Original Article

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Exploring the causes of peripheral intravenous catheter failure based on shape of catheters removed from various insertion sites

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Summary **The risk of peripheral intravenous catheter failure varies according to the insertion site. This study examined catheter shape just after removal to evaluate the causes of catheter failure according to site. This study was a secondary analysis of previous study data. Our observational study was conducted during a 6-month period at The University of Tokyo Hospital. Participants were hospitalized adults who received infusion therapy *via* a short peripheral catheter. We acquired ultrasound images of blood vessels and surrounding tissues at the catheter insertion site before catheter removal and clinical images of the removed catheters. We analyzed 184 catheters from 142 participants. There were no significant differences in the catheter failure rate (29.9%) among insertion sites. Curvature in the middle of the catheter was present in 9.2% of cases; the median bend angle at the catheter base was 9.1° (range: 0.0°-68.3°). The bend angle of catheters inserted in the upper arm was significantly greater than of catheters in the forearm (p = 0.013). Catheter curvature was related to catheter failure (14.8% of failed catheters had curvature; p = 0.035) and occlusion (35.3% of occluded catheters had curvature; p = 0.008) in upper arm and forearm placements. The median distance from the elbow to the insertion site was shorter for failed catheters than for surviving catheters. To prevent catheter failure, especially occlusion resulting from catheter curvature, a catheter should be inserted at an appropriate insertion site far from the antecubital fossa.**

Keywords: Catheter deformation, peripheral intravenous catheterization, peripheral venous access, short peripheral intravenous catheter

1. Introduction

Hospitalized patients often require intravenous therapy. Approximately 300 million peripheral intravenous catheters (PIVC) are used annually in the United States (*1*) and 59% of hospitalized patients have at least one PIVC in place, according to international data (*2*). Regardless of the reason for use, it is important that healthcare providers use an appropriate vascular access device and vein to prevent catheter failure, which can result in adverse events or occlusion (*3-5*).

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We previously recommended selecting a vein that is approximately three times as large as the outer diameter of the PIVC to prevent catheter failure (*6*). Large veins are preferable; for example, veins in the upper arm are larger than those in the forearm (*7*). If an appropriately sized vein cannot be found in the forearm, then a suitable vein in the upper arm should be sought. However, it is reported that catheter insertion in the hand, antecubital fossa, or upper arm is associated with higher rates of occlusion (defined as any circumstance in which the PIVC remains in place but catheter flushing and fluid infusion are not possible) than catheter insertion in the forearm (*8*). It is possible that re-expansion of subcutaneous fat in the upper arm after catheter insertion distorts the catheter track, potentially dislodging or kinking the catheter (**9**). The current guidelines recommend limiting catheter sites to the upper extremities, with a preference for distal locations that avoid the wrist (*10,11*). Although the median cubital vein is generally an easy choice because of its large size, catheters at that site may occlude because of kinking resulting from movement of the elbow and/or a loose attachment. Our previous study revealed that the height-adjusted distance between the puncture point and the antecubital fossa was related to "thrombus with subcutaneous edema related to PIVC failure" (*12*). Movement in the arm joints (*i.e.* shoulder, elbow, and wrist) can place mechanical stress on the catheter. If an external force is applied (*e.g.* elbow flexion causing catheter hub movement), the catheter may bend or otherwise change shape. However, we were unable to find publications to support this assumption.

Indwelling catheters can continuously stimulate vessel walls and subcutaneous tissue, resulting in thrombus formation or subcutaneous edema (*13*). Clarification of these relationships might improve the choice of insertion sites and appropriate catheters to prevent PIVC failure. Therefore, we analyzed information from clinical ultrasound and digital camera images acquired in a previous observational study (*12*) to investigate the questions. In the previous study, nurses and physicians used short peripheral catheters (SPCs) made of Teflon® (ethylene tetrafluoroethylene), which is a plastic. Almost all plastics subjected to a continuous load experience deformation over time (*14*). We thought that the SPCs used in that study would show deformation at removal.

