The Effect of Clinical Experience on the Learning Curve of Pediatric Intensive Care Unit Residents for the Central Venous Catheter Placement Procedure

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Abstract

Keywords

- ▶ central venous catheter
- ▶ peripherally inserted central venous catheter
- ▶ pediatric intensive care unit
- ▶ training simulation
- ▶ learning curve

The objective of this study is to ascertain the effect of clinical experience on pediatric intensive care unit (PICU) residents' learning curve for central venous catheter placement in critically ill children. It was a 58-month retrospective observational study. The setting was multivalent PICU with 20 beds at a tertiary children's hospital. The subjects were PICU residents undergoing training in central venous catheter placement. During the study period, 22 residents were enrolled in the study, and 1,157 catheter placement procedures (485 central venous, 605 peripherally inserted central venous, 57 hemodialysis, and 10 "other" types of catheter placement procedures) were analyzed. The total success rate was 82.7%. After ultrasound-guided training simulation in catheter placement, the residents' learning curve for the procedure rose from 71% in the clinical setting at the first trial to 75% at the fourth trial and 80% by the 24th trial. Significant positive correlation was found between procedure success and number of trials with a Spearman coefficient ($p < 0.019$). Adequate clinical experiences were necessary for PICU residents to achieve competency in central venous catheter placement in critically ill children.

Introduction

Central venous catheter (CVC) insertion in critically ill children remains technically challenging for pediatric intensive care unit (PICU) residents. Ultrasound guidance reportedly increased the success rate of both CVC placement^{1–4} and peripherally inserted CVC (PICC) placement⁵ in pediatric patients. Moreover, several studies have demonstrated the benefits of training simulation for ultrasound-guided CVC placement in both adult^{6–8} and pediatric patients.^{9–11} Residents were able to perform CVC placement with a greater success after undergoing training simulations.^{6,9} However, there are no data assessing the impact of clinical experience following simulation training in CVC placement on PICU resident performance.

The aim of this study was to demonstrate the effect of PICU residents' clinical experience following ultrasound-guided simulation training on their learning curve for catheter placement procedures.

Materials and Methods

Study Design and Setting

This was a retrospective observational study conducted at the PICU of the National Center for Child Health and Development in Tokyo, Japan. This study was approved by the ethics committee at our institution.

The participants were PICU residents during April 2012 through March 2015 who had been working there for at least 1 year. We collected data on the CVC placement procedures performed between April 2012 and January 2017 from the "Procedure Log," a record of all catheter placement procedures maintained by the PICU residents. Every morning, the medical assistants of the PICU checked the performed procedures and then submitted the Procedure Log the day before to eliminate the possibility of residents' forgetting to record their procedures. The records were reviewed, and the following data were collected: patients' age at the time of the procedure, the

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catheter type used (CVC, PICC, hemodialysis catheter, or “other” types), insertion site (internal jugular vein, external jugular vein, femoral vein, upper extremity vein, and other or unknown sites), the success or failure of the procedure, the number of previous CVC placements the resident performed in a clinical setting, and complications due to the procedures. The definition of “success” was that the catheter tip was finally placed in the appropriate position.

We calculated individual residents' success rate over time by dividing the number of successful procedures by the number of previously experienced procedures. The learning curve was drawn by logarithmically approximating the mean success rate of 22 residents.

The setting of this study was a multivalent PICU containing 20 beds in a tertiary pediatric hospital. According to institutional protocol, most central venous cannulations (including PICC) were performed with real-time ultrasound guidance, and the subclavian approach for temporary catheter placement was avoided. None of the residents had worked at any other PICU before coming to our unit. All residents participated in training sessions simulating ultrasound-guided CVC placement before performing the procedure for the first time in the clinical situation.

Ultrasound-Guided CVC Placement Training Sessions

The training sessions consisted of the following three parts: (1) assessment before the procedure including preparation of the necessary items and confirmation of the indications and risks to the patient, (2) at least four sessions of hands-on training using ultrasound echography with a linear transducer (GE LOGIQ-e, GE Healthcare; or SonoSite, FUJIFILM SonoSite) and a vascular model (Blue Phantom: Pediatric 4 Vessel Ultrasound Training Block Model, CAE Healthcare, containing four branched blood vessels of varying sizes ranging from 2 to 6 mm), and (3) passing our unit's eligibility test for performing the procedure. In the sessions, the trainees observed a short-axis image of the vessel and the needle puncturing the anterior wall of the vessel under real-time ultrasound guidance, which would be the key for successful real-time ultrasound-guided puncture. The residents did not place any lines on an actual patient prior to passing the test. Approximately 30 minutes were spent in training per session.

Statistical Analyses

Descriptive statistics were expressed as the mean and standard deviation. The median and interquartile ranges were used for continuous data, and absolute frequencies and percentages were used for categorical data. Comparisons between groups were performed using Kruskal-Wallis test, and $p < 0.05$ was considered statistically significant. Spearman's correlation coefficients were also used. All analyses were performed using R version 3.2.0.

