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*

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Objective: **To determine whether ultrasound (US) increases successful central venous catheter (CVC) placement, decreases site attempts, and decreases CVC placement complications.**

Design and Setting: **A prospective observational cohort study evaluating a transition by the Pediatric Critical Care Medicine service to US-guided CVC placement. Medical and surgical patients in a 21-bed quaternary multidisciplinary pediatric intensive care unit had CVCs placed by attendings, fellows, residents, and a nurse practitioner.**

Patients: **Ninety-three patients were prospectively enrolled into the landmark (LM) group and 119 into the US group.**

Interventions: **After collection of prospective LM data, training with US guidance was provided. CVCs were subsequently placed with US guidance.**

Measurements and Main Results: **Operator information, disease process, emergent/routine, sites attempted, and complications were recorded. Procedure time was from initial skin puncture to guidewire placement. There was no difference overall in success rates (88.2% LM vs. 90.8% US, $p = 0.54$) or time to successful placement (median seconds 269 LM vs. 150 US, $p = 0.14$) between the two groups. Median number of attempts were fewer with US for all CVCs attempted (3 vs. 1, $p < 0.001$) as were attempts at >1 anatomical site (20.7% LM vs. 5.9% US, $p = 0.001$). Use of US was associated with fewer inadvertent artery punctures (8.5% vs. 19.4%, $p = 0.03$). Time to successful placement by residents was decreased with US (median 919 seconds vs. 405 seconds, $p = 0.02$). More internal jugular CVCs were placed during the US period than during the LM period (13.4% vs. 2.1%).**

Conclusions: **US-guided CVC placement in children is associated with decreased number of anatomical sites attempted and decreased number of attempts to gain placement. Time to placement by residents was decreased with US, but not the time to placement by other operators. US guidance increased the use of internal jugular catheter placement and decreased artery punctures. US guidance did not improve success rates. (Crit Care Med 2009; 37:1090–1096)**

Key Words: **children; ultrasonography; vein; central venous cannulation**

In critically ill patients, central venous access is essential for volume resuscitation, administration of medications and blood products, blood sampling, parenteral nutrition, continuous renal replacement therapy, and hemodynamic monitoring. Obtaining central venous access in critically ill children can be a difficult process. Complications include injury to surrounding structures, including vessels, resulting in hematoma, hemothorax, and pneumothorax. Because placement can be challenging, multiple anatomical sites may have to be attempted and an unsuitable length of time may be needed to gain access. Failure rates for central venous catheter (CVC) placement in children range from 5% to 19% with reported complication rates from 2.5% to 22% (1–4).

Studies in adults have shown that ultrasound (US)-guided central venous access decreases the number of attempts and the time required to successfully cannulate the vein (5). The Third Sonography Outcomes Assessment Program Trial of internal jugular (IJ) CVC placement in adults found that US increased the likelihood of success (6). Similarly, a study by Leung et al (7) in adults associated use of US with a higher successful insertion rate and a lower complication rate. Multiple meta-analyses of US-guided central venous access in adults have concluded that for IJ procedures, cannulation using US guidance was more successful than use of the landmark (LM) technique (8–10). A 2001 Agency for Healthcare Research and Quality report listed US guidance of CVC placement as one of the top 11 highly proven patient safety practices that are not routinely used in patient care (11). With recent enhanced focus on patient safety and clinical outcomes, the American College of Emergency Physicians published a policy statement, including guidelines for the use of US guidance for CVC placement in a list of primary applications for US in the emergency department (12).

Evidence for US-guided CVC placement in children is limited. In evaluating the use of US for CVC placement in a total of 95 infants before cardiac surgery,