The aim of this study was to examine the causes of PIVC failure associated with catheter location by evaluating catheter shape just after removal by using data from our previous study (*12*).

2. Materials and Methods

2.1. *Study design and setting*

This study was a secondary analysis of data from our previous study (*12*). Our observational study was conducted at The University of Tokyo Hospital between January and June 2014. Participants were adult patients who received infusion therapy *via* SPCs during medical ward hospitalization. Patients with poor cognitive ability were excluded from the study.

2.2. *Study procedure*

All SPCs (Surshield® Surflo®2; Terumo Corp., Tokyo, Japan) were made of Teflon® (ethylene tetrafluoroethylene). One of three catheter sizes (length, outer diameter) was chosen: 20 gauge (32 mm, 1.1 mm), 22 gauge (25 mm, 0.9 mm), or 24 gauge (19 mm, 0.7 mm). All PIVCs were fixed with dressing films and tape or bandage after insertion.

Risk management for each catheter was based on the hospital's policies. Researchers were present when catheters were removed because of completion of fluid therapy, routine replacement, or catheter failure with adverse symptoms (such as swelling, redness, pain, or occlusion). Nurses assessed catheter failure, which was defined as interruption of fluid therapy associated with signs and symptoms such as occlusion, swelling, redness, and pain. If nurses confirmed that the infusion volume was insufficient or stopped, the case was defined as "occlusion".

Researchers obtained clinical images of the insertion site with a digital camera and ultrasound. Images of the removed catheters were acquired from different angles. Background demographic data, such as age, sex, and duration of catheter insertion, were recorded from medical charts.

2.3. *Ultrasound scanning technique*

B-mode ultrasonography is a real-time, noninvasive method for exploring subcutaneous tissues and blood vessels (*15*). Ultrasound diagnostic equipment (Hitachi Healthcare Manufacturing, Tokyo, Japan) with linear-array transducers (5-18.0 MHz) was used to observe blood vessels and subcutaneous tissues in this study. The image depth was set at 1.5-2 cm. Echo gain was set at 25 and the dynamic range at 65. Because the pressure of the transducer compresses veins, we used ultrasound gel (Aquasonic 100; Parker Laboratories, Fairfield, NJ) and also placed gel pads (Sonar Pad; Nippon BXI, Tokyo, Japan) over the transparent dressing (*12*).

2.4. *Data analysis*

2.4.1. *Insertion sites*

A total of 184 catheter insertion sites were classified into four groups: upper arm (n = 9), forearm (n = 167), antecubital fossa (n = 3), and dorsum of hand (n = 5). Parameters were compared among all four groups and between upper arm and forearm. Forearm placements were further classified as cephalic vein (n = 107), median vein (n = 30), and basilic vein (n = 30); differences among these veins were analyzed.

2.4.2. *Definitions of catheter bend angle and catheter curvature*

We found two types of catheter shape. The first was a bend at the base of the catheter and the second was a curve or kink in the middle of the catheter. The bend angle was measured on a photograph by a single researcher blind to the site of catheter insertion. First, a line passing through the center of the catheter hub was drawn; next, a line was drawn along the catheter. The angle between these lines was measured with open-source software ImageJ (Figure 1B) (*16*). The researcher selected the greatest angle among several pictures taken from different angles. Catheter curvature was defined as a clear curve or kink in the middle of the catheter (Figure 1C).

2.4.3. *Ultrasonography images*

All images were assessed by a certified sonographer with over 10 years' experience who was blind to the catheter insertion site.

The definitions of thrombus formation and subcutaneous edema were based on our previous study (*15*). Intravenous thrombus was defined as a marked echogenic mass with an uneven surface. Subcutaneous edema was defined as a homogeneous cobblestone appearance of the subcutaneous fat layer resulting from excessive fluid in the interstitium. Presence or absence of subcutaneous edema and intravenous thrombus were assessed on both transverse and longitudinal ultrasound images (Figures 1D and 1E).

