Ultrasound-Guided Infraclavicular Axillary Vein Versus Internal Jugular Vein Cannulation in Critically Ill Mechanically Ventilated Patients: A Randomized Trial

Tomasz Czarnik, MD, PhD[1]
Miroslaw Czuczwar, MD, PhD[2]
Michal Borys, MD, PhD[2]
Olimpia Chrzan, MD[3]
Kamil Filipiak, MD[4]
Magdalena Maj, MD[5]
Maciej Marszalski, MD[1]
Marta Miodonska, MD[5]
Maciej Molsa, MD[1]
Marek Pietka, MD[5]
Maciej Piwoda, MD[1]
Pawel Piwowarczyk, MD, PhD[2]
Zuzanna Rogalska, MD[5]
Jakub Stachowicz, MD[6]
Ryszard Gawda, MD, PhD[1]

OBJECTIVES: This clinical trial aimed to compare the ultrasound-guided in-plane infraclavicular cannulation of the axillary vein (AXV) and the ultrasound-guided out-of-plane cannulation of the internal jugular vein (IJV).

DESIGN: A prospective, single-blinded, open label, parallel-group, randomized trial.

SETTING: Two university-affiliated ICUs in Poland (Opole and Lublin).

PATIENTS: Mechanically ventilated intensive care patients with clinical indications for central venous line placement.

INTERVENTIONS: Patients were randomly assigned into two groups: the IJV group ($n = 304$) and AXV group ($n = 306$). The primary outcome was to compare the IJV group and AXV group through the venipuncture and catheterization success rates. Secondary outcomes were catheter tip malposition and early mechanical complication rates. All catheterizations were performed by advanced residents and consultants in anesthesiology and intensive care.

MEASUREMENTS AND MAIN RESULTS: The IJV puncture rate was 100%, and the AXV was 99.7% (chi-square, $p = 0.19$). The catheterization success rate in the IJV group was 98.7% and 96.7% in the AXV group (chi-square, $p = 0.11$). The catheter tip malposition rate was 9.9% in the IJV group and 10.1% in the AXV group (chi-square, $p = 0.67$). The early mechanical complication rate in the IJV group was 3% (common carotid artery puncture–4 cases, perivascular hematoma–2 cases, vertebral artery puncture–1 case, pneumothorax–1 case) and 2.6% in the AXV group (axillary artery puncture–4 cases, perivascular hematoma–4 cases) (chi-square, $p = 0.79$).

CONCLUSIONS: No difference was found between the real-time ultrasound-guided out-of-plane cannulation of the IJV and the infraclavicular real-time ultrasound-guided in-plane cannulation of the AXV. Both techniques are equally efficient and safe in mechanically ventilated critically ill patients.

KEY WORDS: axillary vein; central venous cannulation; complication; internal jugular vein; success rate; ultrasound

The real-time ultrasound-guided infraclavicular cannulation of the axillary vein (AXV) is one of the methods of central venous catheterization used in ICUs (1–10). This technique is recommended by experts in the field as the method of choice for infraclavicular central venous cannulation (11). Although this approach to central vein catheterization is growing in popularity, there is a lack of the randomized trials to prove its usefulness (12). Furthermore, cannulation of the AXV via infraclavicular route has only been addressed in one scientific guideline (13). Whether the infraclavicular

DOI: 10.1097/CCM.0000000000005740

KEY POINTS

Question: To compare the ultrasound-guided in-plane infraclavicular cannulation of the axillary vein (AXV) and the ultrasound-guided out-of-plane cannulation of the internal jugular vein (IJV).

Findings: The primary outcome of a prospective, single-blinded, open label, parallel-group, randomized trial was to compare the IJV group and AXV group through the venipuncture and catheterization success rates. The IJV puncture rate was 100% and the AXV was 99.7%, whereas the catheterization success rate in the IJV group was 98.7% and 96.7% in the AXV group.

Meaning: Both techniques are equally efficient and safe in mechanically ventilated critically ill patients.

approach to the AXV is as safe and effective as the internal jugular approach is thus unclear.