***See also p. 1170.**

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Verghese et al (13) demonstrated a 77% success rate for IJ CVC placement in infants in the LM group with 25% incidence of carotid artery puncture, compared with 100% success in the US group, with no carotid artery punctures. Another study by Verghese et al (14) in 45 infants in the operating suite showed quicker cannulation time and decreased attempts for IJ CVC placement with US. A retrospective study of IJ placement in 149 children >10 kg before cardiac surgery showed improved success with US guidance (15). A 2003 meta-analysis of 167 pediatric patients (79 in LM vs. 88 in the US group) also demonstrated improved success for US-guided IJ CVC placement (10). Conversely, a report by Grebenik et al (16) showed increased complications and lower success rate with US-guided IJ CVC placement compared with LM technique by anesthesiologists before cardiac surgery, although the study methodology has been criticized. A recent study suggested that US could be used in the placement of subclavian CVCs in children, but no comparison to other approaches was examined (17). Finally, a study by Iwashima et al (18) evaluated femoral placement in a total of 87 children before cardiac catheterization and found decreased inadvertent arterial punctures in the US group. Currently, there are no prospective studies evaluating the use of US-guided central vascular access in critically ill children in the pediatric intensive care unit (PICU). Also, data supporting US-guided femoral line placement, a site commonly used in children, are limited (18, 19).

We hypothesized that US guidance would decrease the overall time required to insert CVCs in critically ill children by increasing the probability of successful cannulation by the first operator, decreasing the number of attempts required for successful placement, and/or eliminating the need to attempt multiple anatomical sites for access when compared with the traditional LM method. Additionally, this study evaluated whether US-guided CVC placement would decrease the likelihood of complications.

METHODS

Study Design. This prospective study of a planned transition by the Pediatric Critical Care Medicine service at Children's Healthcare of Atlanta at Egleston to US CVC placement was approved by the Children's Healthcare of Atlanta Institutional Review Board. Medical and surgical patients in a 21-bed quaternary multidisciplinary PICU, in which CVCs were placed by attendings, fellows, residents, and a nurse practitioner, were enrolled from January 2005 to December 2006. Patients were included in the study if they required CVC placement by the critical care team while in the PICU. Catheters placed outside the PICU (operating room, emergency room, etc.) or placed by non–critical care services were not included in the study. The choice of site of catheter placement was at the discretion of the operator inserting the catheter.

LM-Placed CVC. The initial study group consisted of traditional anatomical LM CVC placement utilizing palpation and the Seldinger technique. Operator training level, patient disease process, situation (emergent vs. routine), number of anatomical sites attempted, and complications, including inadvertent artery puncture, hemothorax, pneumothorax, and hematoma formation, were recorded. Success or failure, the number of kits opened, and the number of additional guidewires used were also recorded. The procedure was timed with a stop watch by the PICU staff, with the procedure start time recorded as the time the needle initially penetrated the skin. The time to first blood flash, the number of skin entries, and the time to successful guidewire placement were recorded. The procedure end times were recorded as the time to successful guidewire insertion. Attempts in which the guidewire threaded but the catheter placement was not successful (i.e., lack of blood return) were treated as failures. Data collection for the LM group was completed and closed before US training and use.

US-Guided Technique. All critical care fellows and attendings, and our nurse practitioner were trained in dynamic (real time) US-guided CVC placement using a SonoSite 180 plus (SonoSite, Bothell, WA) in which US is used to visualize and guide the needle into the vessel. The SonoSite probe was dressed in a telescopically folded sterile sheath (CIVCO Medical Solutions, Kalona, IA); although the use of needle guides was permitted, none were used during the study. Information about whether a one-person technique (one hand to hold the US probe, the other to place the line) or a two-person technique (one operator to hold the US probe and one operator to place the line) was recorded. The vessel to be catheterized was located in the transverse plane with the US probe perpendicular to the skin, and the needle was directed at the vessel in real time. Once a blood flash was obtained, the CVC was placed using the Seldinger technique identical to the LM group. If the guidewire could not be successfully threaded, the US probe was used to redirect the needle until successful wire placement was achieved, or to begin another needle entry into the skin. In patients in the US group, the number of previous US lines placed by the operator (none, one, two, three, or >three), comfort with the US device, and opinion of the utility of the US device were recorded. The time needed to set up the US machine and sheath the probe was not recorded.

Statistics. Patient demographics and clinical characteristics were summarized descriptively between placement methods (LM and US). These measures were compared between groups with the Wilcoxon's rank sum test for continuous variables and the chi-square test of independence or Fisher's exact test for proportions.

