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Real-time ultrasound-guided infraclavicular axillary vein cannulation: A prospective study in mechanically ventilated critically ill patients☆,☆☆,★,★★

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ABSTRACT

Purpose: The main purpose of this study was to define the venipuncture and catheterization success rates and early mechanical complication rates of ultrasound-guided infraclavicular axillary vein cannulation.
Materials and methods: We performed in-plane, real-time, ultrasound-guided infraclavicular axillary vein catheterizations under emergency and nonemergency conditions in mechanically ventilated, critically ill patients.
Results: We performed 202 cannulation attempts. One hundred and twenty-six procedures (62.4%) were performed under emergency conditions. The puncture of the axillary vein was successful in 98.5% of patients, and the entire procedure success rate was 95.1% (95% confidence interval, 91.1%-97.6%). For the majority of patients (84.1%; $P < .001$, exact test), the venipuncture occurred during the first attempt. We noted a 22.4% overall complication rate, and most of the complications were malpositions (13.4%). We observed 8.5% of cases with potentially serious complications (puncture of the axillary artery and needle contact with the brachial plexus) and 1 case (0.5%) of pneumothorax. The puncture of the axillary artery occurred in 5 (2.5%) patients.
Conclusions: In-plane, real-time, ultrasound-guided, infraclavicular axillary vein cannulation in mechanically ventilated, critically ill patients is a safe and reliable method of central venous cannulation and can be considered to be a reasonable alternative to other central venous catheterization techniques.

1. Introduction

Ultrasound-guided central venous catheterization has established a role as the standard procedure in many intensive care units worldwide [1–4]. It increases the venipuncture and cannulation success rates and significantly decreases complication rates [5–9]. Real-time ultrasound guidance is superior to static imaging (indirect guidance) with subsequent blind cannulation [1,4,7–9].

The infraclavicular landmark-based method of the axillary vein cannulation was first described by Nickalls [10] in 1987 and by Taylor and Yellowless [11] in 1990. It never gained popularity because of the relative complexity of the technique. In the era of ultrasound-guided central venous cannulation, the infraclavicular approach to the axillary vein was rediscovered [12–17]. Surprisingly, recently published results of the observational study demonstrated that despite a strong level of evidence and recommendations favoring the use of ultrasound guidance during central line placement and equipment availability in European critical care units, only 50% of central venous catheterizations were performed under ultrasound guidance [18]. We hypothesized that in-plane, real-time, ultrasound-guided infraclavicular axillary vein cannulation in mechanically ventilated, critically ill patients can be an alternative to the ultrasound-guided internal jugular vein catheterization and could broaden the spectrum of possibilities in the field of central venous cannulation in this particular group of patients.

The main objective of this study was to define the venipuncture and catheterization success rates and early mechanical complication rates of in-plane, real-time, ultrasound-guided infraclavicular axillary vein cannulation performed under emergency and nonemergency conditions in mechanically ventilated, critically ill patients. A secondary objective was to determine the relationships between the following variables: a successful cannulation attempt, more than 1 venipuncture attempt, puncture of the axillary vein, depth of the axillary vein, width of the axillary vein, body mass index (BMI), cannulation side, and the needle's visibility.

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★ Conflicts of interest: none.

★★ Author contributions: TC designed the trial, supervised the conduct of the trial and data collection, drafted the manuscript, and takes responsibility for the paper as a whole. TC and RG undertook recruitment of participants and managed the data, including quality control. JN provided statistical advice on study design and analyzed the data. TC, RG, and JN contributed substantially to the final version of the manuscript.

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2. Materials and methods

This was a prospective study conducted from August 2013 to March 2015 in a single, 11-bed, medical/surgical intensive care unit. Written informed consent was obtained from the patients' relatives. The study was approved by Regional Ethics Committee in Opole, Poland (protocol no.: 194/2012; date of approval: 15/11/2012), registered before the recruitment of participants (clinicaltrials.gov NCT01919528), and carried out according to the principles of the Declaration of Helsinki.

Mechanically ventilated patients admitted to the critical care unit with clinical indications for placement of the central venous line were included. Clinical indications for central venous catheter insertion were the following: the administration of catecholamines, lack of peripheral intravenous access, hemodynamic monitoring, continuous renal replacement therapy, and parenteral nutrition. The exclusion criteria were the following: trauma and hematoma at the catheterization site, a history of multiple ipsilateral subclavian or axillary central venous catheterizations (3 or more), chest wall deformities, major blood coagulation disorders coinciding with active bleeding, history of thoracic surgery, anatomical abnormalities at the cannulation site, skin infection at the cannulation site, age younger than 18 years, and lack of consent from relatives.