We prospectively compared two methods of real-time ultrasound-guided central venous cannulation, namely infraclavicular axillary and internal jugular, in terms of success rate, overall complication, rate and first-time puncture success rate. The aim of our trial was to test the hypothesis that real-time ultrasound-guided infraclavicular cannulation of the AXV is as effective and safe as the real-time ultrasound-guided cannulation of the internal jugular vein (IJV).

MATERIALS AND METHODS

This was a prospective, single-blinded, open label, parallel-group, randomized trial conducted between 2 August 2016, and 16 August 2020, in two university-affiliated ICUs in Poland (Opole and Lublin). The management committee developed the trial protocol using a predefined sample size calculation and statistical analysis. The study protocol was approved by two local ethics committees, one per site (Komisja Bioetyczna Opolskiej Izby Lekarskiej w Opolu; decision number: 224/2015). Written informed consent for enrollment was obtained from the patients' closest relatives. The trial was registered before the recruitment of participants (ClinicalTrials.gov: NCT02624323) and carried out according to the principles of Good Clinical Practice and the Declaration of Helsinki.

Trial investigators consisted of intensivists directly involved in the day-to-day management of ICU patients. Minimal requirements for investigators performing procedures were established. The investigator was either a consultant in anesthesiology and intensive care (7 consultants) or a resident (after completion of fourth yr of specialized training in anesthesiology and intensive care—8 residents). Minimal documented experience consisted of 10 procedures of real-time ultrasound-guided internal jugular out-of-plane (transverse) catheterization and 10 procedures of real-time ultrasound-guided infraclavicular AXV in-plane (longitudinal) catheterizations. Out-of-plane technique was used for the IJV as short-axis view is a typical visualization for this access. In-plane technique was used for AXV as it is a standard procedure applied in both participating centers.

Inclusion criteria comprised mechanically ventilated ICU patients with clinical indications for central venous catheter placement in the area of the superior thoracic aperture. In addition, initial ultrasound prescanning of both IJVs and both AXVs had to demonstrate acceptable conditions for the catheterization of at least one IJV and at least one AXV. Exclusion criteria comprised age under 18 years old, trauma, or/and hematoma at the catheterization site, clinically significant coagulation disorders, anatomical abnormalities at the catheterization site, local infection at the catheterization site, catheterization for renal replacement therapy, and lack of closest relative consent. All catheterization procedures were performed at two ICUs of two participating sites using Affinity 50, Affinity 70, and CX-50 ultrasound machines (Philips Medical Systems, Andover, MA) and L12-4 or L12-3 linear probes (Philips Medical Systems).

Mechanically ventilated patients requiring central venous catheterization were screened and enrolled by trial investigators immediately prior to procedure using opaque, sealed envelopes containing blank catheterization protocols that directed the investigator to cannulate either the internal jugular or AXV. The exterior of each envelope was printed with a consecutive randomization number. The investigator was instructed to choose the lowest consecutive envelope number. The computer-generated randomization sequence was 1:1. The randomization in blocks of four was selected to obtain an equal size of study arms.

The two study groups consisted of: the internal jugular group (IJV) and AXV group. The randomization procedure was performed in advance by the primary investigator (T.C.) using Randomizer for Clinical Trial (Version 2.0; Medsharing 2012, Fontenay Sous Bois, France) mobile application for iPad or/and iPhone (Apple inc., Cupertino, CA). All cannulation procedures were performed using the Seldinger technique (a thin-walled introducer needle, 18 Ga × 6.35 cm) and double, three- or four-lumen, 16 cm (for the right IJV) or 20 cm (for the left IJV or AXVs), central venous catheters (Arrow International, Reading, PA).

