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ORIGINAL

Complications in internal jugular vs subclavian ultrasound-guided central venous catheterization: a comparative randomized trial

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Abstract

Purpose: The use of real-time ultrasound (US) has been shown to reduce complications of central venous (CV) catheterization. However, complication rates have not been compared according to insertion points for CV catheterization using US. Accordingly, this study aimed to compare the complication rates of internal jugular vein (IJV) with those of subclavian vein (SCV) catheterization.

Methods: Three tertiary academic hospitals in South Korea participated in this multicenter, randomized study. A total of 1484 patients were preoperatively randomized into two groups. The IJV group ($n = 742$) was cannulated via the right IJV, and the SCV group ($n = 742$) was cannulated via the right SCV under US guidance. The primary outcome measure was total complication rate. Secondary outcomes included access time for the first attempt, number of attempts, and catheter position.

Results: The total complication rate did not demonstrate a significant difference between the IJV (0.1%) and SCV (0.7%) groups ($P = 0.248$). In the IJV group, arterial puncture occurred in 0.1% of patients; in the SCV group, arterial puncture occurred in 0.6% and pneumothorax in 0.1%. The success rate on the first attempt was significantly higher in the IJV group (98.4%) than in the SCV group (95.9%) ($P = 0.004$). The access time for the first attempt ($P < 0.001$) and the median number of attempts ($P = 0.006$) were significantly lower in the IJV group than in the SCV group. More catheter misplacements were observed in the SCV group (5.9%) than in the IJV group (0.4%) ($P < 0.001$).

Conclusion: Results demonstrated that the complication rates of IJV and SCV catheterizations using US are very low, showing no superiority of the SCV approach compared to the IJV.

Keywords: Central venous catheterization, Jugular vein, Subclavian vein, Ultrasound, Complication

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Introduction

Central venous (CV) catheterization is an important intervention used for various purposes including hemodynamic monitoring, renal replacement therapy, rapid fluid resuscitation, and administration of parenteral nutrition and medications in the operating room, emergency room, and/or intensive care unit.

Although placement of a CV catheter is a common practice in clinical fields, various complications such as arterial puncture, hemothorax, pneumothorax or infection, may occur [1]. In particular, anatomical variations, which have been described in a relevant proportion of patients for the internal jugular vein (IJV), the subclavian vein (SCV), and the femoral vein, can lead to unwanted problems and, are therefore, considered to be limitations of the landmark-based technique for CV catheterization [2–5].

For CV catheterization, ultrasound (US) can be used to easily visualize anatomical structures and confirm patency of the veins and, thus, help to avoid unintended puncture or unsuccessful cannulation [6]. As a result, many clinical guidelines recommend the use of US in CV catheter insertion [6–10]. In general, the SCV and IJV are the most commonly used sites for CV catheter placement with US [11]. Interestingly, although the results were drawn from different studies, the complication rates for SCV catheterization were lower (0.5–2.0%) [12, 13] than the IJV approach (2.3–10%) [14–16] when using a real-time US-guided method. However, data are lacking in direct comparisons of complication rates of CV catheterization using US according to insertion points.

In the present study, therefore, and based on the hypothesis that the incidence of complications related to CV cannulation is lower in the SCV than in the IJV, we performed real-time US-guided SCV and IJV catheterization to compare complication rates between these two approaches.

Take-home message

In this study, the total complication rate was 0.7% in subclavian approach vs 0.1% in internal jugular approach, without a significant difference.
Results demonstrated that the complication rates of IJV and SCV catheterizations using US are very low, showing no superiority of the SCV approach compared to the IJV.

Methods

Study setting

Three tertiary academic hospitals in South Korea participated in this prospective, multicenter, randomized study (clinicaltrials.gov identifier NCT01510743), which was conducted from February 2012 to April 2018. Institutional review board approval was obtained from the following centers: Seoul National University Bundang Hospital (Gyeonggi, Korea, IRB No. B-1112/069-002), Asan Medical Center (Seoul, Korea, IRB No. 2012-0104), and Seoul Metropolitan Government Seoul National University Boramae Medical Center (Seoul, Korea, IRB No. 20-2017-3). Informed written consent was obtained from all patients before participation.

