Case Report

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Ultrasound-Guided Central Vein Catheterization in Pediatrics

***M.A. Leontiev*[1] ✉, *S.V. Kravchuk*[1], *A.V. Vodova*[2]**

Department of Anesthesiology and Resuscitation
[1] Morozov Children's Municipal Clinical Hospital of the Moscow City Health Department
1/9, 4th Dobryninsky lane, Moscow, 119049, Russian Federation
[2] Pirogov Russian National Research Medical University
1 Ostrovityanova St., Moscow, 117997, Russian Federation

✉ **Contacts:** Mikhail A. Leontiev, Candidate of Medical Sciences, anesthesiologist-resuscitator; Morozov Children's Municipal Clinical Hospital. Email: miwa_leontev@mail.ru

ABSTRACT In this article the most relevant methods of subclavian vein catheterization were considered in order to find the optimal technique that can be used in routine clinical practice by pediatric intensive care physicians.

OBJECTIVE To compare the efficiency and safety of subclavian vein catheterization by supraclavicular access under ultrasound control and subclavian access by anatomical landmarks in children.

RESULTS The number of attempts for successful catheterization was statistically lower in ultrasound-control group compared to the anatomical landmarks group (1.2±0.4 vs. 2.6±1.3, p<0.0001); in the anatomical landmarks group such complications as catheter malposition (14% vs. 0), arterial puncture (5% vs. 1%) and pneumothorax (10% vs. 0) were observed more often than in the ultrasound group.

CONCLUSIONS We recommend catheterization of the subclavian vein by supraclavicular access under ultrasound control to be commonly used in clinical practice due to its high efficiency and safety.

Keywords: central vein catheterization, catheterization of the subclavian vein, central venous catheter, ultrasound guidance, supraclavicular access, pediatrics

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Affiliations

Mikhail A. Leontiev	Candidate of Medical Sciences, anesthesiologist-resuscitator; Morozov Children's Municipal Clinical Hospital; https://orcid.org/0000-0001-7625-2771, miwa_leontev@mail.ru; 45%, setting goals, formulating the research concept, analyzing the results, text writing
Sergey V. Kravchuk	Head, Department of Anesthesiology and Resuscitation, anesthesiologist-resuscitator, Morozov Children's Municipal Clinical Hospital; https://orcid.org/0000-0001-7342-6254, anesthmdgkb@gmail.com; 40%, research idea generation, analysis of the results, final editing of the text
Anastasia V. Vodova	Student, Pirogov Russian National Research Medical University; https://orcid.org/0000-0003-3637-9895, ms.vodova@mail.ru; 15%, systematization and statistical processing of the results, text writing

SVC – superior vena cava
IJV – internal jugular vein
RA – right atrium
IC – infraclavicular approach
SC – supraclavicular approach
US – ultrasonic
CVC – central venous catheter

INTRODUCTION

Central venous catheter (CVC) placement is one of the most important invasive procedures in the intensive care for children of all ages. And health care outcomes largely depend on the success of its implementation. There are a large number of historically and clinically significant methods of central venous catheterization, and the advantages and disadvantages of each of them have been discussed for many years [1-5]. The search for the optimal technique of central venous catheterization has led the medical community to use ultrasonic (US) navigation methods, which, due to ease of use and high efficiency, have been already included in many national clinical practice guidelines and medical manuals in America and Europe as

mandatory and (or) auxiliary methods for central vein catheterization [6–8]. Despite this, there is still no single global standard that provides the highest speed, efficiency and safety of catheterization, so many specialists routinely use in their practice the classical methods of CVC insertion by anatomical landmarks, without thinking about the advisability of changing their strategy. Meanwhile, numerous studies have shown that ultrasound navigation significantly reduces the number of attempts, decreasing the duration of catheterization, and its use is associated with a lower risk of unintentional damage to nearby anatomical structures [1, 3, 5, 9–11]. This fact demonstrates the need to introduce a new, carefully developed and convenient technique that has been tested on a large number of patients and has confirmed its practical significance in clinical trials and everyday work.

