; <sup>†</sup>Between pre-intervention and post-intervention; <sup>††</sup>Between pre-intervention and complete algorithm-use in post-intervention.



emulsion ( $p = 0.024$ ), infusion of anticoagulants ( $p = 0.015$ ), experience level ( $p < 0.001$ ), and polyurethane catheter ( $p < 0.001$ ; Table 2).

The compliance rate as the secondary outcome was 16.1% (23/143).

### 3.2.3. Factor analysis for the relationship between CF and Compliance to the algorithm

Several variates of patient and catheter characteristics showed significant differences in the both ITT and PP analysis sets, thus, we adjusted these variates to determine the factor of CF.

There were significant differences in patient and catheter characteristics between the complete algorithm-use group and the other groups (54 PIVs in the pre-intervention group and 120 PIVs except those in the post-intervention algorithm-compliant group) as follows: albumin ( $p = 0.003$ ), infusion of antibiotics ( $p = 0.010$ ), infusion of anticoagulants ( $p = 0.008$ ), and polyurethane catheter ( $p = 0.001$ ; Table 3). The interaction was confirmed among the variates at  $p$  values of  $< 0.15$  in the univariate model. The variates were used to assess for

correlations with other variates (at  $\rho > 0.4$  and  $p < 0.050$ ), and covariates were selected for the multivariate model. Ultimately, polyurethane catheter, age, sex, infusion of antibiotics, infusion of anticoagulants, undergoing training session, and compliance to the algorithm were introduced to the logistic regression model to calculate ORs and 95% CIs. In this analysis model, compliance to the algorithm and infusion of anticoagulants were significantly correlated with CF (OR, 0.19; 95% CI, 0.04-0.87;  $p = 0.032$  and OR, 0.24; 95% CI, 0.80-0.74;  $p = 0.013$ , respectively; Table 4).

### 3.3. Harm

No patients reported any adverse events; thus, this algorithm had acceptable safety in the clinical setting.

## 4. Discussion

This is the first study in which a US-assisted PIV algorithm demonstrated a decrease in the incidence rate of CF. The defining characteristic of our originally developed algorithm was that it used US for adjustment

**Table 3. Patients and catheters characteristics with high compliance**

Characteristic	Complete algorithm-use in post-intervention ( $n = 23$ )	Pre- and post-intervention expect 23 (complete) ( $n = 174$ )	$p$ Value
<b>Patient factor</b>			
Male	38 (32%)	117 (67%)	0.823
Age, median (IQR)	69 (57-75)	71 (64-78)	0.205
BMI, median (IQR)	24 (21-27)	22 (20-25)	0.055
Diabetes	4 (17%)	51 (29%)	0.231
Organ cancer	8 (35%)	86 (50%)	0.186
<b>Oral medicine</b>			
Antimicrobials	2 (8.7%)	34 (20%)	0.164
Steroids	5 (22%)	16 (9.2%)	0.078
Anticoagulants and antiplatelets	10 (44%)	51 (29%)	0.167
Ambulatory status [KANGODO III and IV]	19 (80%)	124 (71%)	0.252
<b>Blood examination</b>			
C-reactive protein [mg/dL], median (IQR)	0.5 (0.1-2.6)	1.3 (0.2-4.7)	0.196
Albumin [g/dL], median (IQR)	3.8 (3.3-3.9) <sup>a</sup>	3.1 (2.8-3.6)	0.003*
Platelets [ $10^4/\mu\text{L}$ ], median (IQR)	19 (17-30)	25 (20-31)	0.178
Multiple entry in each group	6 (26%)	79 (45%)	0.079
<b>Chemical factor</b>			
<b>Infusion</b>			
Hyperosmolality	4 (17%)	52 (30%)	0.212
Antimicrobials	2 (8.7%)	62 (36%)	0.010*
Lipid emulsion	3 (13%)	9 (5%)	0.151
Anticoagulants	9 (39%)	26 (15%)	0.008*
<b>Technical factor</b>			
Experience level			0.953
Beginner [ $< 100$ catheters]	2 (8.7%)	13 (7.5%)	
Intermediate [100–800 catheters]	9 (39%)	88 (51%)	
Expert [ $> 800$ catheters]	12 (52%)	73 (42%)	
First attempt success	17 (74%)	110 (66%) <sup>b</sup>	
<b>Mechanical factor</b>			
Insertion in the forearm	23 (100%)	159 (95%)	0.349
Polyurethane catheter	17 (74%)	63 (37%)	0.001*
Catheter lock period, median (IQR)	0 (0-13)	0 (0-12)	0.441

Pearson's chi-square test or Fisher's exact test, Mann-Whitney  $U$  test; <sup>a</sup> $n = 22$ ; <sup>b</sup> $n = 167$ ; \* $p < 0.05$ .