Participants, trial design, and randomization

Patients (age range 20–80 years) who participated in this study were scheduled to undergo major operations that required CV catheterization. Individuals with a history of previous surgical intervention at the cannulation site, presence of a CV catheter during the past 72 h (in the same vein in which the present cannulation was planned), infection signs or hematoma near the puncture site, recent cervical trauma or surgery with present neck immobilization, laboratory data suggesting severely impaired hemostasis (international normalized ratio > 2, platelet count < 50,000/μl), emergency surgery, a history of multiple ipsilateral SCV or IJV catheterizations (≥ 3), chest wall deformities, history of thoracic surgery, or anatomical abnormalities at the cannulation site, were excluded.

A total of 1484 patients were preoperatively randomly assigned to 1 of 2 groups: the IJV group, in which CV catheterization was performed via the right IJV; and the SCV group, in which CV catheterization was performed at the right SCV. This study was a block-randomized, with a block size of 4, single-blinded, parallel-group trial with 2 groups of equal size. A randomization chart was generated using a web-based randomizing system (https://www.randomization.com). The allocation ratio was 1:1. Randomization was performed by an anesthesiologist not involved in the study, who prepared opaque, sealed envelopes each containing a slip of paper with a computer-generated description of whether the patient was to undergo IJV or SCV catheterization. The investigating anesthesiologists who performed the CV catheterizations were not blinded to the method of catheterization being used in the operating room. Access time and complications during the catheterization were recorded by another investigating physician.

General anesthesia

All patients were pre-medicated with 0.03 mg/kg midazolam administered intravenously in a preoperative holding area of the operating suite. Upon patient arrival to the operating room, standard monitoring (pulse oximetry, electrocardiogram, and non-invasive arterial pressure) was established. General anesthesia was performed

using one of the balanced or total intravenous anesthetic methods.

Balanced anesthesia was induced using intravenous propofol (2 mg/kg), sevoflurane, remifentanil (target effective concentration 4 ng/ml), and rocuronium (0.6 mg/kg). Total intravenous anesthesia induction was performed as follows: 2% propofol (Fresofol®, Fresenius Kabi, Korea Ltd, Korea) and remifentanil (Ultiva®, GlaxoSmithKline, United Kingdom) diluted to 50 μg/mL were administered using a target-controlled infusion device (Orchestra®, Fresenius vial, France) until the effective concentration reached 4 μg/mL and 4 ng/mL, respectively. After unconsciousness was confirmed and muscle relaxation was achieved, an endotracheal tube was inserted for ventilation support.

Central venous catheterization

After inducing general anesthesia, CV catheterization was performed using a double-lumen CV catheter (Arrow International Inc., Reading, PA, USA) under US guidance. All catheterizations were performed by six anesthesiologists with experience of performing the procedure > 200 times for the IJV and > 50 times for the SCV catheterization under US guidance over 2 years.

Before skin preparation, US scanning and compression with a transducer were performed to distinguish vein from artery and to rule out venous thrombosis. The right SCV and IJV areas were sterilized with chlorhexidine. A US device (SonoSite S-nerve, SonoSite, Bothell, WA, USA) equipped with a linear 6–13 MHz transducer (HFL38x, SonoSite, Bothell, WA, USA) was used. The surface of the transducer was coated with sterilized gel and then wrapped in a sterile cover. All procedures were performed using the Seldinger technique with an 18-gauge, 6.5 cm introducer needle (Arrow International Inc., Reading, PA, USA).

For IJV cannulation, the transducer was placed transversally over the neck (parallel to the clavicle) and venous flow was confirmed using color Doppler view. Once the vein was visible in the middle of the US image, the needle was introduced in a plane perpendicular to the long axis of the transducer. After confirming blood aspiration and needle tip position inside the vein, the syringe was removed before a guide wire was introduced through the needle. After identifying the guidewire inside the jugular vein in a short- and long-axis ultrasound examination, the Seldinger technique was continued until catheter insertion and its position was confirmed by US (Fig. 1a).