Results

Twenty-two residents were enrolled in the study, and 1,157 procedures were analyzed. The residents' median years of experience before working in our unit was 5.4 years

Table 1 Success rate of each catheter device type and each catheter insertion site

Device type and insertion site	Success	Failure	Total	Success rate
Catheter device types				
Central venous catheter	402	83	485	0.829
Peripheral inserted central venous catheter	500	105	605	0.826
Hemodialysis catheter	45	12	57	0.789
The others	10	0	10	1
Catheter insertion sites				
Internal jugular vein	243	54	297	0.818
External jugular vein	3	0	3	1
Femoral vein	207	42	249	0.831
Upper extremity vein	434	79	513	0.846
Other or unknown sites	70	25	95	0.737

(interquartile range: 4.9–8.9), and they had not received any special training in pediatric CVC. The total success rate was 82.7% (957 successes and 200 failures). The mean number of trials for all procedures per resident was 52.6 ± 24 (CVC: 22 ± 9.7 , PICC: 27.5 ± 18.4 , and hemodialysis catheter: 2.6 ± 2.6). The success rate and the insertion site for each type of procedure are shown in ▶Table 1. The residents' success rate did not differ significantly with respect to the procedure type ($p = 0.573$) or insertion site ($p = 0.173$). The patients' median age at the time of the procedure was 15 months (interquartile range: 6–63). There was no relationship between the patients' age and the procedure success with a Spearman coefficient ($p = 0.194$). ▶Fig. 1 shows the success rate of the 22 residents over time. After ultrasound-guided training simulation in catheter placement, the residents' learning curve for the procedure rose from 71% in the clinical setting at the first trial to 75% at the fourth trial and 80% by the 24th trial. Significant positive correlation was found between procedure success and number of trials with a Spearman coefficient ($p = 0.019$).

The total incidence of the reported complications due to the procedures was 2.5% (29 out of 1,157). Specific complications included bleeding or hematoma ($n = 17$; 1.5%), arterial puncture ($n = 7$; 0.6%), and others ($n = 5$; 0.4%).

Discussion

In this study, we demonstrated the learning curve among 22 PICU residents for CVC placement procedures in critically ill children. As mentioned previously, the residents' learning

Fig. 1 Residents' learning curve for central venous catheter placement procedures. The light lines show the success rates of individual residents over time. The learning curve was drawn by logarithmically approximating the 22 residents' mean success rate.

curve for the procedures was drawn by logarithmically approximating the mean success rate.

In previous reports, ultrasound imaging guidance increased the success rate for both CVC placement¹⁻⁴ and PICC placement⁵ in pediatric patients. We therefore normally perform both procedures at our institution using ultrasound guidance. The success rate in this study was somewhat low at 82.7% in comparison to a cumulative catheter placement success rate of 89% described in a recent meta-analysis authored by Shime et al.¹ The studies cited in the latter report were conducted in different situations, and the success rate of the CVC procedures varied from 67 to 100%. We therefore judged that it would be difficult to draw conclusions from a simple comparison of success rates reported by different studies. Our study was held in the PICU, where emergency catheter placement is performed chiefly for hemodynamically unstable patients, and the practitioners have relatively little experience in the procedure. These factors might have affected the lower success rate in our study.

The benefits of training simulation for CVC placement have also been reported.⁶⁻⁹ Thomas et al. reported a 38.5, 80.8, and 65.4% success rate for CVC insertion in pediatric patients by pediatric residents without prior simulation training, immediately after simulation training, and at a 3-month follow-up, respectively.⁹ Several authors have also reported prospectively on training procedures for pediatric ultrasound-guided CVC placement^{10,11} and concluded that ultrasound-guided percutaneous CVC insertion was a safe and reliable method that could be easily and rapidly learned. We thought that the performance of the CVC procedures by residents without simulation training might pose a risk to PICU patients. This study lacked a comparison group and we were unable to evaluate the effect of simulation training.

In our study, after the ultrasound-guided CVC training sessions, the residents' learning curve increased from the baseline of 71%. We demonstrated that the learning curve initially rose dramatically, and then increased more gradually as the number of trials increased. From the baseline value

of 71%, the residents' learning curve reached 75% at the fourth trial and 80% which we thought for "competency" at the 24th trial. Thus, we concluded that adequate clinical experiences were necessary for the PICU residents to achieve competency in CVC placement.

The data analysis also revealed that some of residents fell short of the 80% line. The creation of such curves might allow for focused identification of problems with targeted training.

Limitations

This study has several limitations. First, factors not accounted for such as the patients' disease severity, hypovolemic status, and edema might have affected the success rate of the procedures. Second, because the residents themselves kept the "Procedure Log," the data it contained might not have been entirely objective. Third, there were no data on how many times the residents punctured the vessels and how much time was required from the puncture to catheter placement. Fourth, during the study period, a small number of procedures were performed without ultrasound guidance. Thus, the results do not exclusively reflect the outcome of ultrasound-guided procedures. Fifth, because this was a single-center study, there may be some risk of bias in patient selection. However, the number of procedures analyzed was larger than in any comparable, previous study.

Conclusion

Adequate clinical experiences were necessary for the PICU residents to achieve competency in CVC placement for critically ill children.

Note

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