**Table 4. Risk factors associated with catheter failure**

Items	OR	95% CI	p Value
Polyurethane catheter	1.26	0.59-2.66	0.552
Age	1.00	0.99-1.03	0.798
Sex	0.99	0.51-1.92	0.974
Infusion; antimicrobials	1.07	0.55-2.05	0.852
Infusion; anticoagulants	0.24	0.08-0.74	0.013*
Undergoing training session	1.04	0.46-2.33	0.933
Compliance to the algorithm	0.19	0.04-0.87	0.032*

Logistic regression; OR = odds ratio; CI = confidence interval; \*  $p < 0.05$ ; Hosmer-Lemeshow test  $p = 0.942$ .

and confirmation of the catheter tip position after insertion, not just during the puncture phase. The incidence rate of CF decreased from 35.2% (19/54) to 8.7% (2/23) in cases where ensured compliance to the algorithm. In factor analysis, compliance to the algorithm were significantly correlated with CF. Nevertheless, the compliance rate was unacceptably low, which is considered a future issue.

CF was significantly associated with compliance to the algorithm. The main purpose of compliance to the algorithm was to avoid irritation to the vessel wall. Injury to the vessel wall is the one of the factors which leads to thrombosis (19). In fact, our factor analysis indicated that compliance to the algorithm and anticoagulants infusion contributed to CF.

Our previous study confirmed that thrombus with subcutaneous edema was related to the incidence of CF (20). Therefore, we determined that the compliance to the algorithm worked effectively to inhibit thrombus formation and to reduce the incidence of CF, although it was not found to be signify, which worked more effectively, 1. Appropriate blood vessel or 4. Appropriate catheter tip position, and whether 2. Appropriate insertion and 3. Needle in the blood vessel worked effectively or not.

Even though nurses participated in the training for using algorithm and had sufficient skills for US-assisted PIV placement certified by objective structured clinical examination, compliance to the algorithm was quiet low, at 23/143 (16.1%).

One of the reasons for the low compliance rate, nurses did not have enough time to use the algorithm. The US technique requires additional time on the conventional method of the PIV placement. The setting of this study was a surgical unit at a large tertiary metropolitan affiliated hospital, and consequently, nurses might have been too busy to implement the algorithm.

The other reason that may be considered is that manipulation of the probe and interpretation of the US images are difficult (21). These difficulties might lead to the low compliance rate. The technique of creating images of the both catheters and vessels at the same time was considered of the hardest point. We need to improve the visualization technology or device performance in order to enable all the nurses to acquire the techniques

related to both probe manipulation and interpretation of the US images. Moreover, artificial intelligence technology and high number of inputs with images of the both catheters and vessels might support nurses' interpretation of the US images of the position of the catheter tip within the vessel.

There were several limitations in this study. Firstly, owing to the characteristics of the pretest-posttest study, maturation must be considered as a potential confounding factor. There was a possibility of overestimating the reduction in the incidence of CF due to the maturation of vein catheterization skills. Secondly, there is a problem of device performance. In clinical settings with restricted space, tablet-type US devices are convenient and easy to carry. On the other hand, the image resolution of the tablet-type devices is lower than the stand-type devices. The difficulty of interpretation of the US images due to the low resolution potentially affected the compliance rate. Thirdly, the setting of this study is one large tertiary metropolitan affiliated hospital, hence, we need to be careful to extrapolate our results to home care or health facilities for recuperation.

In conclusion, we developed an algorithm to standardize US-assisted PIV placement for the purpose of decreasing the incidence of CF, from the insertion phase to the securement phase. There was no significant difference in the CF rate between pre- and post-intervention group. On the other hand, there was significant difference between pre- and complete algorithm-use group. The algorithm can reduce the incidence of CF significantly. However, the algorithm compliance rate was low (16.1%). In order to increase the compliance rate, modified algorithm and new visualizing technology is required.

#### Conflict of Interest

Ryoko Murayama Mari Abe-Doi belong to the laboratory supported by Terumo Co. Toshiaki Takahashi belongs to the laboratory supported by Molten Co. Chiho Kanno, Yui shintani, Junko Nogami, Chieko Komiyama and Hiromi Sanada have no conflict of interest.

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#### References

- Alexandrou E, Ray-Barruel G, Carr PJ, Frost S, Inwood S, Higgins N, Lin F, Alberto L, Mermel L, Rickard CM. International prevalence of the use of peripheral intravenous catheters. *J Hosp Med.* 2015; 10:530-533.
- Helm RE, Klausner JD, Klemperer JD, Flint LM, Huang E.