Thus, according to the meta-analysis results by P. Brass et al. (2015), published in the Cochrane database, two dimensional ultrasound guidance for subclavian vein catheterization in adults reduced the risk of unintentional arterial puncture and hematoma formation, it was also noted that puncture by anatomical landmarks may be unsuccessful in 35% of cases [2]. Similar studies were also conducted in children: the results of meta-analyses by T.H. de Souza et al. and Lau & Chamberlain confirm that ultrasound guidance significantly reduces the risk of failed catheterization attempts and unintentional puncture of the arteries, and also reduces the number of puncture attempts [12, 13]. The results of the prospective study by H. Dolu et al. (2015) are along the same line: a significant difference in favor of ultrasound-guided catheterization was noted in terms of the number of attempts and duration of the procedure, they did not note a significant difference in complications [3]. The European Society of Anaesthesiology guidelines on peri-operative use of ultrasound for vascular access (PERSEUS vascular access) published in 2020, despite the relatively low level of evidence, recommend the use of ultrasound guidance at all stages of vascular access procedures in pediatric patients [8], and the recommendations of the American Society of Anesthesiologists for the same year indicate decreased number of attempts and increased procedural success rate when using dynamic ultrasound guidance during catheterization [7].

The use of ultrasound navigation gives clinicians the opportunity to observe in real time not only the position of the needle relative to adjacent structures, but also to assess the patency of the catheterized vein, to detect and study possible vascular anomalies in a given patient; and also in case of concomitant features, such as morbid obesity, scarring, and others, to specify the location of the target veins and select the most appropriate one from a technical point of view. Thus, the safety and efficiency of catheterization are significantly increased.

In addition to imaging methods, the success of CVC insertion greatly depends on the access from which venipuncture is performed. In clinical practice, the subclavian vein is most often used for this purpose, punctured from the subclavian access using anatomical landmarks. Often, the puncture site can be the internal jugular vein (IJV), which catheterization is recommended under ultrasound control [7, 8] in order to avoid the risk of puncture of the common carotid artery or multiple puncture attempts in case of loose type of IJV branching. The femoral vein is the least frequently used for CVC placement, since its catheterization is associated with the highest risks of catheter-associated bloodstream infections and thrombotic complications [14].

According to the study by J.J. Parienti et al. (2015), subclavian vein catheterization is associated with a significantly lower risk of bloodstream infections and symptomatic thrombosis compared to femoral and jugular vein catheterization, which makes it the optimal choice for CVC placement [14]. Despite all the advantages, subclavian puncture also carries a higher risk of pneumothorax compared to jugular vein puncture [14], but according to our data and data from other studies, this risk can be almost completely eliminated when using supraclavicular access under ultrasound guidance [15].

Prior to the widespread introduction of ultrasound machines into practice, supraclavicular access was used extremely rarely due to the high risk of developing serious complications, especially pneumothorax. However, every year new studies demonstrate the high efficiency, safety as well as the lowest risk of complications of this access, used in conjunction with ultrasound navigation [15–18]. Thus, the prospective randomized study of H.J. Byon (2013) compared supraclavicular (SC) and infraclavicular (IC) approaches to the subclavian vein: the average duration of puncture in the IC group was longer than in the SC group (48 seconds vs. 36), over 3 attempts for puncture were more often required in the IC group than in the SC group (24.5% vs. 6.1%). In the SC group, no cases of guide wire migration were detected, while in the IC group, the displacement rate was 20.4%. Catheterization was successfully performed in all the patients, neither pneumothorax nor arterial

punctures were observed in any of the groups [19]. Similar data in the pediatric population were obtained in our study which will be discussed in detail below.

Thus, ultrasound-guided supraclavicular catheterization of the subclavian vein, with proper execution of the procedure technique, is a safe and effective alternative to the existing catheterization methods, and may even become the new "gold standard" of intensive care for patients of different ages.

