Utility of Ultrasound Guidance for Central Venous Access in Children

Chen He, MD, Rebecca Vieira, MD, RDMS,† and Jennifer R. Marin, MD, MSc‡*

Background: Placement of a central venous catheter (CVC) in a pediatric patient is an important skill for pediatric emergency medicine physicians but can be challenging and time consuming. Ultrasound (US) guidance has been shown to improve success of central line placement in adult patients.

Objectives: This article aims to review the literature and evaluate the benefit of US guidance in the placement of CVCs, specifically in pediatric emergency department patients, and to review the procedure.

Results: Four meta-analyses of US-guided CVC placement in adult patients concluded that US guidance reduces placement failure, decreases complications, and decreases the need for multiple attempts. Two studies in the emergency department setting support these conclusions. Pediatric-specific data related to US-guided CVC placement include data suggesting a benefit with US guidance, as well as data indicating no difference in outcome measures when US guidance is used compared with the landmark technique.

Conclusions: The evidence surrounding US-guided CVC insertion supports its use in adult patients. Pediatric-specific literature is sparse and includes mixed results. As more pediatric emergency physicians adopt the use of point-of-care US, we expect an increase in data supporting its use for CVC placement in pediatric emergency department patients.

Key Words: central venous access, intravenous, ultrasound

(*Pediatr Emer Care* 2017;33: 359–364)

TARGET AUDIENCE

This CME activity is intended for providers who care for pediatric patients who may require central venous access. Physicians and allied health professionals working in emergency departments, pediatric emergency departments, operating rooms, perioperative care units, and pediatric intensive care units will find this article helpful.

LEARNING OBJECTIVES

After completion of this article, the reader should be able to:

1. Summarize the evidence for using ultrasound guidance in the placement of central venous catheters in adult and pediatric patients.
2. Explain the procedure for ultrasound-guided central venous catheter insertion in pediatric patients.

*Associate Program Director and Assistant Professor (He), Department of Emergency Medicine, Mount Sinai St. Luke's/Mount Sinai West Hospitals, Icahn School of Medicine at Mount Sinai, New York, NY, †Staff Physician and Assistant Professor (Vieira), Division of Emergency Medicine, Boston Children's Hospital; and Departments of Pediatrics and Emergency Medicine, Harvard Medical School, Boston, MA; and ‡Associate Professor (Marin), Departments of Pediatrics and Emergency Medicine, University of Pittsburgh School of Medicine, Pittsburgh, PA.

The authors, faculty, and staff in a position to control the content of this CME activity and their spouses/life partners (if any) have disclosed that they have no financial relationships with, or financial interest in, any commercial organizations pertaining to this educational activity.

Reprints: Chen He, MD, Department of Emergency Medicine, Mount Sinai Health System, 1000 Tenth Avenue, New York, NY 10019 (e-mail: chen.he@mountsinai.org).

ISSN: 0749-5161

Pediatric resuscitation in the emergency department is contingent upon gaining rapid and sufficient intravenous access in order to administer lifesaving fluids and medications. Compared with adult patients, peripheral venous access is more challenging to obtain even in stable pediatric patients, because of their smaller veins and increased amount of subcutaneous fat.[1] In emergent situations, patients' hemodynamic instability and cardiopulmonary compromise may further complicate an already difficult procedure. When initial attempts at obtaining peripheral intravenous access are unsuccessful, the next step is generally to place an intraosseous (IO) line. However, there are situations when IO placement is unsuccessful or more definitive access is needed, and it is necessary to obtain central venous access. In 2001, the Agency for Healthcare Research and Quality recommended the use of ultrasound (US) for the placement of central venous catheters (CVCs) as 1 of their 11 practices to improve patient care.[2] Other agencies, such as the American Society of Anesthesiologists, make the same recommendation.[3] In 2010, an expert panel met at the World Conference on Vascular Access. They recommended the use of US guidance in the placement of CVCs and proposed the creation of a US curriculum on vascular access.[4] Ultrasound guidance is recommended as the preferred method for insertion of catheters into the internal jugular vein in adult patients and in children in elective situations.[5] Its benefit in children in the emergency department and in resuscitative scenarios is less clear.[6]