The infraclavicular approach was used for the SCV catheterization to obtain a longitudinal view of the SCV based on the method described by Fragou et al. [13]. After confirming venous flow using color Doppler view, the needle was advanced under real-time US guidance toward the lumen of the vein. After venous puncture was confirmed, the guidewire was advanced though the needle and into the vein. The needle was then removed while holding the guidewire in place, and confirming the guidewire in the vessel using US. After proper placement of the guidewire was confirmed, the catheter was inserted and the position was confirmed using US (Fig. 1b).

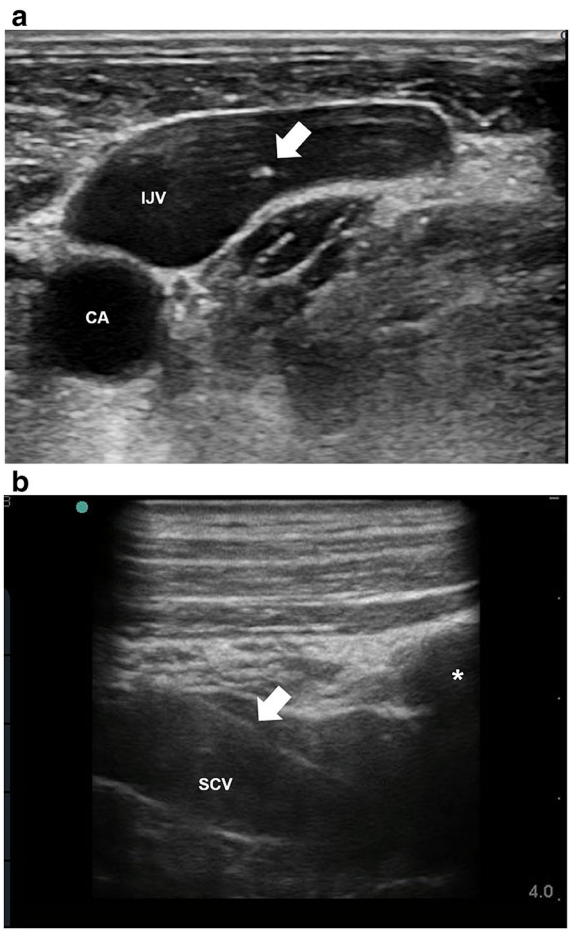

Fig. 1 US images. Short-axis view of the IJV (**a**) and long-axis view of the SCV (**b**). Asterisk = clavicle acoustic shadow, white arrow = needle. *IJV* internal jugular vein, *CA* carotid artery, *SCV* subclavian vein

When the first or second attempts failed, operators compressed the vein for over 3 min to avoid an occurrence of venous thrombosis. Chest X-rays (CXRs) were acquired after the procedure to verify the position of the catheter tip in the operating room, where the target of catheter tip placement was the superior vena cava (SVC).

Outcome variables

The primary outcome measure was total complication rate. Evaluated complications included: arterial puncture (defined as any pulsatile blood reflux through the needle observed during the procedure); pneumothorax; and hemothorax.

As for the secondary outcomes, we assessed the number of attempts to successfully achieve catheter placement and access time (the time between penetration of skin and aspiration of venous blood into the syringe) for the first attempt. The incidence of catheter misplacement and the duration of catheter placement were recorded.

The incidence of catheter misplacement (catheter tip identified at any place other than the superior vena cava on the chest X-ray) and the duration of catheter placement were recorded.

Sample size

In previous studies that evaluated complication rates in CV catheterizations under US guidance [12, 14], the incidence rate was 2.3%, with 667 patients per group required to detect a 1.8% difference with 80% power and a 5% level of significance. Considering a dropout rate of 10%, the required sample size in the present study was 1484 (742 patients per group).