Before the procedure, the patient was placed in a neutral supine position with his or her head laying in the neutral position and arms kept to the sides. Initially, the ultrasound prescan of the infraclavicular fossa for visualizing the anatomy was performed using a MyLabOne ultrasonographic machine with a 10 MHz 40 mm linear probe (The Esaote Group, Genoa, Italy), and 3 crucial anatomical structures were identified in longitudinal view: the axillary artery, axillary vein, and pleural line. The optimal position of the probe was as close as possible to the clavicle, and the aim was to puncture a distal part of the axillary vein near the junction with the subclavian vein, which is placed at the lateral border of the first rib. The least possible pressure was applied on the probe to avoid compressing the vessels. After obtaining optimal visualization of the axillary vein in the longitudinal view, assessment of the patency of the vein with a compression test and color Doppler and freezing of the screen were performed in addition to measurement of the depth and diameter of the vein. The skin was prepared with alcoholic 2% chlorhexidine, and ultrasonographic gel was applied on the transducer. The patient's body and the probe with a cord were covered with sterile sheets. After applying a sterile gel on the skin, an optimal longitudinal view of the vein was obtained. The operator held the probe in the nondominant hand and a syringe with an attached needle in the dominant hand and then punctured the axillary vein under direct visualization. The skin puncture site was as close as possible to the distal short side of the probe. The orientation of the cannulation needle was in-plane (the needle insertion in a plane with the ultrasound beam), and the axillary vein was imaged longitudinally. No assistance was needed to hold the transducer. The proper puncture of the vein was dependent on 3 crucial aspects, including good visualization of the axillary vein, good visualization of the tip of the needle, and the “tenting effect,” which involves bending the anterior wall of the vein under the pressure generated by the needle touching this wall. Because of the collapsibility of the vein walls, a quick, sharp, but cautious movement of the needle toward the lumen of the vein was sometimes necessary to perforate it. The confirmation of the intravascular position of the needle was facilitated when the bevel of the needle was observed as a white dot within the lumen of the axillary vein and was brighter than the needle shaft (Fig. 1). Insertion of a guidewire and a catheter was not performed under direct visualization, but the intravascular position of both the guidewire and the catheter was confirmed and documented (Fig. 1). We defined the procedure as an emergency when the central line placement was urgently needed. Every other clinical condition during the procedure was treated as a nonemergency, and the catheterization was classified as planned. The 8F, 20-cm, double-lumen central venous catheter (Arrow International, Inc, Reading, PA) or 12F, 20-cm, double-lumen dialysis catheter (Biometrix LTD, Jerusalem, Israel) insertion was performed using a standard Seldinger technique, and the length of the catheter insertion was 20 cm on both sides. Pictures of the important stages of the procedure were recorded and stored in the ultrasonographic machine by an assistant nurse. In addition, immediately after the procedure, all demographic data (date, name, hospital documentation number, sex, age, weight, height, and mode of cannulation [emergency or planned]), parameters of mechanical ventilation (tidal volume, peak inspiratory pressure, and positive end-expiratory pressure), technical aspects (cannulation side, tenting, needle visibility, and venipuncture attempts [by means of skin punctures]), measurements (diameter, depth of the location of the axillary vein and the catheter tip's position on chest radiography), and early mechanical complications (catheter malposition, puncture of the axillary artery, pneumothorax, needle contact with the brachial plexus, cardiac tamponade, bleeding into the pleural cavity, significant dysrhythmias, and phrenic nerve injury) were collected and recorded on the designated paper form and stored. The puncture of the axillary vein was additionally confirmed with the absence of a forceful pulsatile blood flow from the needle after syringe disconnection. Chest radiographs were obtained after the procedure to verify the position of the catheter tip and exclude some of the early complications. After the recruitment process, patient data were extracted from the paper forms, patient identification was blinded, and the data were transferred to the electronic database to prepare them for statistical analysis [19].

We summarized patients' descriptive statistics, including the mean, median, interquartile range (25th-75th percentile), and ranges. We computed 95% confidence intervals (CIs) for the probability of success using the exact (Clopper-Pearson) method. To measure the dependence between discrete variables, contingency tables are used, along with maximum likelihood (M-L) χ^2 tests. We also used the Mann-Whitney U test to determine the relationship between groups of variables: successful cannulation attempt, more than 1 venipuncture attempt (as a binary variable), puncture of the axillary vein vs depth of the axillary vein, width of the axillary vein, and BMI. A P value of less than .05 was considered statistically significant. Statistica, version 12 (StatSoft, Inc, Tulsa, OK) was used as a data analysis tool.

3. Results

A total of 202 mechanically ventilated patients were enrolled in the trial (71 women [35.1%] and 131 men [64.9%]). The study included a preliminary portion conducted with a selected, homogenous group of acute kidney injury patients treated with continuous renal replacement therapy, which comprised 29 patients, and among them, the cannulation success rate was 93.2% [19]. Power analysis was performed after treating these 29 patients. It revealed that with the same success rate and with a 1-tail alternative hypothesis, 91 and 124 patients were required to achieve the desired powers of 80% and 90%, respectively. The final number of patients is greater because of the study's time frames.

We performed 131 (64.9%) right-side and 71 (35.1%) left-side cannulation attempts. One hundred and twenty-six procedures (62.4%) were performed under emergency conditions. Patient characteristics and measurements are shown in Table 1; diagnosis on admission and indications for central venous cannulation are shown in Table 2.

The puncture of the axillary vein was successful in 98.5% of patients. In 1 morbidly obese patient (BMI = 44), it was impossible to visualize the axillary vein. In 1 patient, the puncture of the axillary vein and, in 2 patients, the puncture of the axillary artery resulted in hematoma formation and the worsening of visualization, and the procedure was stopped immediately.

The procedure success rate was 95.1% (95% CI, 91.1-97.6%; Table 3). In 6 cases, it was impossible to insert the guidewire, and in 1 case, it was impossible to insert the hemodialysis catheter because of its bending in the subcutaneous tissue. The cannulation was performed by 2 initially inexperienced in ultrasound-guided central venous catheterization physicians (5 axillary and 5 internal jugular real-time ultrasound-