STUDIES IN ADULT PATIENTS

A 1996 meta-analysis reviewed 8 randomized controlled trials evaluating the effect of real-time US guidance for internal jugular and subclavian vein cannulations.[7] The authors concluded that compared with standard techniques the use of US guidance reduced placement failure in both locations (relative risk [RR], 0.32; 95% confidence interval [CI], 0.18–0.55), decreased complications (RR, 0.22; 95% CI, 0.10–0.45), and decreased the need for multiple attempts (RR, 0.60; 95% CI, 0.45–0.79). Hind et al[8] published in 2003 a meta-analysis of 18 randomized clinical trials involving US guidance for central venous access. They concluded that there is evidence to support the use of US guidance to place CVCs in internal jugular veins in adults, with lower failure rates overall (RR, 0.14; 95% CI, 0.06–0.33) and with the first attempt (RR, 0.59; 95% CI, 0.39–0.88).

In 2002, Keenan[9] evaluated 17 randomized controlled trials and 1 quasi-randomized trial comparing the relative effectiveness and morbidity of the 2 insertion techniques. Pooled results showed a significant reduction in failure (risk difference [RD], −0.12; 95% CI, −0.18 to −0.06), number of attempts (risk reduction, 0.81; 95% CI, 0.64–0.97), and arterial puncture rate (RD, −0.07; 95% CI, −0.10 to −0.03). The number of successful venous cannulations on first attempt was higher using US (RD, 0.24; 95% CI, 0.08–0.39), and no difference was found in time to insertion. Subgroup analyses suggested that US improved outcomes most convincingly for cannulations of internal jugular veins and by less experienced clinicians. A 2013 meta-analysis[10] examined 26 studies comparing the 2 techniques. Compared with the landmark

technique, adult patients with real-time 2-dimensional US had decreased risk of cannulation failure (RR, 0.18; 95% CI, 0.10–0.32), arterial puncture (RR, 0.25; 95% CI, 0.15–0.42), hematoma (RR, 0.30; 95% CI, 0.19–0.46), pneumothorax (RR, 0.21; 95% CI, 0.06–0.73), and hemothorax (RR, 0.10; 95% CI, 0.02–0.54).

The superiority of US-guided placement of CVCs compared with landmark-guided placement is not as well studied in the emergency department setting. One study[11] from 2006 of 130 patients evaluated the use of US guidance for internal jugular central line placement. In this study, successful placement was more likely with the US-guided (93.9%) compared with landmark (78.5%) techniques (difference, 15.4%; 95% CI, 3.8%–27.0%). Complication rates were also significantly lower in the US group (4.6%) versus the landmark (16.9%) group (difference, 12.3%; 95% CI, 1.9%–22.8%). A study by Miller et al[12] compared real-time US insertion with the landmark technique. The conclusion was that in various vessels with operators of different experience levels time from skin puncture to blood flash was reduced (mean, 8.5 [SD, 11.6]minutes vs 1.9 [SD, 3.1]minutes; $P < 0.0001$), and there were fewer mean number of attempts in the US group (mean, 1.6 [SD, 1.0]) compared with the landmark group (mean, 3.5 [SD, 2.7]; $P < 0.0001$).