The aim of this study is to compare the efficacy and safety of subclavian vein catheterization by ultrasound-guided supraclavicular access and anatomic landmark-guided infraclavicular access in children.

Tasks:

1. To develop and describe a convenient and effective method of subclavian vein catheterization via supraclavicular access under ultrasound control in children.
2. Using statistical analysis methods to compare the effectiveness and safety of the technique used by us and the classical technique of anatomic landmark-guided CVC placement.

MATERIAL AND METHODS

The study included 3375 children aged from 3 days to 17 years who were treated at the Morozov Children's Municipal Clinical Hospital of the Moscow City Health Department in the period from 2019 to 2020. In accordance with the treatment plan, all children underwent subclavian vein catheterization. The patients were divided into two groups: the first group included children who underwent "blind" - anatomic landmark-guided subclavian vein catheterization (2133 children), the second - children who underwent catheterization performed via supraclavicular approach under ultrasound control (1242 children). Ultrasound imaging and vein catheterization were performed by one operator, an anesthesiologist-resuscitator. The average age of the first group was 7.1 years, the second - 6.9 years. Several parameters were compared: the number of attempts before successful catheterization, the adequacy of catheter placement after catheterization, and the presence of complications such as damage to the subclavian artery and pneumothorax. Statistical analysis of the patient evaluation results was carried out using the Statistica 10.0 for Windows software package (StatSoft-Russia), GraphPad Prism 6 for Windows (GraphPad Software), Microsoft Excel 2016.

The nonparametric Mann–Whitney U test was used; the level of $p \leqslant 0.05$ was considered the minimum threshold for significant differences.

RESULTS

In the first group, where the "blind" subclavian cannulation technique was used, the number of attempts before successful catheterization was statistically significantly higher than in the group where supraclavicular access and ultrasound control were used (2.6 ± 1.3 versus $1.2 \pm 0, 4$, $p<0.0001$).

For clarity and better understanding of the process, we consider it necessary to describe the applied algorithm for placing CVC in the subclavian vein. We use the supraclavicular approach to ultrasound-guided subclavian vein cannulation along the long axis of scanning. This technique makes it possible to observe the trajectory of the needle in real time which guarantees the fastest and safest catheterization (Fig. 1). This method allows good visualization of the subclavian vein, artery and pleural dome, which reduces the likelihood of their unintentional damage to a minimum or completely eliminates it. The undoubted advantage of this technique is that in almost every case the catheter occupies an adequate position in the superior vena cava (SVC) or right atrium (RA), and this is achieved due to the angle of the needle during vein puncture, and thus, the advance of the guide wire and catheter in the opposite direction and in the direction of the IJV is excluded.