- Accepted but unacceptable: peripheral IV catheter failure. *J Infus Nurs.* 2015; 38:189-203.
3. Murayama R, Uchida M, Oe M, Takahashi T, Oya M, Komiyama C, Sanada H. Patient risk factors for developing sign- and symptom-related peripheral intravenous catheter failure: a retrospective study. *J Jpn WOCM.* 2015; 19:394-402.
  4. Rickard CM, Webster J, Wallis MC, Marsh N, McGrail MR, French V, Foster L, Gallagher P, Gowardman JR, Zhang L, McClymont A, Whitby M. Routine versus clinically indicated replacement of peripheral intravenous catheters: a randomised controlled equivalence trial. *The Lancet.* 2012; 380:1066-1074.
  5. Wallis MC, McGrail M, Webster J, Marsh N, Gowardman J, Playford G, Richard CM. Risk factors for peripheral intravenous catheter failure: a multivariate analysis of data from a randomized controlled trial. *Infect Control Hosp Epidemiol.* 2014; 35:63-68.
  6. Reunes S, Rombaut V, Vogelaers D, Brusselaers N, Lizy C, Cankurtaran M, Labeau S, Petrovic M, Blot S. Risk factors and mortality for nosocomial bloodstream infections in elderly patients. *Eur J Intern Med.* 2011; 22:e39-44.
  7. Nassaji-Zavareh M, Ghorbani R. Peripheral intravenous catheter-related phlebitis and related risk factors. *Singapore Med J.* 2007; 48:733-736.
  8. Hadaway L. Infiltration and extravasation. *Am J Nurs.* 2007; 107:64-72.
  9. Timmer J, Schipper H. Peripheral venous nutrition: the equal relevance of volume load and osmolarity in relation to phlebitis. *Clin Nutr.* 1991; 10:71-75.
  10. Monreal M, Quilez F, Rey-Joly C, Boderiguez S, Sopena N, Niera C, Roca J. Infusion phlebitis in patients with acute pneumonia: a prospective study. *Chest.* 1999; 115:1576-1580.
  11. Gorski L, Hadaway L, Hagle M, McGoldrick M, Orr M, Doellman D. Infusion therapy standards of practice (Alexander M, ed.). Infusion Nursing Society, Norwood, USA, 2016; pp. 95.
  12. Uslusoy E, Mete S. Predisposing factors to phlebitis in patients with peripheral intravenous catheters: a descriptive study. *J Am Acad Nurse Pract.* 2008; 20:172-180.
  13. Karadag A, Gorgulu S. Effect of two different short peripheral catheter materials on phlebitis development. *J Intraven Nurs.* 2000; 23:158-166.
  14. Takahashi T, Ryoko M, Mari Abe-Doi, Maki Miyahara-Kaneko, Chiho K, Miwa N, Mariko M, Chieko K, Hiromi S. Preventing peripheral intravenous catheter failure by reducing mechanical irritation. *Sci Rep.* 2020; 1550.
  15. Gaddis G, Greenwald P, Huckson S. Toward improved implementation of evidence-based clinical algorithms: clinical practice guidelines, clinical decision rules, and clinical pathways. *Acad Emerg Med.* 2007; 14:1015-1022.
  16. Anderson J, Greenwell A, Louderback J, Polivka BJ, Behr JH. Comparison of Outcomes of Extended Dwell/Midline Peripheral Intravenous Catheters and Peripherally Inserted Central Catheters in Children. *J Assoc Vasc Access.* 2016; 21:158-164.
  17. Duran-Gehring P, Bryant L, Reynolds JA, Aldridge P, Kalynych CJ, Guirgis FW. Ultrasound-Guided Peripheral Intravenous Catheter Training Results in Physician-Level Success for Emergency Department Technicians. *J Ultrasound Med.* 2016; 35:2343-2352.
  18. Rippey J CR, Carr PJ, Cooke M, Higgins N, Rickard CM. Predicting and preventing peripheral intravenous cannula insertion failure in the emergency department: Clinician 'gestalt' wins again. *Emerg Med Australas.* 2016; 28:658-665.
  19. Anning S. The historical aspects of venous thrombosis. *Med Hist.* 1957; 1:28-37.
  20. Takahashi T, Murayama R, Oe M, Nakagami G, Tanabe H, Yabunaka K, Arai R, Komiyama C, Uchida M, Sanada H. Is Thrombus With Subcutaneous Edema Detected by Ultrasonography Related to Short Peripheral Catheter Failure? A Prospective Observational Study. *J Infus Nurs.* 2017; 40:313-322.
  21. Panebianco NL, Fredette JM, Szyld D, Sagalyn EB, Pines JM, Dean AJ. What you see (sonographically) is what you get: vein and patient characteristics associated with successful ultrasound-guided peripheral intravenous placement in patients with difficult access. *Acad Emerg Med.* 2009; 16:1298-1303.

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