Real-Time Ultrasound-Guided IJV Out-of-Plane Catheterization

The preferred side for this technique was chosen after an ultrasound prescan of the neck. The orientation of the cannulation needle was out-of-plane, and the jugular vein was imaged transversely (**Supplemental Digital Content—Fig. 1**, ***A*** and ***B***, http://links.lww.com/CCM/H249). To puncture the vein, the needle was inserted through the skin and directed slowly at an angle of 30° above the skin toward the wall of the vein. The introduced needle caused so called "tenting effect" which was a deflection of the wall of the vein when the tip of the needle encountered the wall of the vein (**Supplemental Digital Content—Fig. 1*C***, http://links.lww.com/CCM/H249). When the needle punctured the vein, the blood was aspirated, and the needle was visualized on the screen as a white dot within the lumen of the vein (**Supplemental Digital Content—Fig. 1*D***, http://links.lww.com/CCM/H249). Insertion of a guidewire and a catheter was not performed under direct visualization; however, the intravascular position of both a guidewire and catheter were immediately confirmed.

Real-Time Ultrasound-Guided Infraclavicular AXV Catheterization

The preferred side for this technique was chosen after an ultrasound prescan of the infraclavicular fossa. The orientation of the cannulation needle was in-plane, and the AXV was imaged longitudinally (**Supplemental Digital Content—Fig. 1**, ***E*** and ***F***, http://links.lww.com/CCM/H249). To puncture the vein, the needle was inserted through the skin and directed slowly at an angle of 30° above the skin toward the wall of the vein. When the tip of the needle encountered, the wall of the vein the "tenting effect" was observed on the screen (**Supplemental Digital Content—Fig. 1*G***, http://links.lww.com/CCM/H249). When the needle punctured the vein, the blood was aspirated, and the needle was visualized on the screen with the tip within the lumen of the vein (**Supplemental Digital Content—Fig. 1*H***, http://links.lww.com/CCM/H249). Insertion of a guidewire and a catheter was not performed under direct visualization; however, the intravascular position of both the guidewire and the catheter was confirmed.

Postprocedure Imaging

Directly after finishing the procedure, the investigator performed a lung ultrasonography and a transthoracic echo in order to diagnose any early mechanical complications, and within 2 hours of the catheterization, chest radiography was necessary in anteroposterior view to localize the tip of the catheter and to diagnose any early mechanical complications. The localizations of the tip of the catheters were assessed by consultant radiologists.

Outcomes

The primary outcome of the trial was to compare the IJV group and AXV group through the venipuncture and catheterization success rates. A successful venipuncture was defined as the cannulation needle insertion into the lumen of the vein under real-time ultrasound imaging and visualization of the needle in the lumen of the cannulated vein. A successful catheterization was defined as the insertion of a catheter into the lumen of the cannulated vein with subsequent confirmation of IV position by ultrasound visualization and blood aspiration.

Secondary outcomes were the catheter tip malposition rate (misguided position of the tip of the cannula outside the junction of the right atrium with the distal part of superior vena cava); the early mechanical complication rates (artery puncture, pneumothorax, hemothorax, cardiac tamponade, perivascular hematoma); and cardiac arrhythmias incidents. Mechanical complications were diagnosed with lung ultrasonography, transthoracic echocardiography, chest radiography, and physical examination. Cardiac arrhythmias were detected with electrocardiographic monitoring.

Statistical Analysis

Assuming a difference between trial arms of 10% according to the primary outcome, and drop-out rate of up to 20%, a sample size of 600 patients was calculated as providing 90% power. The quantitative variables were characterized by the arithmetic mean, SD, median or maximum/minimum (range), and 95% CI. The categorical variables were presented with the use of count and percentage. In order to check whether quantitative variables were derived from a population of normal distribution, the W Shapiro-Wilk test was used. On the other hand, to prove the hypotheses regarding the homogeneity of variances, the Levene (Brown-Forsythe) test was used.

The statistical significance of differences between two groups (unpaired variables model) was processed with the *t* Student test (or Welch test in the case of lack of homogeneity) or Mann-Whitney *U* test (where conditions for the *t* Student test were not satisfied or for variables measured by ordinal scale). Chi-square tests for independence were used for categorical variables (with the use of Yates' correction for cell counts below 10 and using Cochrane's conditions or with Fisher exact test). In order to determine dependence, strength, and direction between variables, correlation analysis was used by determining the Pearson or Spearman correlation coefficients. In all calculations, a statistical significance level of *p* value equals to 0.05 was used. Statistica, Version 12 (StatSoft, Tulsa, OK), was used as the data analysis tool.