2.4.4. *Statistical analysis*

Data are presented as mean with standard deviation (SD) or median with range. Chi-square tests and Fisher's exact test were used for categorical data; Mann-Whitney *U* tests were used for quantitative data. A two-tailed *p*-value < 0.05 was considered statistically significant. Data were analyzed with Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, ver. 22.0; IBM Corp., Armonk, NY).

2.5. *Ethical considerations*

All patients who had planned medical treatment with fluid therapy were informed about the purpose and methods of the study, safety considerations, and right to revoke consent at any time. Patients were enrolled after providing written informed consent. The study was approved by the Research Ethics Committee of the Graduate School of Medicine at The University of Tokyo (#10348).

3. Results

3.1. *Participant characteristics*

Images of 217 removed catheters were taken with a digital camera. Thirty-three catheters were excluded because ultrasound images were not obtained before catheter removal. The remaining 184 catheters from 142 participants were analyzed. Mean patient age (SD) was 69.6 (12.7) years; 84 participants (59.2%) were male (Table 1).

3.2. *Insertion site, catheter characteristics, and catheter failure*

SPCs were frequently inserted into the forearm (90.8%). The most common catheter size was 22 gauge (81.5%). Mean indwelling time was 45.7 h.

The median bend angle, measured at the base of the catheter, was 9.1° (range: 0.0°-68.3°). The bend angle was significantly greater in upper arm placements than in forearm placements ($p = 0.013$). The distance from the joint was shorter in upper arm placement than in forearm placement ($p < 0.001$). All three catheters inserted in the

Table 1. Patient characteristics, catheter shape, and ultrasound findings

Items	Total (*n* = 184)	Upper arm (*n* = 9, 4.9%)	Forearm (*n* = 167, 90.8%)	Antecubital fossa (*n* = 3, 1.6%)	Hand (*n* = 5, 2.7%)
Age (years), mean (SD)	70.2 (12.6)	69.3 (18.9)	70.2 (12.5)	72.7 (3.8)	72.4 (11.1)
Sex, *n* (%)					
Male	110 (59.8)	6 (66.7)	99 (59.3)	1 (33.3)	4 (80.0)
Female	74 (40.2)	3 (33.3)	68 (40.7)	2 (66.7)	1 (20.0)
Catheter gauge, *n* (%)					
20-gauge	3 (1.6)	0 (0.0)	2 (1.2)	0 (0.0)	1 (20.0)
22-gauge	150 (81.5)	8 (88.9)	140 (83.8)	1 (33.3)	1 (20.0)
24-gauge	31 (16.8)	1 (11.1)	25 (15.0)	2 (66.7)	3 (60.0)
Indwelling time (hours), mean (SD)	45.7 (27.3)	60.1 (40.4)	44.5 (26.4)	72.7 (3.8)	44.3 (28.6)
Bend angle[a] (°) , median (range)	9.1 (0.0 - 68.3)	18.9 (1.3 - 68.3)*[e]	8.5 (0.0 - 54.0)*[e]	18.1 (12.1 - 30.6)	4.6 (4.1 - 30.9)
The distance from the joint[b] (cm), median (range)	10.7 (2.5 - 25.8)	6.0 (3.2 - 9.4)**[e]	11.5 (2.8 - 25.8)**[e]	–	3.3 (2.5 - 6.2)
Catheter curvature, *n* (%)[c]	17 (9.2)	1 (11.1)	13 (7.8)	3 (100.0)	0 (0.0)
Catheter failure, *n* (%)	55 (29.9)	3 (30.3)	51 (30.5)	0 (0.0)	1 (20.0)
US images, *n* (%)					
Subcutaneous edema	81 (44.0)	5 (55.6)	73 (43.7)	1 (33.3)	2 (40.0)
Thrombus[d]	106 (60.6)	6 (66.7)	94 (59.1)	2 (66.7)	4 (100.0)

[a]Bend at catheter base. [b]Upper arm: from antecubital fossa, Forearm: from wrist joint. [c]Curve or kink in the middle of the catheter. [d]Nine images were excluded because they were unclear. [e]Comparison between forearm placement and upper arm placement, Mann-Whitney *U* test, *$p = 0.013$, **$p < 0.001$.