Differences between the LM and US groups were assessed for these outcomes: rate of placement success, the number of attempts until success or failure, complications (both arterial puncture and other), and time to wire in patients where CVC placement was successful. Success and complication proportions were compared between treatment groups using the chi-square test of independence, with odds ratios of each occurring in the US group compared with the LM group calculated as well. The number of attempts was categorized and summarized using an odds ratio for the US method relative to LM. The Cochran-Armitage trend test was used to assess a linear decline in the odds of being in US group compared with LM as the number of attempts increased. The difference in median time to wire and median attempts was tested using the Wilcoxon's rank sum test. All statistical tests were two-sided and unadjusted for multiple testing. A value of $p < 0.05$ indicated statistical significance. Because of multiple outcomes and multiple subset analyses, a cautious interpretation of the study results that focuses on the magnitude of the differences is important.

As plots of the number of attempts suggested different patterns in low- and high-weight children, we next looked at these primary outcome measures between placement methods separately in children above and below the median weight of the sample. We also divided the data based on access site and assessed between-technique differences in the measures. To explore whether there were differences in these outcomes based on operator experience, these comparisons between CVC methods were also repeated separately for residents, fellows, attendings, and our nurse practitioner.

Modeling beyond univariate methods was restricted to the number of placement attempts, because this primary outcome provided information on all patients in the study. Furthermore, this outcome showed a between-method difference in univariate analyses. Poisson regression was originally considered but provided poor goodness of fit. A multiple negative binomial regression model, performed using SAS Proc GENMOD, best fit this count-to-success data, with placement method, weight, and their interaction as predictors (20). Operator experience and location of line placement were not included in the model because of sparseness at some levels of these variables. The parameter estimate for the treatment group was tested for significance, and the model equations were computed and plotted. The adjusted geometric mean number of attempts (approximately equivalent to the median) and the 95% confidence intervals were computed for each placement method at the overall median weight. Goodness of fit was assessed by examining the ratio of the scaled deviance to the model degrees of freedom. All statistical analyses were conducted in SAS v9.1 (Cary, NC).

RESULTS

Two hundred twelve CVC placements were performed and evaluated: 93 during the LM phase and 119 in the US phase. No difference was seen between patients in whom CVCs were placed using the LM- or US-guided approach with respect to age, weight, diagnosis, sedation, neuromuscular blockade, or mechanical ventilation (Table 1). The median patient age was 30.3 months for the LM group and 56.3 months for the US group ($p = 0.11$). Median patient weight of LM group was 13.6 kg vs. 18.0 kg for the US group ($p = 0.07$).

The overall rate of CVC placement success did not significantly differ between LM and US groups (88.2% and 90.8%, respectively, $p = 0.54$; Table 2). Time to success-

Table 1. Demographics and baseline characteristics for 212 children in whom central venous catheters (CVC) were place by landmark or ultrasound-guided approach

	Landmark			Ultrasound			
	n	Median	(Q1, Q3)	n	Median	(Q1, Q3)	p Value
Age (months)	93	30.3	(6.4, 130.8)	119	56.3	(9.7, 137.0)	0.11
Weight (kg)	93	13.6	(5.4, 30.0)	119	18.0	(9.0, 41.0)	0.07
		Count	%		Count	%	
Primary disease process							
Respiratory failure		31/93	33.3		45/119	37.8	0.56
Sepsis		14/93	15.1		10/119	8.4	0.19
Neurologic		13/93	14.0		20/119	16.8	0.70
Cancer		8/93	8.6		5/119	4.2	0.25
Renal		8/93	8.0		8/119	6.7	0.61
Trauma		6/93	6.5		7/119	5.9	1.00
Liver failure		5/93	5.4		9/119	7.6	0.59
Heart disease		4/93	4.3		1/119	0.8	0.17
Hematologic		2/93	2.2		5/119	4.2	0.47
Electrolyte abnormalities		1/93	1.1		7/119	5.9	0.08
Respiratory distress		1/93	1.1		2/119	1.7	1.00
Sedated		85/93	91.4		114/119	95.8	0.25
Ventilated		73/93	78.5		86/119	72.3	0.34
Neuromuscular blockade		49/89	55.1		55/119	46.2	0.26
Vasoactive infusions		29/92	31.5		33/119	27.7	0.65
History of difficult CVC		18/90	20.0		17/119	14.3	0.35
Previous CVC		35/90	38.9		39/119	32.8	0.38
Emergent		27/92	29.4		21/119	17.7	0.05