RESULTS

A total of 614 critically ill, mechanically ventilated patients requiring central venous cannulation were enrolled. The study flow chart is shown in **Figure 1**. Of the 614 randomized patients, 304 were assigned to the IJV group and 306 to the AXV group. Four patients died after randomization and before cannulation, and a total of 610 patients completed the study.

Supplemental Digital Content—Table 1 (http://links.lww.com/CCM/H249) presents the demographic characteristics of both study groups. There were no significant differences between groups with respect to sex, age, body mass index (BMI), variables of mechanical ventilation, indications for central venous catheterization, and cannulation settings (emergency vs planned). Acute respiratory failure, sudden cardiac arrest, and septic shock are common prerandomization diagnoses among the patients enrolled in this clinical trial.

The IJV puncture rate reached 100% (79.9% in the first attempt) and the AXV reached 99.7% (74.1% in the first attempt). No differences between groups were noted (chi-square, $p = 0.19$). The catheterization success rate in the IJV group was 98.7% and 96.7% in the AXV group. No differences between groups were noted (chi-square, $p = 0.11$).

The catheter tip malposition rate was 9.9% in the IJV group and 10.1% in the AXV group. No differences between groups were noted (chi-square, $p = 0.67$).

The early mechanical complication rate in the IJV group was 3% (common carotid artery puncture—4 cases, perivascular hematoma—2 cases, vertebral artery puncture—1 case, pneumothorax—1 case) and 2.6% in the AXV group (axillary artery puncture—4 cases, perivascular hematoma—4 cases). No differences between groups were noted (chi-square, $p = 0.79$). Ultrasound visualization variables and detailed trial outcomes are shown in **Table 1**.

There was no difference in the success and complication rates between consultants and residents. Consultants performed 495 cannulations with 97.98% success rate (75.5% in the first attempt). Residents performed 115 cannulations with 96.5% success rate (73.9% in the first attempt). The complication rate did not differ as consultants placed almost 4.5 times as many catheters as residents, which is about the same ratio as the complication rates.

The following relationships were not confirmed between: BMI and catheterization success rate (IJV group: Mann-Whitney *U*, $p = 0.22$; AXV group: Mann-Whitney *U*, $p = 0.24$), variables of mechanical ventilation and catheterization success rate (IJV group: Mann-Whitney *U*, Vt, $p = 0.77$, PIP, $p = 0.18$, positive end-expiratory pressure [PEEP], $p = 0.7$; AXV group: Mann-Whitney *U*, Vt, $p = 0.96$, PIP, $p = 0.76$, PEEP, $p = 0.69$), cannulation setting and catheterization success rate (IJV group: chi-square, $p = 0.58$; AXV group: chi-square, $p = 0.33$), cannulation side (left or right) and catheterization success rate (IJV group: chi-square, $p = 0.67$; AXV group: chi-square, $p = 0.19$), needle visibility and catheterization success rate (IJV group: chi-square, $p = 0.57$; AXV group: chi-square, $p = 0.71$), and tenting effect visibility and catheterization success rate (IJV group: chi-square, $p = 0.06$; AXV group: chi-square, $p = 0.55$).