Table 2. Catheter shapes and ultrasound findings in surviving *vs.* failed catheters

Items	Total (n = 176)			Upper arm (n = 9)			Forearm (n = 167)		
	CF (n = 54)	Non-CF (n = 122)	p-value	CF (n = 3)	Non-CF (n = 6)	p-value	CF (n = 51)	Non-CF (n = 116)	p-value
Age (years), mean (SD)	71.9 (14.4)	69.4 (12.0)	0.056[e)]	56.3 (30.4)	75.8 (7.3)	0.548[e)]	72.8 (12.9)	69.1 (12.2)	0.022[e)]*
Indwelling time (hours), mean (SD)	36.0 (26.6)	49.3 (26.8)	< 0.001[e)]**	25.0 (20.3)	77.7 (36.5)	0.095[e)]	36.7 (26.9)	47.9 (25.5)	0.002[e)]
Bend angle[a)] (°), median (range)	7.9 (1.0 - 54.0)	9.6 (0.0 - 68.3)	0.875[e)]	22.1 (1.3 - 24.8)	18.2 (9.0 - 68.3)	0.905[e)]	7.7 (0.1 - 54.0)	9.2 (0.0 - 37.8)	0.971[e)]
Catheter curvature[b)], n (%)	8 (14.8)	6 (4.9)	0.035[f)]*	0 (0.0)	1 (16.7)	1.0[f)]	8 (15.7)	5 (4.3)	0.023[f)]*
The distance from the joint[c)] (cm), median (range)	12.5 (3.2 - 25.8)	10.3 (2.8 - 23.1)	0.139[e)]	3.3 (3.2 - 6.0)	7.2 (5.3 - 9.4)	0.095[e)]	12.6 (3.5 - 25.8)	10.9 (2.8-23.1)	0.068[e)]
US images, n (%)									
Subcutaneous edema	42 (77.8)	36 (29.5)	<0 .001[f)]**	2 (66.7)	3 (50.0)	1.0[f)]	40 (78.4)	33 (28.4)	< 0.001[f)]**
Thrombus[d)]	39 (76.5)	61 (52.1)	0.004[f)]**	2 (66.7)	4 (66.7)	1.0[f)]	37 (77.1)	57 (51.4)	0.003[f)]**
Symptoms, n (%)									
Occlusion	22 (40.7)	0 (0.0)		2 (66.7)	0 (0.0)		20 (39.2)	0 (0.0)	
Swelling	32 (59.3)	13 (10.7)		2 (66.7)	1 (16.7)		30 (58.8)	12 (10.4)	
Redness	24 (44.4)	31 (25.6)		1 (33.3)	1 (16.7)		23 (45.1)	30 (26.1)	
Pain	30 (55.6)	10 (8.2)		2 (66.7)	0 (0.0)		28 (54.9)	10 (8.6)	

[a)]Bend at catheter base. [b)]Curve or kink in the middle of the catheter. [c)]Upper arm: from antecubital fossa, Forearm: from wrist joint. [d)]Eight images were excluded because they were unclear. [e)]Mann-Whitney U test, [f)]Fisher's exact test,, $*p < 0.05$, $**p < 0.01$.