Statistical analysis

All variables were tested for normality using the Shapiro–Wilk test. The data are expressed as mean (standard deviation) or median (interquartile range) according to the normality of data distribution, or as number (percentage). Considering the appropriateness of each test, either the Student's t test or Mann–Whitney U test was performed to compare continuous variables between the two groups. Categorical data were analyzed using the χ^2 test or Fisher's exact test, as appropriate.

SPSS version 22 (IBM Corporation, Armonk, NY, USA) for Windows/Macintosh (Microsoft Corporation, Redmond, WA, USA) was used for all analyses and a P value of < 0.05 was considered statistically significant.

Results

Of 1660 patients evaluated for eligibility, 176 were excluded (152 did not fulfill the inclusion criteria and 24 refused to participate). The remaining 1484 patients were assigned to one of two groups, and 1,350 completed the study (Fig. 2). The characteristics of the patients are summarized in Table 1.

The total complication rate did not demonstrate a significant difference between the IJV (0.1%) and SCV (0.7%) groups ($P = 0.248$) (Table 2). In the IJV group, only one arterial puncture was recorded. In the SCV group, four arterial punctures and one pneumothorax (Fig. 3a) occurred.

The success rate on the first attempt was significantly higher in the IJV group (98.4%) compared with the SCV group (95.9%) ($P = 0.004$) (Table 2). In addition, access time was longer ($P < 0.001$) and the average number of attempts was higher ($P = 0.006$) in the SCV group than in the IJV group (Table 2).

More catheter misplacements were observed in the SCV group than in the IJV group ($P < 0.001$, Table 2). The CV catheters were placed at the right IJV (Fig. 3b) in 5.5% and at the left brachiocephalic vein (Fig. 3c) in 0.4% of patients in the SCV group. In the IJV group, only 0.4% of patients experienced catheter misplacements at the right SCV (Fig. 3d).

On average, most CV catheters were removed 2 days after surgery when their role was fulfilled. Additionally, there were no cases of infection.

Discussion

The present study assessed the complication rate of US-guided SCV and IJV catheterization. The overall incidence of procedure-related complications was very low in both approaches, and not significantly different between SCV and IJV cannulations. However, the access time was longer and misplacement was higher in the SCV group than in the IJV group.

Advances in technology and the wide availability of US have altered the standard for establishing vascular access. US enables direct visualization of the target vessel and monitoring of all steps of catheterization including confirmation of the needle, guidewire, and catheter position [17–19]. Multiple studies have compared US-guided CV catheterization to landmark-based techniques, and found that the US method reduced the total complication rate by 71%, arterial puncture by 72%, access time to successful cannulation by 30.5 s, and the number of attempts required for successful catheterization (1.19 fewer attempts) for IJV placement [20]. Additionally, the use of US in SCV cannulation reduced the risk for inadvertent arterial puncture by 79% and hematoma formation by 74% compared with landmark-based methods [21]. The present study supports these positive roles of US, demonstrating low complication rates both in SCV (0.7%) and IJV (0.1%) cannulation.

Our results support the opinion that US-guided SCV catheterization could be used as a viable alternative to cannulation of the IJV [22]. With regard to complication rate, no significant differences were demonstrated between the SCV and IJV groups. Moreover, the total complication rate was very low in the US-guided SCV group (0.7%). Shah et al. [23] suggested that further randomized trials comparing US-guided SCV and IJV catheterization to determine which route is better are needed. The present study may be the first to address this suggestion in performing a prospective randomized trial to compare complication rate, access time, and misplacement of catheter between the SCV and IJV approaches under US guidance.