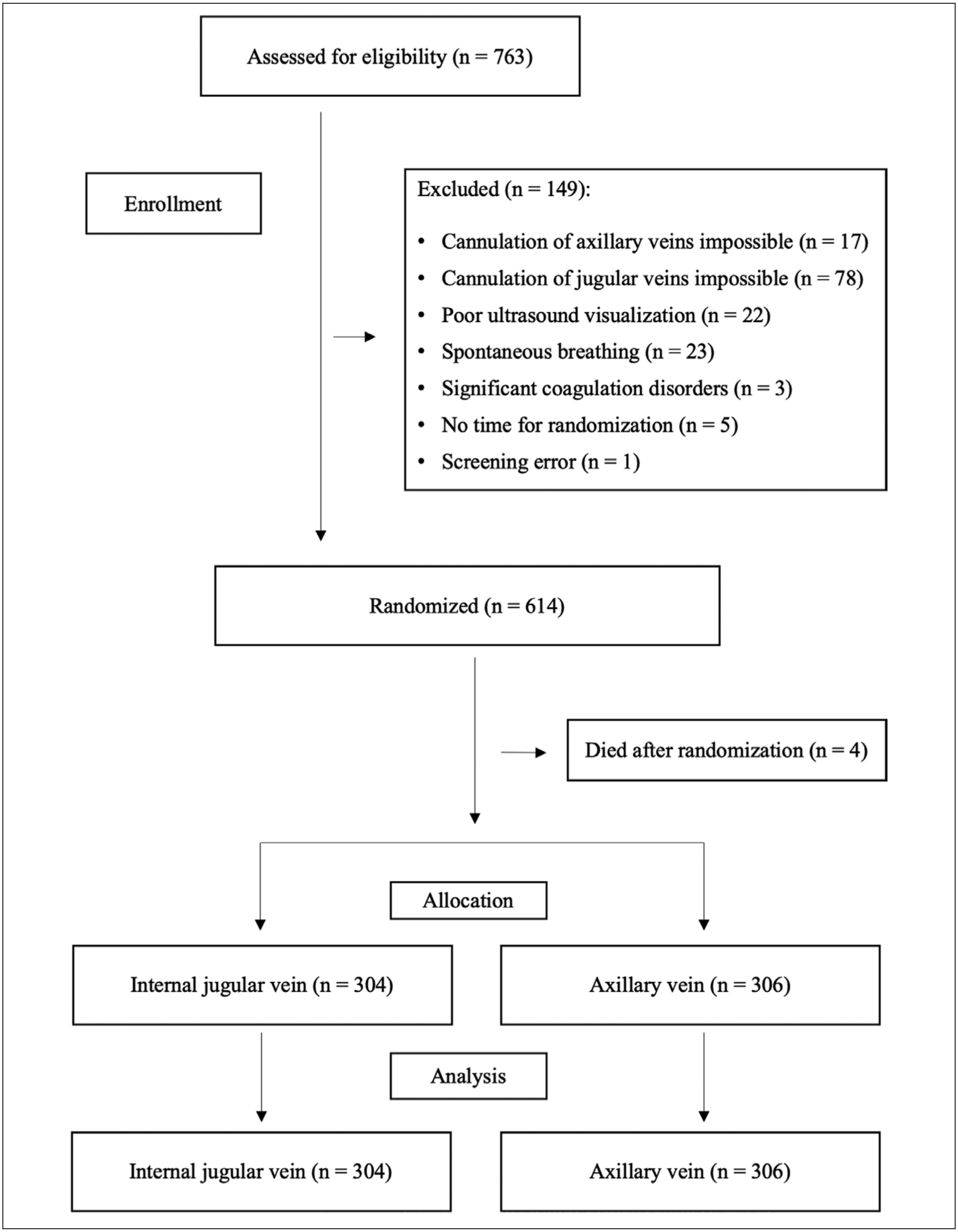

Figure 1. Study flow chart.

TABLE 1.
Ultrasound Visualization Variables and Trial Outcomes

Variables	Internal Jugular Vein Group ($N = 304$), n (%)	Axillary Vein Group ($N = 306$), n (%)	p
Needle visibility	282 (92.8)	302 (98.7)	0.0003
Tenting effect visibility	289 (95.1)	296 (98.7)	0.2993
Number of venipuncture attempts			0.1903
1	243 (79.9)	226 (74.1)	
2	48 (15.8)	54 (17.7)	
3	11 (3.6)	21 (6.9)	
4	2 (0.7)	4 (1.3)	
Catheterization success rate	300 (98.7)	296 (96.7)	0.1074
Guidewire visibility	297 (99)	292 (98.6)	0.6906
Cannula visibility	265 (88.3)	256 (86.5)	0.4967
Early mechanical complication rate	9 (3)	8 (2.6)	0.7951
Cannula tip positions			0.6735
Superior vena cava	269 (90.0)	265 (89.5)	
Right atrium	25 (8.4)	23 (7.8)	
Right internal jugular vein	2 (0.7)	4 (1.4)	
Right ventricle	1 (0.3)	0 (0.0)	
Left internal jugular vein	0 (0.0)	1 (0.3)	
Left brachiocephalic vein	1 (0.3)	1 (0.3)	
Right brachiocephalic vein	0 (0.0)	1 (0.3)	
Right subclavian vein	1 (0.3)	1 (0.3)	