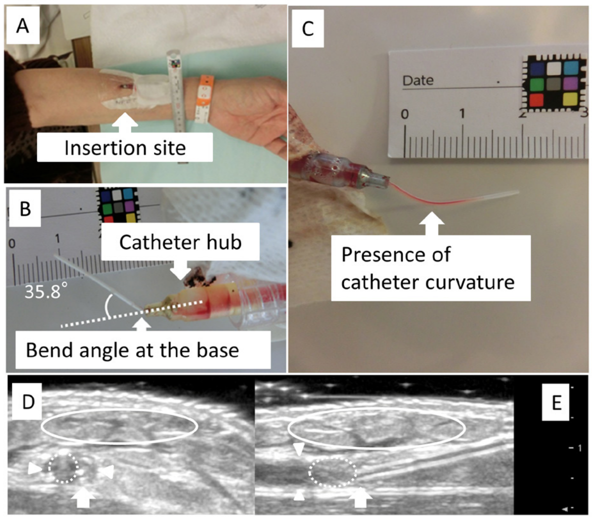

Figure 1. Definition of bend angle, catheter curvature, and ultrasound findings. (A) Photograph of forearm insertion site. **(B)** Photograph of removed catheter, showing bend angle (angle between a line passing through the center of the catheter hub and a line along the catheter). **(C)** Catheter curvature is defined as presence of a curve or kink in the middle of the catheter. **(D)** Ultrasound image before catheter removal (transverse image). **(E)** Ultrasound image (longitudinal image). Ultrasound images showing vessel wall (arrows) catheter tip (arrowheads), subcutaneous edema (circle), and thrombus (dotted circle).

antecubital fossa had a curve or kink in the middle of the catheter. In contrast, none of the catheters inserted in the dorsum of the hand were curved or kinked in the middle of the catheter.

Catheter failure occurred in 29.9% of all catheters. There was no significant difference in catheter failure rate among insertion sites (Table 1).

Table 2 shows catheter shapes and ultrasound findings in surviving *vs.* failed catheters inserted in the upper arm and forearm. Bend angle at the base of the catheter was not related to catheter failure (CF). However, curving or kinking in the middle of the catheter was related to CF (14.8% of failed catheters had curving, $p = 0.035$). Furthermore, catheter curving was related to occlusion (35.3% of occluded catheters had curving, $p = 0.008$; data not shown). The median distance between the insertion site and the elbow joint was shorter in CF cases (median, range: 3.3, 3.2-6.0) than in non-CF cases (7.2, 5.3-9.4) in the upper arm. Thrombus formation or subcutaneous edema was seen on US images in 75% of CF cases (Table 2).

In forearm placement, catheter curving was related to CF ($p = 0.023$), occlusion (46.2% of occluded catheters were curved, $p = 0.001$), and thrombus formation (90.9% of catheters with thrombi were curved, $p = 0.028$; data not shown). Half of catheters inserted in the median vein failed (53.3%, $p = 0.007$; data not shown). The median distance (range) between the joint and catheter insertion site in the cephalic vein, median vein, and basilic vein was 9.6 mm (2.8-24.1), 13.4 mm (7.5-25.8), and 12.3 mm (4.2-21.7), respectively. Median bending angle (range) of catheters in the cephalic vein, median vein,

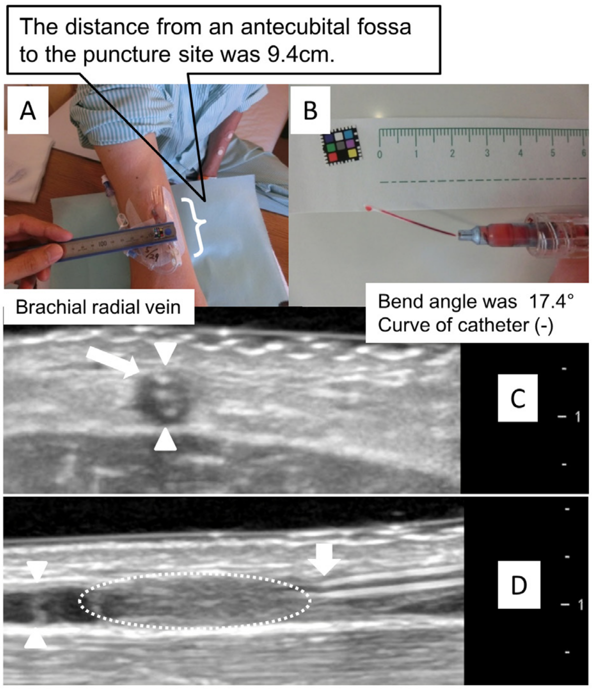

Figure 2. Upper arm vein (non-CF): Case 16202. (A) Upper arm insertion site. **(B)** Bend angle. **(C)** Ultrasound image before catheter removal (transverse image). **(D)** Ultrasound image (longitudinal image). Ultrasound images showing vessel wall (arrowheads), catheter tip (arrows), and thrombus (dotted circle).