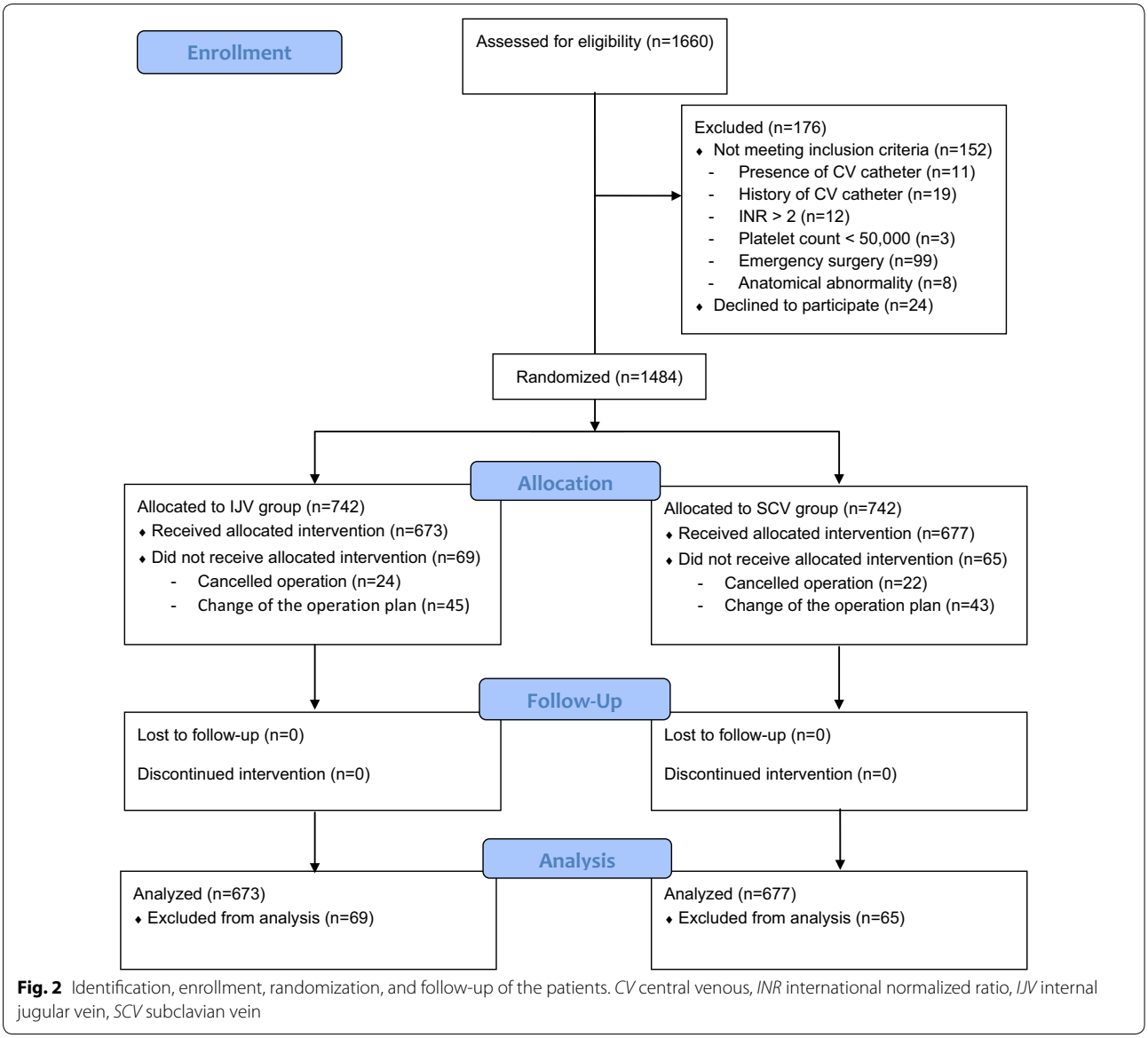

Fig. 2 Identification, enrollment, randomization, and follow-up of the patients. *CV* central venous, *INR* international normalized ratio, *IJV* internal jugular vein, *SCV* subclavian vein

The difference in the rate of arterial puncture, catheter misplacement, and access time may be explained by anatomical aspects of each vessel (i.e., SCV and IJV). When acquiring the target view using US, the IJV and carotid artery can be visualized easily, without any bony obstacles, such as the clavicle, in the sonographic view. This advantage may play an important role in avoiding accidental arterial puncture and decreasing access time compared with the SCV approach. In addition, the vascular route to reach the junction of the superior vena cava and the right atrium is straight in the IJV approach. In contrast, there is an acute angle between the SCV and superior vena cava [24]. These anatomical differences may lead to a higher rate of misplacement of the catheter in SCV cannulation than in the IJV.