DISCUSSION

In this clinical trial, no difference was found between IJV group and AXV group with regard to success rate variables and safety measures.

Several prospective observational or randomized controlled studies have proved the higher success rate of real-time ultrasound-guided techniques of central venous cannulation over landmark-based methods (14–21). However, there are still too few prospective randomized trials directly comparing different central venous approaches with the most commonly used jugular approach (12).

In a prospective, multicenter, randomized trial, Shin et al (22) assessed the complication rate and procedure-related complications of ultrasound-guided subclavian vein (SCV) versus jugular vein cannulation. The complication rate for both approaches was very low (0.7% for SCV and 0.1% for IJV; $p = 0.248$). The success rate on the first attempt was significantly higher in the IJV group compared with the SCV group (IJV 98.4%, SVC 95.9%; $p = 0.004$). However, all study procedures were planned and performed by experienced anesthesiologists. In our study, the complication rate was higher (IJV 3%, AXV 2.6%; $p = 0.795$) without separation between groups. Furthermore, the majority of the study procedures were performed at admission, under emergency conditions, and in hemodynamically compromised patients (patients receiving vasopressors).

In a prospective, single-center, randomized trial, Shinde et al (23) compared out-of-plane IJV with in-plane AXV approach in 97 spontaneously breathing anesthesia patients scheduled for cardiac surgery. The author reported high first pass success rates (98% IJV vs 95.8% AXV) with a low rate of potentially dangerous early mechanical complications and confirmed the efficacy of AXV cannulation in this specific group of patients. Unlike in our study, all procedures were planned and performed in spontaneously breathing patients, solely by experienced cardiac anesthesiologists.

There was no difference in the success and complication rates between consultants and residents in our study. As the learning curve of ultrasound-guided central venous cannulation is steep (authors' personal opinion), we established minimal requirements for investigators performing procedures, which consisted of minimal documented experience of 10 procedures of real-time ultrasound-guided internal jugular out-of-plane (transverse) catheterization and 10 procedures of real-time ultrasound-guided infraclavicular AXV in-plane (longitudinal) catheterizations. However, one scientific guideline recommends that each trainee should perform at least 30 successful procedures within 12 months (13).

An optimal insertion site of short term central venous catheters in relation to catheter-related blood stream infection (CRBSI) remains undetermined. Some data favor the subclavian approach over the IJV, whereas recent cumulative data show no differences in this regard (24–26). However, existing guidelines recommend using the infraclavicular approach to the SCV, rather than jugular or femoral approach in adult patients (27). The infraclavicular approach to the AXV could represent an alternative regarding the CRBSI risk reduction technique possibly through the anatomical location of the skin puncture site.

Several limitations to our clinical trial need to be considered. First, it was a two-center trial, and the participating centers had significant experience in ultrasound-guided central venous cannulation. The procedure success rate may be lower when cannulations are performed by physicians with less experience in critical care ultrasonography. Second, we did not record the differences in cannulation times between both techniques. However, successful completion of procedures within 30 minutes and total procedure times are performance indicators recommended by some experts in the field. Shorter time to successful cannulation may reduce infectious complications rate (13). Third, in line with recent evidence, the routine postprocedural chest radiography for positioning the tip of the central venous catheter is not an optimal procedure, and ultrasonography seems to be a more reliable screening tool (13, 28, 29). Fourth, the pulsatile blood flow from a cannulating needle is not a reliable diagnostic sign of an accidental artery puncture in hemodynamically compromised patients. A careful ultrasonographic examination of the position of the needle should be performed instead (authors' personal opinion). However, accidental artery puncture with subsequent hematoma formation precludes proper ultrasonic visualization in the vast majority of patients.

