

ADVANCEMENTS IN CENTRAL VENOUS CATHETERIZATION IN PEDIATRIC PATIENTS: COMPARING ULTRASOUND GUIDANCE TO LANDMARK-BASED TECHNIQUES

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ABSTRACT

Central venous catheterization (CVC) is a vital procedure in pediatric intensive care, essential for monitoring and administering treatments. This review evaluates recent research comparing ultrasound-guided CVC with traditional landmark-based techniques. By analyzing findings from various studies, we highlight the comparative efficacy and complication rates of each method. Ultrasound guidance is shown to offer higher success rates and fewer complications, including reduced instances of arterial punctures and hematomas. Notably, the integration of ultrasound guidance has been associated with improved procedural efficiency and enhanced patient safety. This review also synthesizes results from meta-analyses and key studies, providing a comprehensive overview of current advancements and ongoing challenges in pediatric CVC. The evidence underscores the significant benefits of incorporating ultrasound guidance into clinical practice to optimize outcomes and reduce procedural risks for pediatric patients.

KEYWORDS: Central venous catheterization (CVC), Ultrasound.

INTRODUCTION

Central venous catheterization (CVC) is a critical procedure in pediatric intensive care, enabling effective hemodynamic monitoring and the rapid administration of fluids and medications to critically ill patients.^[1] CVC can be performed through the femoral, internal jugular (IJV), or subclavian veins, with the femoral vein often preferred in emergency settings due to its accessibility and relatively lower complication rates.^[2,3] However, the IJV is frequently targeted for pediatric resuscitation due to its high success rate and clinical importance.^[4,5] Recent advancements have

highlighted the benefits of ultrasound guidance in improving the accuracy and safety of CVC procedures. Studies have shown that ultrasound-guided CVC offers higher success rates and fewer complications compared to traditional landmark-based techniques.^[6] This review evaluates the efficacy and safety of ultrasound guidance versus landmark methods by analyzing recent studies and meta-analyses. It provides an in-depth examination of how ultrasound has become the gold standard for IJV cannulation due to its superior success rates and reduced complication risks.

The review underscores the importance of integrating ultrasound guidance into clinical practice to enhance procedural outcomes and patient safety. It aims to offer a comprehensive understanding of current practices and future directions in pediatric CVC, reflecting on the significant improvements brought about by technological advancements in imaging and procedural techniques.

Comparative Analysis of CVC Techniques

Ultrasound-guided CVC has a high success rate as stated to be between 90-99.8% of pediatric patients in various published reports.^[7,8]

Hayashi et al.^[9] performed research on 106 premature infants, who were having IJV catheterization for heart surgery procedures, and were the subjects of their study. A great effort was made in choosing the needle with X-ray guidance. In some cases, direct venipuncture was utilized while in other cases, the Seldinger method was employed. Catheterization duration mean was 353 seconds, proportionality makes it 97.2%. Local complications included arterial puncture (11.3%), hematoma formation (3.8%), and catheter Malposition (1.9%). Geriatric as well as overweight patients exhibited increased time taken for catheterization. In an abstract of Asheim^[10], ultrasonography was utilized as a directive instrument to cannulate 42 kids. In 95% of cases, standard 16 gauge was used and it was placed on the first attempt, which was the preferred approach in this protocol. The goal was of just a few seconds duration and transitioned at the onset and the end in 12 seconds. In their investigation of the central venous catheter causes, McGee and Gould^[11] realized the probability of mechanical problems increased six times among the cases where three or more attempts were made in comparison to the cases one was made.

Chuan et al.^[12] conducted a study on 62 pediatric patients with congenital cardiac disease undergoing elective surgery with the same procedure, but the recruitment plan was to allocate patients randomly to 2 groups. Compared to the technique of pre-location transesophageal echo and intraoperative probe except for portable scanner, the method of anatomical landmark yielded an 80% cannulation rate, 26.7% rate of arterial punctures, and an average number of attempts was 2.55 whereas it was 100%, 31%, and 1.57, respectively in the former.

The crucial finding that had emerged from the comprehensive review conducted by Hind^[13] and associates on pediatric research was that, contrary to the traditional procedure, it was the 2D ultrasound-guided method that had been demonstrated to have a greater overall success rate for right jugular vein cannulation. What empowers it is that the ultrasound guidance increases the speed with which it accesses events. So, fewer complications are witnessed. These advantages are, probably, the reasons for the excellent visibility of the needle, vein, and their neighboring structures. Contrary to the achievements of the landmark method, both adults and children face fewer risks and the examination takes less time with the aid of 2D ultrasonography.

In the pediatric population, a study by Hosokawa et al., real-time USG was demonstrated to be highly accurate in comparison to ultrasound skin marking.^[6] Venous thrombosis rates in the literature are as low as 3% following ultrasound-guided cannulation.^[7] In other research,^[14] 95 newborns who received intraosseous vessel cannulation either for CVC or heart operation, were randomly divided into two groups: landmark based insertion and one that uses ultrasound. The USG group had a 100% success rate because there were no carotid artery punctures. On the other hand, the landmark group yielded a 77% success rate, in which 25 % of the artery punctures occurred. Another research^[15] on 45 newborns receiving cardiopulmonary bypass found that they have no significant difference in carotid artery puncture incidence, success rate, and cannulation time between the landmark and the USG imaging groups. On the other hand, the landmark method was less efficient since the median number of attempts made with guidance from the USG approach $p < 0.05$.

In 2009, a meta-analysis completed by scientists of three previously documented studies^[14-16] showed that ultrasound guidance is as good as or even better than landmark technique with no significant difference in observed side effects (internal jugular vein access failure, carotid artery puncture, hematoma, hemothorax, pneumothorax) though longer. Froehlich et al.^[8] evaluated a total of 119 CVC insertions with ultrasound assistance that were performed in the PICU, when compared with 93 landmark technique-assisted CVC placement attempts. Contrary to the key finding, this study revealed that the USG directed placement of CVC in children had only one attempt to have a placement ($p < 0.001$), and only five anatomical sites (5.9%) were tapped due to the multiple attempts ($p = 0.001$) depicted in the literature, in addition, only eight children had unintentional artery punctures, as in their research, Gallagher et al.^[17] later on tried to implement both of the techniques to place a femoral and an internal jugular CVC in emergencies under the guidance of USG and without it, respectively. This is when the two methods were used, and those trying to occupy the secure location while using the USG help were much more successful than those using the landmark technique (OR 31.1, 95% CI 2.9-59.4).

CONCLUSION

This review consolidates evidence showing that ultrasound guidance markedly improves the accuracy and safety of central venous catheterization (CVC) in pediatric patients compared to landmark-based techniques. Ultrasound guidance is associated with higher success rates, fewer complications, and reduced procedural times. The ability to visualize vascular structures in real-time allows for precise catheter placement and minimizes risks such as arterial punctures and hematomas. However, continued research is essential to further optimize ultrasound techniques and integrate them into standard clinical practice. Future studies should focus on refining ultrasound protocols, enhancing provider training, and assessing long-term patient outcomes. Evaluating the cost-effectiveness of ultrasound guidance will also be important for its broader adoption.

In summary, ultrasound guidance demonstrates clear advantages over traditional methods for CVC in pediatric care, and ongoing advancements in this field are crucial for improving procedural outcomes and patient safety.

DECLARATIONS

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