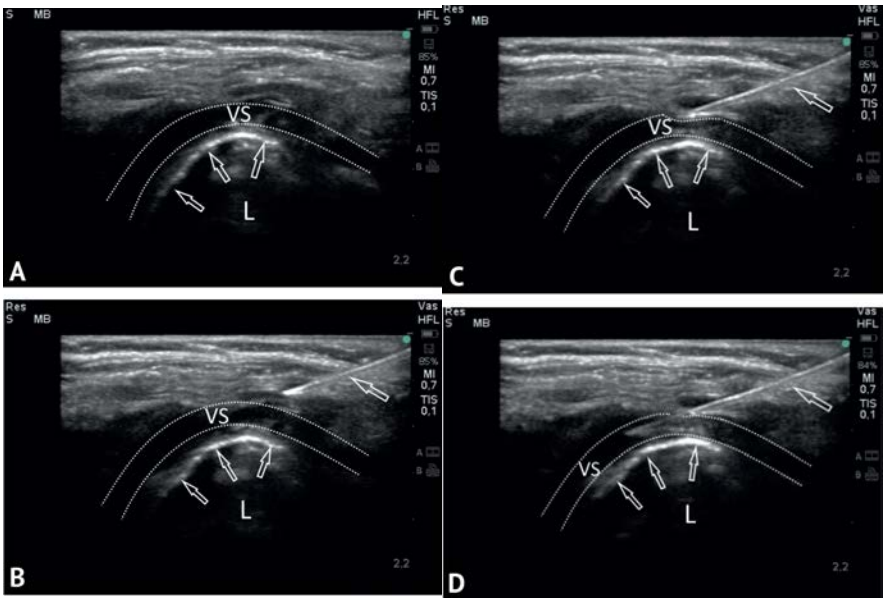

Fig. 1. The supraclavicular technique to puncture the subclavian vein using ultrasound navigation: A — general view during ultrasound scanning from the supraclavicular region: VS — subclavian vein, L — lung, arrows indicate the parietal pleura; B — an 18-gauge needle is inserted through the skin into the soft tissues, the needle is marked with an arrow; C — the moment of a puncture of the vein's wall; D — intravascular needle tip position

The correct location of the installed catheter is the most important condition for its adequate functioning and the guarantee of the absence of iatrogenic complications. The optimal location of the distal end of the catheter is in the SVC or RA cavity.

Our hospital works to an internal protocol, according to which, 2 hours after the CVC placement, it is necessary to conduct an X-ray control in order to assess the correctness of its position and timely diagnosis of complications associated with catheterization.

In the group of patients who underwent blind catheterization, the incidence of incorrect catheter placement was statistically significantly higher — 299 cases (14%) than in the group with ultrasound control — 0 cases ($p<0.0001$). Most often (213 cases, 71.6%) retrograde cannulation of the IJV from the side of catheterization occurred, less often (85 cases, 28%) a catheter was inserted into the subclavian vein from the opposite side, a single case of catheterization of the subclavian artery was also recorded (0.4%).

It should be noted that supraclavicular approach to ultrasound-guided subclavian vein cannulation has another advantage - the ability to immediately examine all possible locations to detect the catheter. To do this, without displacing the linear probe from the supraclavicular region, the subclavian vein and the initial sections of the SVC are examined; it is also possible to use a microconvex or phased probe from the jugular notch (Fig. 2).

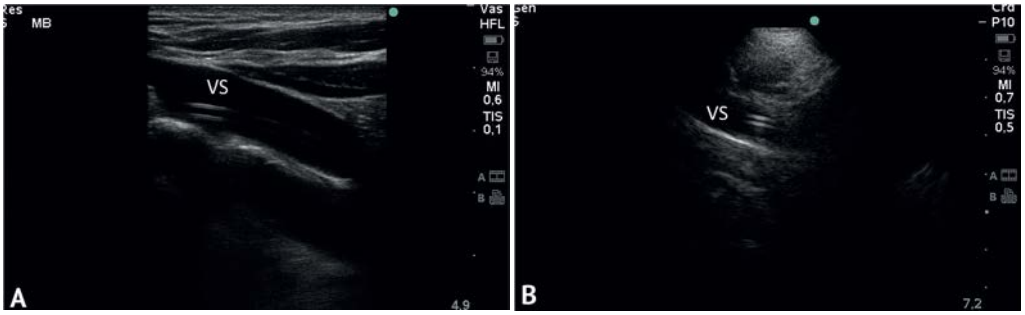

Fig. 2. A — scanning of the subclavian vein from the supraclavicular approach, B — scanning from the jugular notch

If the catheter cannot be visualized in the SVC, the subclavian vein is examined from the opposite side with the same probe: in rare cases, due to the anatomical and topographic features of the child, the catheter is

located there. If the search did not bring results, the IJV is examined from both sides to exclude retrograde catheter insertion. In the event that the catheter was not visualized, but there is confidence that it is in the RA or SVC, this can be confirmed by ultrasound scanning with a phased probe using the subcostal or apical approaches (Fig. 3).