CONCLUSIONS

There were no differences between real-time ultrasound-guided internal jugular out-of-plane cannulation and real-time ultrasound-guided infraclavicular AXV in-plane cannulation techniques in critically ill, mechanically ventilated patients with regard to the procedure success rate and early mechanical complication rate.

1 Department of Anesthesiology and Intensive Care, Institute of Medical Sciences, University of Opole, Opole, Poland.

2 2nd Department of Anesthesiology and Critical Care, Medical University of Lublin, Lublin, Poland.

3 Department of Anesthesiology and Intensive Care, 4th Military Hospital, Wroclaw, Poland.

4 Department of Anesthesiology, Medical Center in Brzeg, Brzeg, Poland.

5 Department of Anesthesiology and Intensive Care, University Hospital in Opole, Opole, Poland.

6 Department of Anesthesiology and Critical Care, Pulmonary Hospital Zakopane, Zakopane, Poland.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (http://journals.lww.com/ccmjournal).

Drs. Czarnik and Gawda contributed to the conception and design of the trial and the analysis and interpretation of data. All authors contributed to the acquisition of data and provided final approval of the version submitted for publication. Dr. Czarnik contributed to draft of the article. Drs. Czuczwar, Borys, Chrzan, Filipiak, Maj, Marszalski, Miodonska, Molsa, Pietka, Piwoda, Piwowarczyk, Rogalska, Stachowicz, and Gawda provided critical revision of the article.

The authors have disclosed that they do not have any potential conflicts of interest.

The work was performed in Department of Anesthesiology and Intensive Care, Institute of Medical Sciences, University of Opole, Aleja Witosa 26, 45-401, Opole, Poland and 2nd Department of Anesthesiology and Critical Care, Medical University of Lublin, ul. Staszica 16, 20-081, Lublin, Poland.

For information regarding this article, E-mail: tczarnik@mac.com

REFERENCES

1. Bodenham A, Babu S, Bennett J, et al: Associacion of anaesthetists of Great Britain and Ireland, safe vascular access 2016. *Anaesthesia* 2016; 71:573–585