One factor to consider in performing CV catheter placement using US is the technical aspect. When compared with US-guided IJV cannulation, technical difficulties with visualizing the SCV on US, due to its route beneath the clavicle, has been reported [7, 25]. Griswold-Theodorson et al. [26] reported that greater technical US skill is required for SCV catheterization than for IJV catheterization. Although SCV cannulation offers several advantages (i.e., lower incidence of thrombosis and infection, better patient comfort, and retained structure in hypovolemic states) [1, 23, 27, 28], this barrier has led

Table 1 Characteristics of patients

	IJV group (*N* = 673)	SCV group (*N* = 677)
Age, median (IQR), year	64 (52–73)	64 (54–71)
Gender, *N* (%)		
Male	350 (52%)	334 (49%)
Female	323 (48%)	343 (51%)
Weight, median (IQR), kg	61 (53–69)	60 (53–68)
Height, median (IQR), cm	162 (155–168)	161 (154–168)
BMI, median (IQR), kg/cm^2	23 (21–26)	23 (21–26)
Surgical types		
Neurosurgery	242 (36%)	223 (33%)
Abdominal surgery	188 (28%)	203 (30%)
Vascular surgery	114 (17%)	108 (16%)
Cardiac surgery	108 (16%)	122 (18%)
Orthopedic surgery	14 (2%)	13 (2%)
Urological surgery	7 (1%)	8 (1%)
Co-morbidities		
Hypertension	278 (41.3%)	277 (40.9%)
Diabetes mellitus	70 (10.4%)	76 (11.2%)
Chronic kidney disease	10 (1.5%)	12 (1.8%)
Ischemic heart disease	17 (2.5%)	16 (2.3%)
Cerebrovascular disease	18 (2.7%)	20 (3.0%)
Chronic lung disease	12 (1.8%)	10 (1.5%)

Data are expressed as median (interquartile range) or number of the patients (%)

IJV internal jugular vein, *SCV* subclavian vein, *BMI* body mass index

physicians to favor the IJV for CV cannulation. However, education using simulation models can provide excellent technical practice, and sufficient SCV cannulation skill can be learned more rapidly with US guidance compared with the landmark-based technique (3 versus 9 attempts), based on a study involving medical trainees by Tokumine et al. [29]. Additionally, results of several studies demonstrate a significant effect of US on the safety and efficacy of SCV catheterization [13, 30]. In the present study, although the access time was longer in SCV cannulation compared with that of IJV cannulation, US-guided SCV cannulation demonstrated acceptable access times and number of attempts.

There were several limitations to our investigation that should be considered. First, the sample size was determined based on a superiority trial. However, the complication rates were lower than the estimated rates and the power to detect the differences between SCV and IJV declined from 80 to 41.4% in the post hoc power analysis. Second, only experienced anesthesiologists performed US-guided CV cannulation in the present study. It is possible, therefore, that significant differences in overall complication rates between SCV and IJV approaches can occur when cannulation is performed by less experienced physicians. Third, because only elective surgical patients participated, our results could not provide efficacy or complication rates in emergency situations. In addition, we conducted the present study on patients

Table 2 Characteristics of CV catheter placement and the incidence of complications