Table 2. Clinical outcomes by catheter placement method and weight

	Overall						Low Weight (<Median of 16.3 kg)						High Weight (≥Median of 16.3 kg)					
	Landmark		Ultrasound				Landmark		Ultrasound				Landmark		Ultrasound			
	%	Count	%	Count	OR	p	%	Count	%	Count	OR	p	%	Count	%	Count	OR	p
Success	88.2	82/93	90.8	108/119	1.32	0.54	83.0	44/53	79.3	42/53	0.78	0.62	95.0	38/40	100.0	66/66	—	0.14
Placement attempts					<.001						0.23						<.001	
1	34.4	32/93	54.6	65/119	1.00		28.3	15/53	35.9	19/53	1.00		42.5	17/40	69.7	46/66	1.00	
2	15.1	14/93	17.7	21/119	0.74		15.1	8/53	20.8	11/53	1.09		15.0	6/40	15.2	10/66	0.62	
3	10.8	10/93	7.6	9/119	0.44		11.3	6/53	7.6	4/53	0.53		10.0	4/40	7.6	5/66	0.46	
4+	39.8	37/93	20.2	24/119	0.32		45.3	24/53	35.9	19/53	0.63		32.5	13/40	7.6	5/66	0.14	
Complications																		
Arterial puncture	19.4	18/93	8.5	10/118	0.39	0.03	24.5	13/53	15.4	8/52	0.56	0.33	12.5	5/40	3.0	2/66	0.22	0.10
Other	17.2	16/93	12.6	15/119	0.69	0.44	26.4	14/53	22.6	12/53	0.82	0.82	5.0	2/40	4.6	3/66	0.91	1.00

	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p
Time to wire (sec)	269	(75, 900)	82	150	(76.5, 435)	108	0.14	281	(96, 1354)	44	213	(112, 695)	42	0.62	212	(46, 619)	38	100	(47, 345)	66	0.45

OR, odds ratio; Med., median.

ful CVC placement was not statistically different between the two groups ($p = 0.14$). The number of attempts for the two groups was found to be significantly different ($p < 0.001$) and is shown in Table 2. Forty percent (37 of 93) of the children in the LM group required four or more attempts, whereas only 20.2% (24 of 119) needed this many attempts in the US group. The odds ratio of 0.32 given may be interpreted as the odds of being in the US group compared with being in the LM group for children with four or more placement attempts, relative to those who required one attempt. When evaluating complications of CVC placement, 19.4% (18 of 93) of the patients in whom access was attempted by the LM technique experienced inadvertent artery puncture compared with 8.5% (10 of 118) of the patients in the US group ($p = 0.03$), all occurring in the femoral location. The ratio of the odds of having an arterial puncture in the US group compared with the LM group was estimated to be 0.39, indicating a 61% lower risk of puncture. No differences were seen in other complications by placement technique (Table 2).

We also present the outcomes for children above and below the median weight of 16.25 kg in Table 2. Children in the low-weight group required more placement attempts for both techniques, but the frequency distributions were not distinguishable ($p = 0.23$). For high-weight children, the patterns were significantly different ($p < 0.001$), with 32.5% of the children in the LM group requiring four or more attempts and only 7.6% in the US group requiring that many. There was no difference in time to successful placement in children either ≥16.25 kg or <16.25 kg nor were complications different between the two weight-based groups.

The need to attempt greater than one anatomical site for access occurred 20.7% (19 of 92) of the time for LM patients compared with 5.9% (7 of 119) of the time for US patients ($p = 0.001$). Catheters that required more than one operator did not differ between the two groups (16.1% LM vs. 7.6% US, $p = 0.087$). Median time to placement of femoral CVCs was not significantly different between groups (281.0 seconds for LM, 150.0 seconds for US, $p = 0.18$). For CVCs placed in the femoral site, a median of three attempts were made using the LM technique, whereas a median of one attempt was required using US ($p = 0.006$). Only two of the 93 CVCs (2.1%) were placed in the IJ in the LM group, whereas 16 of 119 CVCs (13.4%) were IJ in the US-guided group ($p = 0.007$). Because of the low numbers for comparison, time to successful IJ placement and number of placement attempts were not significant. There was no significant difference in time to place IJ CVCs compared with non-IJ sites (femoral and subclavian) using US guidance, nor was a difference in attempts required ($p = 0.49$ and $p = 0.33$, respectively). A one-person US technique was used in 82 (70.7%) patients compared with a two-person technique in 32 (27.6%) patients. In two patients both techniques were used.