STUDIES IN PEDIATRIC PATIENTS

There is a paucity of pediatric-specific data related to US-guided CVC placement, and most of the literature is limited to infants undergoing cardiac surgery. The meta-analyses by Hind et al[8] and Keenan[9] included 3 infant studies.[13–15] One study was a randomized controlled trial of 40 patients younger than 2 years who underwent percutaneous insertion of an internal jugular cannula during cardiac surgery.[13] Compared with cannulation by anatomic landmarks, cannulation guided by US resulted in less time to locate the vein ($P = 0.01$), fewer needle insertions ($P = 0.02$), and fewer complications ($P < 0.05$). Another study randomized 95 infants scheduled for cardiac surgery and undergoing internal jugular vein cannulation to either CVC placement using the landmark technique or US-assisted CVC placement.[14] The success rate was 100% in the US group, with no carotid artery punctures, and 77% in the landmarks group, with a 25% incidence of carotid artery punctures. Both differences were significant ($P > 0.0004$). The same investigators[15] studied 45 infants undergoing cardiopulmonary bypass, finding that time to cannulation, success rate, and incidence of carotid artery puncture were not significantly different between the landmark method and US imaging groups. However, the median number of attempts was greater using the landmark technique compared with US-guided cannulation (2 vs 1, $P < 0.05$). Hind et al[8] concluded that there was a lower risk of failure with US compared with the landmark technique for internal jugular vein cannulations (RR, 0.15; 95% CI, 0.03–0.64), as well as a lower risk of complications (RR, 0.27; 95% CI, 0.08–0.91). By comparison, 124 infants and children undergoing cardiac surgery were randomized to either US-guided or landmark-guided CVC placement in a 2004 study. It showed that success rates were significantly greater in the landmark group compared with the US group (89.3% vs 78%, $P < 0.01$), and arterial puncture rates were significantly lower in the landmark group (6.2% vs 11.9%, $P < 0.03$).[6] There was no significant difference in time to catheterization. A 2009 meta-analysis,[16] including the 3 studied described previously,[13–15] concluded that in comparison to the landmark technique US guidance did not have a significant effect on internal jugular venous access failure, carotid artery puncture, hematoma, hemothorax, pneumothorax, or time to internal jugular vein access.

In 2009, Froehlich et al[17] compared 93 CVC placement attempts using the landmark technique to 119 US-guided CVC placement attempts in pediatric intensive care unit patients. This study found that US-guided CVC placement in children was associated with fewer number of attempts to gain placement (1 vs 3, $P < 0.001$), fewer attempts at more than 1 anatomical site (5.9% vs 20.7%, $P = 0.001$), and fewer inadvertent artery punctures (8.5% vs 19.4%, $P = 0.03$) compared with the landmark technique. Ultrasound guidance did not improve success rates. More recently, Gallagher et al[18] retrospectively compared femoral and internal jugular CVC placement attempts with and without US assistance in a pediatric emergency department. They found that the proportion of successful placement attempts was significantly higher when using US assistance compared with those attempted with the landmark technique, (98% vs 79%; odds ratio, 13.1; 95% CI, 2.9–59.4). Complication rates were similar in both groups.

US GUIDANCE FOR CENTRAL VENOUS CANNULATION: A REVIEW OF THE PROCEDURE

There are 2 approaches to the insertion of CVCs: the traditional landmark approach and the US-guided approach. The traditional landmark approach, where the provider uses known anatomic landmarks to guide needle insertion, has long been used in emergent situations, when time to insertion is critical. The US-guided approach is recommended as the preferred method for insertion of catheters into the internal jugular vein in adult patients and in children in elective situations.[5] There are several considerations for implementing this technique.

Site Selection

In pediatric patients in the emergency department, the femoral vein has traditionally been the preferred site for CVC placement for pediatric resuscitations.[19] The femoral site is easy to access, especially if there are airway or cervical spine stabilization considerations, and is associated with high success rates.[20] By comparison, in a survey of pediatric surgeons,[21] most respondents indicated their preference to place CVCs in the subclavian or internal jugular veins over the femoral vein. Froehlich et al[17] and Vieira et al[22] have shown that the use of the internal jugular site for CVC placement in pediatric patients increased with the use of US guidance.

Site Identification: B-Mode or Real-Time Method Versus Continuous Doppler Method

There are 2 main methods to identify the vessels in US-guided central venous cannulation: B-mode/real-time and continuous Doppler. B-mode US converts reflected sound waves into a real-time gray-scale image.[23] Fluid is anechoic, appearing dark on the screen, whereas tissue is more isoechoic and appears gray. The vein can be differentiated from the nearby artery in that the vein is more compressible, nonpulsatile or less pulsatile than the accompanying artery, and distensible in the case of the internal jugular vein by the Valsalva maneuver or the Trendelenburg position. If time allows, both sides of the patient should be interrogated, as 1 side may have more favorable anatomy.[24]

Doppler US transforms the sound waves reflected from a moving object (ie, blood flow) into an amplified audio signal. The venous waveform is distinctly different from arterial pulsations.[24] The continuous Doppler method is rarely used alone but can be helpful in identifying actual blood flow in vessels, confirming vascular structures and differentiating vein and artery. It is most useful in identifying artery versus vein prior to the procedure. The data behind using Doppler for vascular access are

associated with a longer learning curve than B-mode US and a longer overall average time necessary to achieve cannulation.[25]

Procedure: Static Technique Versus Dynamic Technique

The 2 commonly used methods for US-guided CVC placement are the static technique and the dynamic technique. In the static technique, the vein is identified with US and marked prior to sterile preparation of the site. Ultrasound is not used during needle insertion.[26] In the dynamic technique, cannulation of the target vein is performed with direct visualization of the needle entering the vein under US visualization.