	IJV group (*N* = 673)	SCV group (*N* = 677)	*P*
Access time in first attempt, median (IQR), s	5 (4–7)	15 (10–23)	< 0.001
Median number of attempts	1 (1–1)	1 (1–1)	0.006
Success, no. (%)			
First attempt	662/673 (98.4%)	649/677 (95.9%)	0.004
Second attempt	10/11 (90.9%)	23/28 (82.1%)	0.441
Third attempt	1/1 (100%)	5/5 (100%)	NA
Catheter tip position			< 0.001
SVC	670 (99.6%)	637 (94.1%)	
IJV (right)	0 (0%)	37 (5.5%)	
IJV (left)	0 (0%)	0 0%)	
SCV (right)	3 (0.4%)	0 (0%)	
BCV (left)	0 (0%)	3 (0.4%)	
Duration of catheter placement, median (IQR), days	2 (1–3)	2 (1–3)	0.855
Complications, no. (%)			0.248
No	672 (99.9%)	672 (99.3%)	
Arterial puncture	1 (0.1%)	4 (0.6%)	
Pneumothorax	0 (0%)	1 (0.1%)	
Hemothorax	0 (0%)	0 (0%)	

Data are expressed as median (interquartile range) or number of the patients (%)

CV central venous, *SVC* superior vena cava, *RA* right atrium, *IJV* internal jugular vein, *SCV* subclavian vein, *BCV* brachiocephalic vein