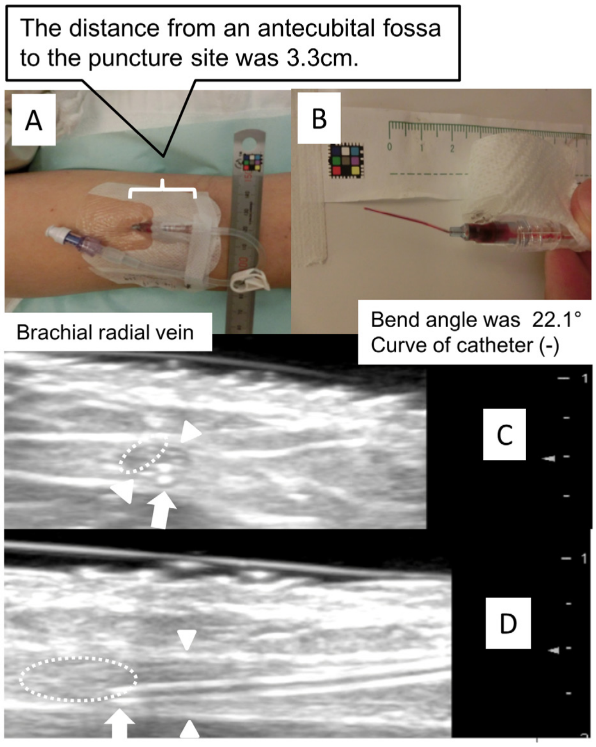

Figure 3. Upper arm vein (CF): Case 22302. (A) Upper arm insertion site. **(B)** Bend angle. **(C)** Ultrasound image before catheter removal (transverse image). **(D)** Ultrasound image (longitudinal image). Ultrasound images showing vessel wall (arrowheads), catheter tip (arrows), and thrombus (dotted circle).

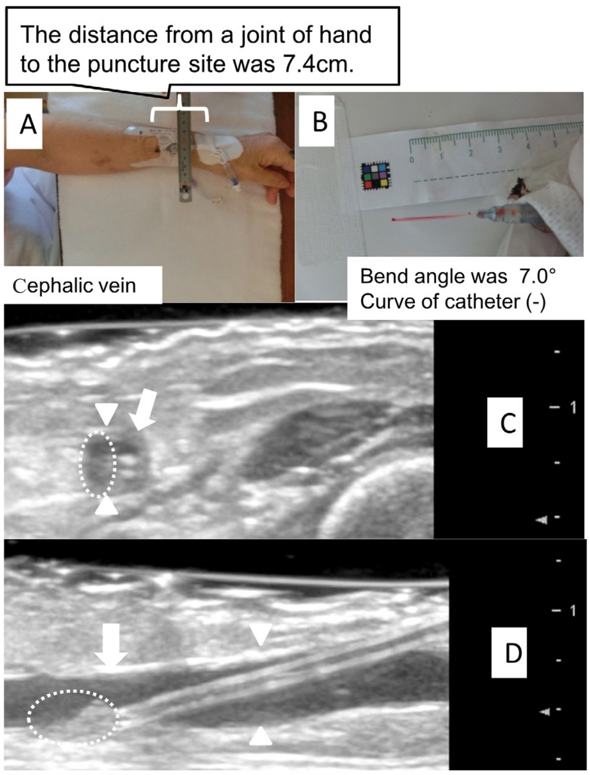

Figure 4. Forearm vein (non-CF): Case 20201. (A) Forearm insertion site. **(B)** Bend angle. **(C)** Ultrasound image before catheter removal (transverse image). **(D)** Ultrasound image (longitudinal image). Ultrasound images showing vessel wall (arrowheads), catheter tip (arrows), and thrombus (dotted circle).