Cannulation can be performed using either a transverse (short axis) or longitudinal (long axis) approach, although the transverse approach is used more frequently because of the easier visibility of small vessels and shorter learning curve.[27] Although blood present in the syringe with aspiration suggests needle entry into the vessel, CVC placement is confirmed with direct US visualization of the wire or catheter in the vein.

Ultrasound guidance with the dynamic technique can be performed with either the "1-person" or "2-person" method. In the 1-person method, the operator can perform the procedure by himself/herself, controlling the US probe with the nondominant hand and the needle with the dominant hand. The 2-person technique requires an assistant (also with full-barrier sterile precautions) to hold the probe, while the operator controls the needle and performs the procedure.

EDUCATION

Vieira et al[22] described the development of an emergency US program in a pediatric emergency department and its association with a significant increase in the use of US for CVC placement. Werner et al[28] showed that the use of a simulation-based educational intervention resulted in improved pediatric emergency medicine physician competency in US-guided CVC placement, the effect of which was maintained over time. Other such programs and studies may lead to the proliferation of US guidance as the standard of care in obtaining central vascular access in pediatric patients. Further research may be done in this area, specifically evaluating teaching modalities and quality assurance programs involving pediatric emergency medicine programs.

SUMMARY

The evidence surrounding US-guided CVC insertion supports its use in adult patients. Multiple meta-analyses have shown that compared with the landmark technique the use of US guidance improves overall success, as well as success on the first attempt, and decreases complications. Pediatric-specific literature is sparse, mainly confined to the anesthesia literature, and includes mixed results. It should be noted that much of this early work regarding US-guided CVC placement in children was done in infants requiring internal jugular vein placement during cardiac surgery. Therefore, the results of these studies may not be generalizable to the pediatric ED setting.

Evidence does continue to mount, and as more pediatric emergency physicians adopt use of point-of-care US, it is likely there will be more data evaluating US guidance for CVC placement in pediatric emergency department patients.