Data were analyzed with respect to level of training (Table 3). For residents, successful CVC placement in the LM group required a median time of 919 seconds vs. 405 seconds in the US group ($p = 0.02$). There was a greater number of attempts by residents in the LM group compared with the US group for all CVC attempts ($p = 0.001$). This pattern was seen with fellows as well ($p = 0.04$), although the median time to successful placement did not differ. In addition, neither the time nor the attempts were different in CVCs placed by attendings or our nurse practitioner in the LM compared with the US-guided approach, although the number of observations in each group was small.

Complications with respect to level of training were not significant between groups, with the exception that more inadvertent artery punctures occurred with fellows in the LM group (14 of 66, 21.2%) compared with the US group (4 of 80, 5.0%, $p = 0.003$). A survey of US-placed CVCs found that 78% of first operators believed US was beneficial.

Multivariable modeling of the number of attempts suggested that the CVC placement technique and child weight were associated with outcome (technique, $p < 0.0001$; weight, $p < 0.0001$), although the interaction term was not significant. The data and the estimated model equations for both techniques are plotted in Figure 1. The estimated geometric mean number of attempts at the median weight of 16.25 kg in the LM group is 5.9 (95% confidence interval [4.9–7.1]) and for the

Table 3. Clinical outcomes by catheter placement method and operator experience

	Resident, n = 35						Fellow, n = 147						Attending, n = 14						PNP, n = 16					
	Landmark		Ultrasound				Landmark		Ultrasound				Landmark		Ultrasound				Landmark		Ultrasound			
	%	Count	%	Count	OR	p	%	Count	%	Count	OR	p	%	Count	%	Count	OR	p	%	Count	%	Count	OR	p
Success	100.0	(11/11)	91.6	(22/24)	—	1.00	87.9	(58/66)	90.1	(73/81)	1.26	0.66	77.8	(7/9)	80.0	(4/5)	1.14	1.00	85.7	(6/7)	100.0	(9/9)	<.001	0.43
Placement attempts					.001						0.04						0.25						0.28	
1	9.1	(1/11)	41.7	(10/24)	1.00		40.9	(27/66)	56.8	(46/81)	1.00		22.2	(2/9)	60.0	(3/5)	1.00		28.6	(2/7)	66.7	(6/9)	1.00	
2	9.1	(1/11)	33.3	(8/24)	0.80		13.6	(9/66)	14.8	(12/81)	0.78		11.1	(1/9)	0.0	(0/5)	—		42.9	(3/7)	11.1	(1/9)	0.11	
3	18.2	(2/11)	12.5	(3/24)	0.15		12.1	(8/66)	6.2	(5/81)	0.37		0.0	(0/9)	0.0	(0/5)	—		0.0	(0/7)	11.1	(1/9)		
4+	63.6	(7/11)	12.5	(3/24)	0.04		33.3	(22/66)	22.2	(18/81)	0.48		66.7	(6/9)	40.0	(2/5)	0.22		28.6	(2/7)	11.1	(1/9)	0.17	
Complications																								
Art puncture	18.2	(2/11)	12.5	(3/24)	0.64	0.64	21.2	(14/66)	5.0	(4/80)	0.20	.003	0.0	(0/9)	40.0	(2/5)	—	0.11	28.6	(2/7)	11.1	(1/9)	0.31	0.55
Other	9.1	(1/11)	8.3	(2/24)	0.91	1.00	16.7	(11/66)	13.6	(11/81)	0.79	0.60	33.3	(3/9)	20.0	(1/5)	0.50	1.00	14.3	(1/7)	11.1	(1/9)	0.75	1.00

	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p	Med.	(Q1, Q3)	n	Med.	(Q1, Q3)	n	p
Time to wire (sec)	919	(268, 1606)	11	405	(133, 512)	22	0.02	153	(48, 619)	58	124	(62, 278)	73	0.67	340	(89, 1470)	7	100	(50, 989)	4	0.32	314	(182, 335)	6	114	(86, 317)	9	0.20

OR, odds ratio; Med., median; PNP, pediatric nurse practitioner.