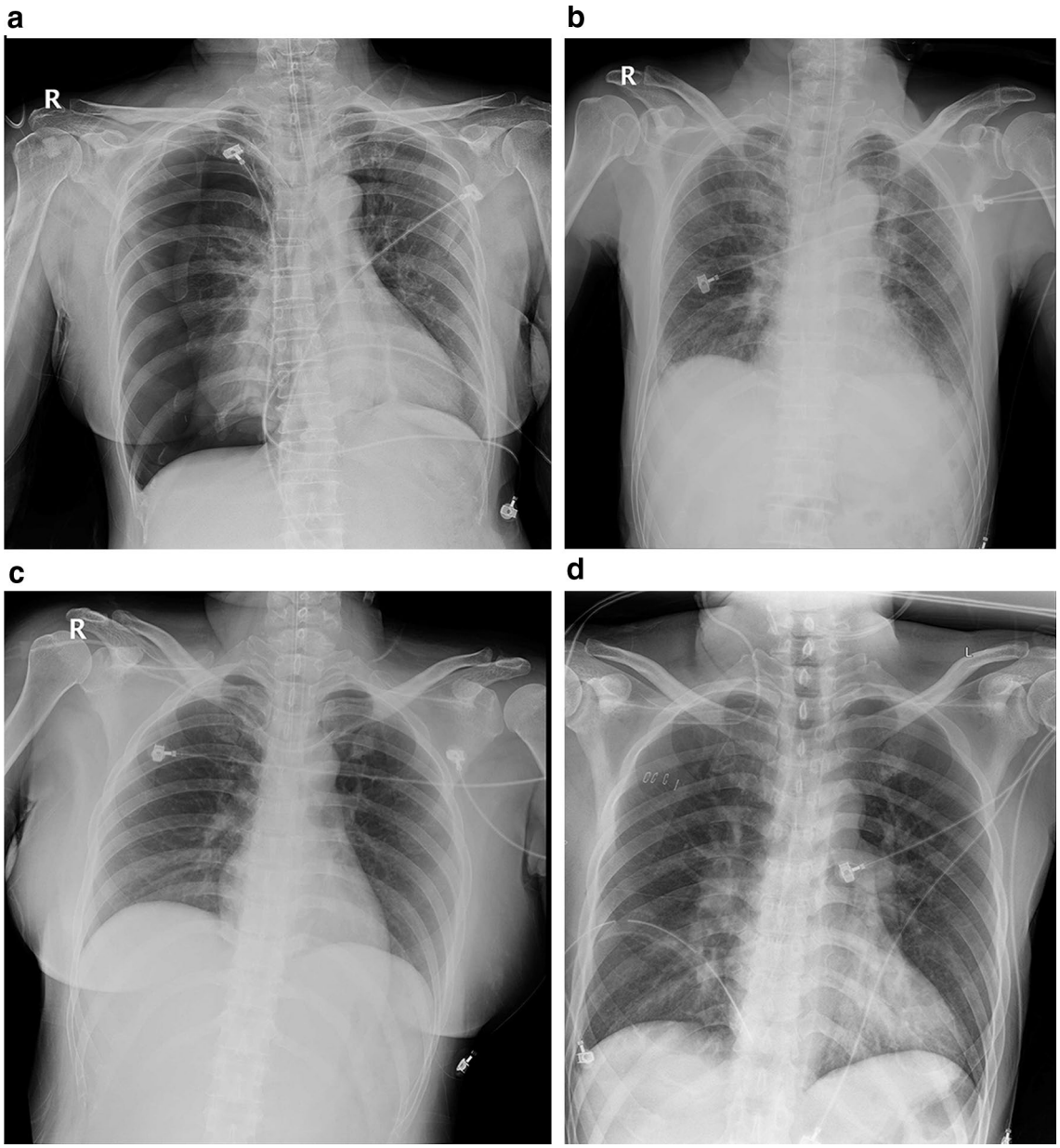

Fig. 3 Procedure-related complications. Pneumothorax (**a**), catheter malposition to internal jugular vein (**b**), left brachiocephalic vein (**c**), and right subclavian vein (**d**)

under general anesthesia. Recently, Vezzani et al. [31] reported a relatively higher complication rate (14%) and lower first-attempt success rate (64%) than our results in a clinical trial, which was performed in non-anesthetized patients after cardiac surgeries. Therefore, further studies are needed to expand our results to non-anesthetized populations, such as critically ill or emergent patients. Fourth is the confirmation method for puncture of the appropriate vessel. Pulsatile blood flow from the needle may not be sufficiently sensitive to detect accidental artery puncture in a hemodynamically compromised patient. However, proper US identification of anatomical structures and satisfactory visualization play a crucial role in the safety margin of the procedure. Fifth, the median BMI of the participants was 23 kg/cm^2. Massive obesity may hinder our ability to obtain an optimal US view of the SCV, which could impact success rates in CV cannulation. Sixth, in the present study, CXRs

were used for detecting early post-procedure complications. However, CXRs have low sensitivity (27–82%) and appear to be less accurate than US scans in detecting the occurrence of pneumothorax [32]. Therefore, the chest US seems to generally be preferred for detecting post-procedure complications in the operating room. Seventh, anatomically, the axillary vein has continuity with the SCV until it reaches the first rib. Although investigators obtained an optimal US view and tried to perform the SCV cannulation using anatomic landmarks, such as the acoustic shadows of the underlying first rib, the chance of axillary vein puncture could not be ruled out completely. Eighth, we used different approach techniques in the SCV (in-plane) and the IJV (out-of-plane) to obtain the US image. The out-of-plane approach is known to be associated with a relatively high rate of posterior wall injury and a high risk of pneumothorax at the subclavian site [33]. On the other hand, in the US-guided IJV cannulation, the out-of-plane technique showed better [34] or similar [35] outcomes compared to the in-plane technique. Although different approach techniques were chosen to reduce the complication rates, this difference could influence the complication rates, and therefore, our results should be interpreted considering these approach differences. Finally, center effect was not assessed in data analysis. Although the institutions participated in the present study were all tertiary academic hospitals, this may be a bias in the results.

In conclusion, the present study demonstrated no superior results in overall complication rates of SCV (long-axis approach) catheterization compared to IJV (short-axis approach) catheterization under US guidance. Although US-guided SCV cannulation is as safe as IJV cannulation, it requires more time, and may increase the incidence of catheter misplacement.

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Author contributions
HJS: performing the procedure, writing the first manuscript, and statistical analysis; HSN: study design, writing the first manuscript, and statistical analysis; WUK: performing the procedure; YJR: study design and revising the manuscript; YJC: performing the procedure; JML: performing the procedure; S Park: performing the procedure; JHK: performing the procedure, revision and final approval of the version to be submitted.

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Compliance with ethical standards

Conflicts of interest
All authors report no conflict of interest.

Ethical approval
This study was conducted in accordance with the Declaration of Helsinki and was approved by the local research ethics committee.

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