2. Frykholm P, Pikwer A, Hammarskjold F, et al: Clinical guidelines on central venous catheterization. *Acta Anaesthesiol Scand* 2014; 58:508–524
3. Frankel HL, Kirkpatrick AW, Elbarbary M, et al: Guidelines for the appropriate use of bedside general and cardiac ultrasonography in the evaluation of critically ill patients – Part I: General ultrasonography. *Crit Care Med* 2015; 43:2479–2502
4. Troianos CA, Hatman GS, Glas KE, et al: Guidelines for performing ultrasound-guided vascular cannulation: Recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. *J Am Soc Echocardiogr* 2011; 24:1291–1318
5. Practice Guidelines for Central Venous Access 2020: An updated report by the American Society of Anesthesiologists task force on central venous access. *Anesthesiology* 2020; 132:8–43
6. Lampeti M, Bodenham AR, Pittiruti M, et al: International evidence-based recommendations on ultrasound-guided vascular access. *Intensive Care Med* 2012; 38:1105–1117
7. Brass P, Hellmich M, Kolodziej L, et al: Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. *Cochrane Database Syst Rev* 2015; 1:CD006962
8. Gawda R, Czarnik T, Lysenko L: Infraclavicular access to the axillary vein – New possibilities for the catheterization of the central veins in the intensive care unit. *Anaesthesiol Intensive Ther* 2016; 48:360–366
9. Bodenham A: Ultrasound-guided vascular access. *Eur J Anaesthesiol* 2020; 37:341–343
10. Simpson BD, Bodenham A: Central venous access by the subclavian vein – What is best practice? *Anaesthesia* 2022; 77:12–15
11. Bodenham A, Lamperti M: Ultrasound guided infraclavicular axillary vein cannulation, coming of age. *Br J Anaesth* 2016; 116:325–327
12. Brass P, Hellmich M, Kolodziej L, et al: Ultrasound guidance versus anatomical landmarks for subclavian or femoral vein catheterization. *Cochrane Database Syst Rev* 2015; 1:CD011447
13. Lamperti M, Biasucci DG, Disma N, et al: European society of anaesthesiology guidelines on peri-operative use of ultrasound-guided for vascular access (PERSEUS vascular access). *Eur J Anaesthesiol* 2020; 37:344–376
14. Czarnik T, Gawda R, Nowotarski J: Real-time, ultrasound-guided infraclavicular axillary vein cannulation for renal replacement therapy in the critical care unit – A prospective intervention study. *J Crit Care* 2015; 30:624–628
15. O'Leary R, Ahmed SM, McLure H, et al: Ultrasound-guided infraclavicular axillary vein cannulation: A useful alternative to the internal jugular vein. *Br J Anaesth* 2012; 109:762–768
16. Gawda R, Czarnik T, Weron R, et al: A new infraclavicular landmark-based approach to the axillary vein as an alternative method of central venous cannulation. *J Vasc Access* 2016; 17:273–278
17. Glen H, Lang I, Christie L: Infraclavicular axillary vein cannulation using ultrasound in a mechanically ventilated general intensive care population. *Anaesth Intensive Care* 2015; 43:635–640
18. Czarnik T, Gawda R, Nowotarski J: Real-time, ultrasound-guided infraclavicular axillary vein cannulation: A prospective study in mechanically ventilated critically ill patients. *J Crit Care* 2016; 33:32–37
19. Timsit JF, Rupp M, Bouza E, et al: A state of the art review on optimal practices to prevent, recognize, and manage complications associated with intravascular devices in the critically ill. *Intensive Care Med* 2018; 44:742–759
20. Saugel B, Scheeren TWL, Teboul JL: Ultrasound-guided central venous catheter placement: A structured review and recommendations for clinical practice. *Crit Care* 2017; 21:225
21. Schmidt GA, Blaivas M, Conrad SA, et al: Ultrasound-guided vascular access in critical illness. *Intensive Care Med* 2019; 45:434–446
22. Shin HJ, Na HS, Koh WU, et al: Complications in internal jugular vs subclavian ultrasound-guided central venous catheterization: A comparative randomized trial. *Intensive Care Med* 2019; 45:968–976
23. Shinde PD, Jasapara A, Bansode K, et al: A comparative study of safety and efficacy of ultrasound-guided infra-clavicular axillary vein cannulation versus ultrasound-guided internal jugular vein cannulation in adult cardiac surgical patients. *An Card Anaesth* 2019; 22:177–186
24. Arvaniti KA, Lathyris D, Blot S, et al: Cumulative evidence of randomized controlled and observational studies on catheter-related infection risk of central venous catheter insertion site in ICU patients: A pairwise and network meta-analysis. *Crit Care Med* 2017; 45:e437–e448
25. Parienti JJ, Mongardon N, Megarbane B, et al; 3SITES Study Group: Intravascular complications of central venous catheterization by insertion site. *N Engl J Med* 2015; 373:1220–1229
26. Lutwick L, Al-Maani AS, Mehtar S, et al: Managing and preventing vascular catheter infections: A position paper of the international society for infectious diseases. *Int J Infect Dis* 2019; 84:22–29
27. Timsit JF, Baleine J, Bernard L, et al: Expert consensus-based clinical practice guidelines management of intravascular catheters in the intensive care unit. *An Intensive Care* 2020; 10:118
28. Chui J, Saeed R, Jakobowski L, et al: Is routine chest x-ray after ultrasound-guided central venous catheter insertion choosing wisely?: A population-based retrospective study of 6875 patients. *Chest* 2018; 154:148–156
29. Ablordeppey EA, Drewry AM, Beyer AB, et al: Diagnostic accuracy of central venous catheter confirmation by bedside ultrasound versus chest radiography in critically ill patients: A systematic review and meta-analysis. *Crit Care Med* 2017; 45:715–724