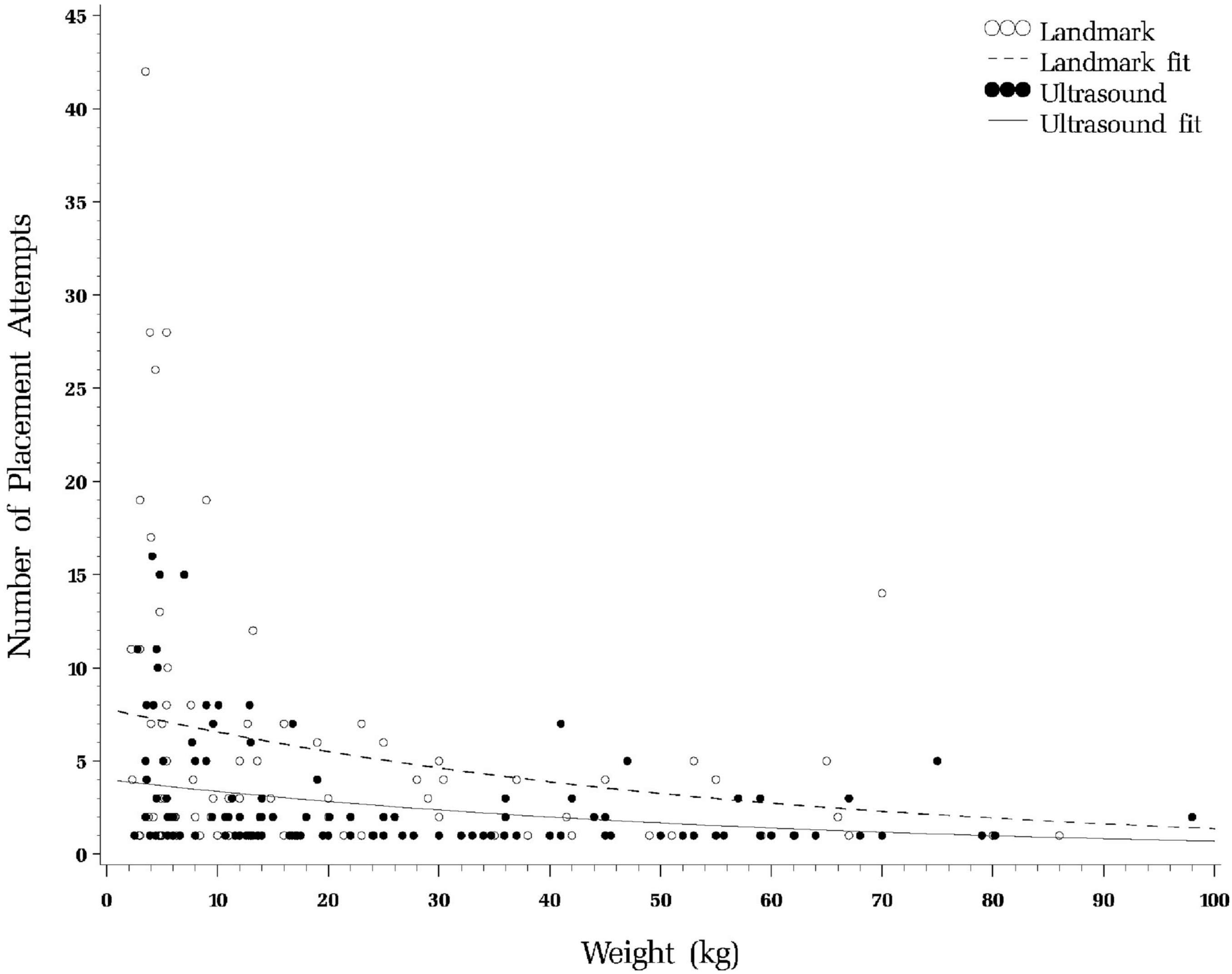

Figure 1. Model equation: ln (sticks) = 1.388 + 0.667 * (landmark) − 0.012 * (weight). For ease of presentation, one 22-kg child who required 60 attempts was excluded from this figure.