REFERENCES

1. Greene N, Bhananker S, Ramaiah R. Vascular access, fluid resuscitation, and blood transfusion in pediatric trauma. *Int J Crit Illn Inj Sci*. 2012;2:135–142.
2. Shojania KG, Duncan BW, McDonald KM, et al., eds. Making health care safer: a critical analysis of patient safety practices. Evidence Report/Technology Assessment No. 43 from Agency for Healthcare Research and Quality: AHRQ Publication No. 01-E058; July 2001.
3. Rupp SM, Apfelbaum JL, Blitt C, et al. Practice guidelines for central venous access: a report by the American Society of Anesthesiologists Task Force on Central Venous Access. *Anesthesiology*. 2012;116:539–573.
4. Lamperti M, Bodenham AR, Pittiruti M, et al. International evidence-based recommendations on ultrasound-guided vascular access. *Intensive Care Med*. 2012;38:1105–1117.
5. National Institute for Clinical Excellence (NICE). *Guidance on the use of ultrasound locating devices for placing central venous catheters*. Technology appraisal guidance No. 49. September 2002.
6. Grebenik CR, Boyce A, Sinclair ME, et al. NICE guidelines for central venous catheterization in children. Is the evidence base sufficient? *Br J Anaesth*. 2004;92:827–830.
7. Randolph AG, Cook DJ, Gonzales CA, et al. Ultrasound guidance for placement of central venous catheters: a meta-analysis of the literature. *Crit Care Med*. 1996;24:2053–2058.
8. Hind D, Calvert N, McWilliams R, et al. Ultrasonic locating devices for central venous cannulation: meta-analysis. *BMJ*. 2003;327:361–367.
9. Keenan SP. Use of ultrasound to place central lines. *J Crit Care*. 2002;17:126–137.
10. Wu SY, Ling Q, Cao LH, et al. Real-time two-dimensional ultrasound guidance for central venous cannulation: a meta-analysis. *Anesthesiology*. 2013;118:361–375.
11. Leung J, Duffy M, Finckh A. Real-time ultrasonographically-guided internal jugular vein catheterization in the emergency department increases success rates and reduces complications: a randomized, prospective study. *Ann Emerg Med*. 2006;48:540–547.
12. Miller AH, Roth BA, Mills TJ, et al. Ultrasound guidance versus the landmark technique for the placement of central venous catheters in the emergency department. *Acad Emerg Med*. 2002;9:800–805.
13. Alderson PJ, Burrows FA, Stemp LI, et al. Use of ultrasound to evaluate internal jugular vein anatomy and to facilitate central venous cannulation in paediatric patients. *Br J Anaesth*. 1993;70:145–148.
14. Verghese ST, McGill WA, Patel RI, et al. Ultrasound-guided internal jugular venous cannulation in infants: a prospective comparison with the traditional palpation method. *Anesthesiology*. 1999;91:71–77.
15. Verghese ST, McGill WA, Patel RI, et al. Comparison of three techniques for internal jugular vein cannulation in infants. *Paediatr Anaesth*. 2000;10:505–511.
16. Sigaut S, Skhiri A, Stany I, et al. Ultrasound guided internal jugular vein access in children and infant: a meta-analysis of published studies. *Paediatr Anaesth*. 2009;19:1199–1206.
17. Froehlich CD, Rigby MR, Rosenberg ES, et al. Ultrasound-guided central venous catheter placement decreases complications and decreases placement attempts compared with the landmark technique in patients in a pediatric intensive care unit. *Crit Care Med*. 2009;37:1090–1096.
18. Gallagher RA, Levy J, Vieira RL, et al. Ultrasound assistance for central venous catheter placement in a pediatric emergency department improves placement success rates. *Acad Emerg Med*. 2014;21:981–986.
19. Chiang VW, Baskin MN. Uses and complications of central venous catheters inserted in a pediatric emergency department. *Pediatr Emerg Care*. 2000;16:230–232.
20. Venkataraman ST, Thompson AE, Orr RA. Femoral vascular catheterization in critically ill infants and children. *Clin Pediatr (Phila)*. 1997;36:311–319.

21. Dassinger MS, Renaud EJ, Goldin A, et al. Use of real-time ultrasound during central venous catheter placement: results of an APSA survey. *J Pediatr Surg*. 2015;50:1162–1167.
22. Vieira RL, Gallagher RA, Stack AM, et al. Development and evaluation of a program for the use of ultrasound for central venous catheter placement in a pediatric emergency department. *Pediatr Emerg Care*. 2013;29: 1245–1248.
23. Feller-Kopman D. Ultrasound-guided internal jugular access: a proposed standardized approach and implications for training and practice. *Chest*. 2007;132:302–309.
24. Warkentine FH, Clyde Pierce M, Lorenz D, et al. The anatomic relationship of femoral vein to femoral artery in euvolemic pediatric patients by ultrasonography: implications for pediatric femoral central venous access. *Acad Emerg Med*. 2008;15:426–430.
25. Gilbert TB, Seneff MG, Becker RB. Facilitation of internal jugular venous cannulation using an audio-guided Doppler ultrasound vascular access device: results from a prospective, dual-center, randomized, crossover clinical study. *Crit Care Med*. 1995;23: 60–65.
26. Dodge KL, Lynch CA, Moore CL, et al. Use of ultrasound guidance improves central venous catheter insertion success rates among junior residents. *J Ultrasound Med*. 2012;31:1519–1526.
27. Blaivas M, Brannam L, Fernandez E. Short-axis versus long-axis approaches for teaching ultrasound-guided vascular access on a new inanimate model. *Acad Emerg Med*. 2003;10:1307–1311.
28. Werner H, Vieira RL, Rempell RG, et al. An educational intervention to improve ultrasound competency in ultrasound-guided central venous access. *Pediatr Emerg Care*. 2016;32:1–5.