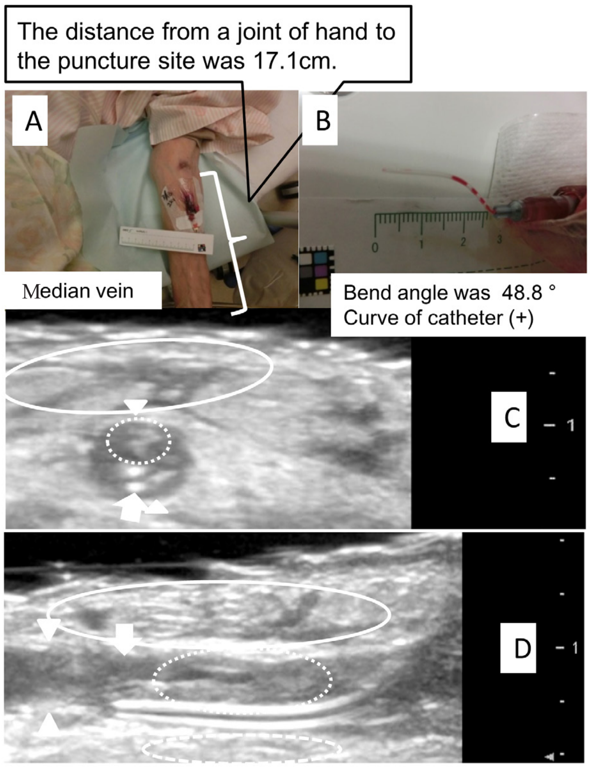

Figure 5. Forearm vein (CF): Case 16701. (A) Forearm insertion site. **(B)** Bend angle. **(C)** Ultrasound image before catheter removal (transverse image). **(D)** Ultrasound image (longitudinal image). Ultrasound images showing vessel wall (arrowheads), catheter tip (arrows), subcutaneous edema (circle), and thrombus (dotted circle).

and basilic vein were 9.3° (0.0°-54.0°), 6.9° (0.2°-48.8°), and 8.4° (0.0°-29.1°), respectively (data not shown).

3.3. *Clinical observations from digital camera and ultrasound images*

Below we describe characteristic non-CF and CF cases of upper arm and forearm placements (Figures 2-5).

Figure 2 and 3 shows cases of catheter insertion in the upper arm. Figure 2 shows non-CF in a 67-year-old man (Case 16202). Indwelling time was 94 h, total infusion volume was 4490 mL, flow rates were 60-250 mL/h, and intravenous lock was performed three times. This patient received an intravenous anticancer agent and a high pH (> 8) agent. The catheter was 22 gauge. The removed catheter had a bend angle of 17.4°; the distance from the antecubital fossa to the puncture site was 9.4 cm. Although thrombus was observed, the patient did not complain of symptoms and medical treatment was completed.

Figure 3 shows CF in a 51-year-old man (Case 22302). Indwelling time was 9.5 h, total infusion volume was 920 mL, flow rates were 20-100 mL/h, and intravenous lock was not used. This patient received antibacterial agents. The catheter was 22 gauge. The removed catheter had a bend angle of 22.1°; the distance from the antecubital fossa to the puncture site was 3.3 cm. Thrombus was observed. The reason for removal was occlusion.

Figures 4 and 5 show cases of forearm vein placement. Figure 4 shows non-CF in a 79-year-old woman (Case 20201). Indwelling time was 70.5 h, total infusion volume was 2150 mL, flow rates were 80-100 mL/h, and intravenous lock was performed twice. This patient received antibacterial agents. The catheter was 22 gauge. The removed catheter had a bend angle of 7.0°; the distance from the wrist to the puncture site was 7.4 cm. Thrombus was observed and medical treatment was completed.

Figure 5 shows CF in an 81-year-old woman (Case 16701). Indwelling time was 11.5 h, total infusion volume was 252 mL, flow rates were 50-100 mL/h, and intravenous lock was not used. This patient received antibacterial agents and a high pH agent. The catheter was 22 gauge. The removed catheter had a bend angle of 48.8°. The distance from the wrist to the puncture site was 17.1 cm. Thrombus and subcutaneous edema was observed; the reason for removal was occlusion. Furthermore, swelling and redness were observed, and the patient had pain.