US group the mean number of attempts is 3.0 (2.5–3.7). Multivariable logistic regression indicated no association between CVC placement success rate and placement method ($p = 0.92$) but weight ($p = 0.001$) was related to outcome. In summary, the success rates decreased and the number of attempts increased for both placement methods as the weight of the child decreased. The number of placement attempts was higher for the LM method compared with the US method, but success rates were not different between placement methods.

DISCUSSION

We believe this is the first systematic evaluation of the US technique specifically performed by pediatric intensivists on critically ill or injured children. We conducted a planned transition of CVC access from our traditional LM technique to the use of access aided by US. We believe our PICU patient population is different from other studies because 31.5% of LM and 27.7% of US patients were on vasoactive infusions and 29.4% in LM group and 17.7% of US group's catheters were placed emergently. The emergent need for placement and the percent of patients on vasoactive infusions may be why our LM artery puncture rates were greater than those reported in other studies in which catheters were placed in the operating room (21). Our complication rates resemble data reported by Miller et al (5) and Leung et al (7); in these two studies CVCs placed in the emergency room had complication rates from 14% to 16.9% for the LM group compared with 4.6% to 12% in the US group. Our failure rate for CVC placements in the LM group is within the range of reported rates, yet interestingly was not improved using US (2, 3).

Our study demonstrated a decrease in the median number of all CVC attempts with the use of US from 3 to 1. Although this may seem like a minimal improvement, we believe it is clinically relevant. Mansfield et al (22) found that the incidence of mechanical complications after three or more insertion attempts was six times the rate compared with the complication rate after a single attempt. This likely contributes to the observed fewer artery punctures with US guidance. For example, the decrease in attempts and complications related to placement becomes important in children who are heparinized after being percutaneously cannulated for extracorporeal membrane oxygenation (as is commonplace at our institution) or continuous renal replacement therapy, or in children who are coagulopathic. Although the difference in median time to placement was about 2 minutes between the techniques, we believe this difference would not be clinically significant.

Only dynamic "real time" US was studied for CVC placement. Static US, a process by which US is used to "mark" the skin overlying the vessel location before CVC placement, was not used. This study allows only the comparison between dynamic US and standard LM technique. Although the Third Sonography Outcomes Assessment Program Trial found static US helpful, dynamic US dramatically improved success rates over static US (6). A static US group for comparison would have been interesting, but we believe dynamic US offered the greatest benefit for CVC placement. Unlike the Third Sonography Outcomes Assessment Program Trial, our US group used a one-person technique with <1/3 of placements using a two-person method. We subjectively found that as users became more accustomed to the US, they felt more comfortable with a one-person method. The dynamic US group in the Third Sonography Outcomes Assessment Program Trial used two people in all cases (6). Our results using dynamic US represent more clinically applicable findings, as an additional person is not always available to assist the operator. In fact, a recent study indicated no advantage in CVC placement using a two-person technique (23).

In the case of inexperienced operators (residents), we did detect a clinically significant difference in time to placement between the LM and US group. Some clinicians believe US could improve CVC placement in the LM group as well by improving the three-dimensional understanding of the anatomy. This understanding could improve the access statistics in patients in whom CVCs were placed with the LM technique, although it has not been studied. Yet, even in more experienced operators (fellows and attendings), we believe US helps confirm the location of the vascular structures, demonstrates pre-existing intravascular clots, and defines anatomically inaccessible vessels, which can encourage the operator to choose a different anatomical location for CVC placement, increasing the likelihood of first attempt placement success. Finally, we found IJ placement of CVCs increased substantially with the adoption of US without addition of new attendings or change in fellows' practice. Before the use of US, the frequency of placement of IJ CVCs was 2.1%. After the introduction of US, IJ CVC placement increased to 13.4% ($p = 0.007$). We speculate the increase in IJ CVC placement is due to the ability to visualize and avoid critical structures, such as the carotid artery, which in the end increases comfort. The increased use of IJ CVCs has many real and potential advantages, including decreased infections and improved ease of care in older children, improved hemodynamic monitoring, and improved site care/nursing care.

Study Limitations. This study evaluated a change in practice from LM-guided CVC placement to US-guided placement. One concern is that there could be a time effect for improving the skills of the US group, i.e., more experience in the US group. As new operators were available to place CVCs (new residents and fellows) they were included in the group for which data were currently being collected. The majority of CVCs placed in both US and LM groups were placed by our first- and second-year fellows, with comparable experience. Therefore, we believe experience between the two groups was similar. Also, setup time and sheathing of the probe was not included in the study, and may add some time to the US-guided procedure. In our experience, this time was minimal and was similar to the time used in the LM group to palpate for the pulse and locate other anatomical landmarks.

CONCLUSIONS

In conclusion, we find that US-guided CVC placement in children decreases the number of anatomical sites attempted, decreases the number of access attempts, and decreases inadvertent artery punctures in children. US does not seem to substantially improve success rates or decrease time to CVC placement across all operators, yet, it did decrease time to placement in operators with minimal training or experience. From our data, given its potential benefits and lack of risk, we believe US guidance should be encouraged for all operators for all CVC placements in patients in the PICU; but particularly, we recommend US guidance for all CVCs placed by inexperienced operators, and for CVCs placed by experienced operators in "high risk" (i.e., coagulopathic) patients.

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REFERENCES

1. Sznajder JI, Zveibil FR, Bitterman H, et al: Central vein catheterization. Failure and complication rates by three percutaneous approaches. *Arch Intern Med* 1986; 146: 259–261
2. Casado-Flores J, Barja J, Martino R, et al: Complications of central venous catheterization in critically ill children. *Pediatr Crit Care Med* 2001; 2:57–62
3. Stenzel JP, Green TP, Fuhrman BP, et al: Percutaneous femoral venous catheterizations: A prospective study of complications. *J Pediatr* 1989; 114:411–415
4. Venkataraman ST, Thompson AE, Orr RA: Femoral vascular catheterization in critically ill infants and children. *Clin Pediatr* (*Phila*) 1997; 36:311–319
5. 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
6. Milling TJ Jr, Rose J, Briggs WM, et al: Randomized, controlled clinical trial of point-of-care limited ultrasonography assistance of central venous cannulation: The Third Sonography Outcomes Assessment Program (SOAP-3) Trial. *Crit Care Med* 2005; 33: 1764–1769
7. 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
8. 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
9. Keenan SP: Use of ultrasound to place central lines. *J Crit Care* 2002; 17:126–137
10. Hind D, Calvert N, McWilliams R, et al: Ultrasonic locating devices for central venous cannulation: Meta-analysis. *BMJ* 2003; 327: 361
11. Shojania KG, Duncan BW, McDonald KM, et al: Making health care safer: A critical analysis of patient safety practices. *Evid Rep Technol Assess (Summ)* 2001:i–x, 1–668
12. American College of Emergency Physicians: Use of ultrasound imaging by emergency physicians. *Ann Emerg Med* 2001; 38: 469–470
13. 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

14. 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
15. Leyvi G, Taylor DG, Reith E, et al: Utility of ultrasound-guided central venous cannulation in pediatric surgical patients: A clinical series. *Paediatr Anaesth* 2005; 15:953–958
16. 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
17. Pirotte T, Veyckemans F: Ultrasound-guided subclavian vein cannulation in infants and children: A novel approach. *Br J Anaesth* 2007; 98:509–514
18. Iwashima S, Ishikawa T, Ohzeki T: Ultrasound-guided versus landmark-guided femoral vein access in pediatric cardiac catheterization. *Pediatr Cardiol* 2008; 29:339–342
19. Stenzel JP, Green TP, Fuhrman BP, et al: Percutaneous central venous catheterization in a pediatric intensive care unit: A survival analysis of complications. *Crit Care Med* 1989; 17:984–988
20. Diggle PJ, Liang KY, Zeger S: Analysis of Longitudinal Data. New York, NY, Oxford University Press, 1995, pp 162–168, 185–189
21. Johnson EM, Saltzman DA, Suh G, et al: Complications and risks of central venous catheter placement in children. *Surgery* 1998; 124:911–916
22. Mansfield PF, Hohn DC, Fornage BD, et al: Complications and failures of subclavian-vein catheterization. *N Engl J Med* 1994; 331:1735–1738
23. Milling T, Holden C, Melniker L, et al: Randomized controlled trial of single-operator vs. two-operator ultrasound guidance for internal jugular central venous cannulation. *Acad Emerg Med* 2006; 13:245–247