4. Discussion

To investigate the associations between PIVC failure and catheter location, we acquired ultrasound images of blood vessels and subcutaneous tissues and clinical images of removed catheters. We found that catheters inserted in the upper extremities had bending at the base of the catheter and curving or kinking in the middle of the catheter. The bend angle of catheters inserted in the upper arm was greater than that of catheters inserted in the forearm. The angle of insertion of needles in upper arm veins is greater, because upper arm veins are deeper than those of the forearm, and the subcutaneous fat of the upper arm is thicker than that of the forearm or hand (*17*). Therefore, healthcare provider must insert SPCs at a greater angle through this subcutaneous fat to prevent the catheter from pulling out of the blood vessel (*9*). Furthermore, the cephalic vein in the upper arm runs along the biceps muscle. Contraction of the biceps muscle flexes the elbow and might exert external force, bending the catheter (Figures 2 and 3). If the catheter hub moves away from the insertion site, the base of the catheter bends easily. These conditions may explain why catheters inserted in the upper arm had a greater bend angle than those inserted in the forearm. However, in this study, the bend angle was not related to CF. This finding might have resulted from the comparatively low number of catheters inserted in the upper arm.

Curving or kinking in the middle of the catheter was related to CF, occlusion, and thrombus formation in the forearm. It may be unusual to find bending or curvature in a removed catheter because the malleability of intravenous catheters has improved in recent years (*18*). There is an association between the materials from which catheters are made and the incidence of thrombophlebitis (*19,20*). Blood vessels tend to be soft and bend easily under pressure, which may result in intravenous catheter bending (*21*). If a catheter is bent within a blood vessel, it might develop a curve or kink. This curving may predispose to phlebitis if excessive movement causes vessel wall trauma (*22*). In the current study, catheter insertion in the median vein was related to CF (Figure 5). The distance from the elbow joint to catheters inserted in the median vein was shorter than to catheters in the cephalic vein, which might have affected CF. Elbow joint flexion can exert external forces that affect the vein and the indwelling catheter.

To prevent catheter failure, especially occlusion resulting from catheter curvature, an appropriate insertion site should be selected. It is important to consider both the method of catheter fixation and the insertion angle to avoid mechanical stimulus from external forces on the catheter hub. If the PIVC is inserted into the upper arm, a suitable catheter length should be used to allow a smaller insertion angle to prevent excessive bending at the base of the catheter; insertion should be as far as possible from the elbow joint. Furthermore, the catheter hub must be fixed rigidly because the base of the catheter may bend with forward movement beyond the insertion site during elbow flexion. Although all catheters were fixed with dressing films and tape or bandage after placement, these methods might not be enough as the catheter hub fixation.

Most plastic catheters are flexible and can bend with the shape of the blood vessel. However, catheters can deform over time (*12*). Catheters inserted at the antecubital fossa all showed deformation in the middle of the catheter. Avoiding curvature of the catheter could reduce the mechanical stimulus that affects the vascular endothelium. Further research to examine the difference between catheter materials and removed catheter shapes is needed.

This study was limited by the small number of catheters inserted in the upper arm, antecubital fossa, and hand compared with the forearm. We could not obtain and analyze detailed data on intravenous fluid therapy conditions. Further observational studies with more catheters inserted in the upper arm and using catheters of the different length are required.

In conclusion, although insertion site was not directly associated with CF, curving or kinking in the middle of the catheter was related to CF, occlusion, and thrombus formation in the forearm. Severe catheter bending at the base may result in occlusion. External forces that deform the catheter could affect blood vessels and subcutaneous tissues by mechanical stimulus.

To prevent catheter failure, especially occlusion resulting from catheter curvature, an appropriate insertion site far from the elbow should be selected. Furthermore, it is important that the catheter is fixed rigidly to prevent movement of the catheter hub.

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Conflict of Interest

This study was a joint project with the Terumo Corp., which provided sponsorship.

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