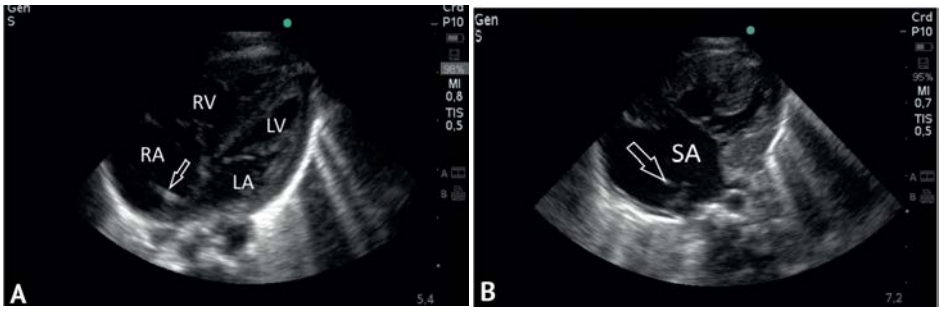

Fig. 3. Visualization of the end of the catheter from the apical approach: A — in the cavity of the right atrium; B — in the cavity of a functionally single atrium with atrioventricular communication
Note: RA — right atrium; LA — left atrium; RV — right ventricle; LV — left ventricle, the end of the catheter is marked with an arrow; SA — functionally single atrium

It should be noted that it is not always possible to see the distal end of the catheter this way. In such cases, without displacing the probe from a position that allows visualization of the right parts of the heart, a syringe is connected to the catheter, and 5–10 ml of sodium chloride solution is simultaneously injected as a bolus, and a "contrasting" pattern should appear on the screen of the ultrasound scanner (Fig. 4). This will indicate that the distal end of the catheter is located either in the RA or in the SVC in close proximity to the RA. With retrograde catheter insertion into the IJV, this phenomenon is not observed.

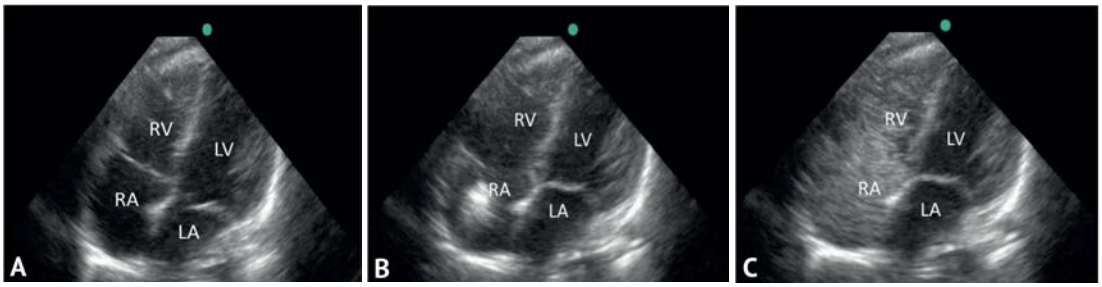

Fig. 4. Contrasting with sodium chloride solution. The end of the catheter is visualized in the cavity of the right atrium. A — before introducing contrast medium; B — the beginning of contrast medium introduction; C — contrast medium filling the right parts of the heart

However, there are cases when you cannot see the contrast: this can happen when the catheter is inserted too deep, when it, bypassing the RA, enters the inferior vena cava. In this case, it is advisable to retract the catheter a little and repeat the imaging. Another undoubted advantage of ultrasound-guided catheterization is the ability to immediately monitor the presence of complications. The figure below shows a normal lung profile in B- and M-modes and a profile in pneumothorax (Fig. 6, 7).

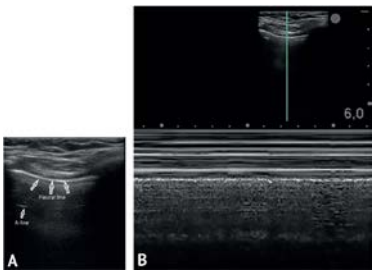

Fig. 5. Lung scanning in B- and M-mode, normal profile: A — B-mode, single A-line; B — M-mode, seashore sign

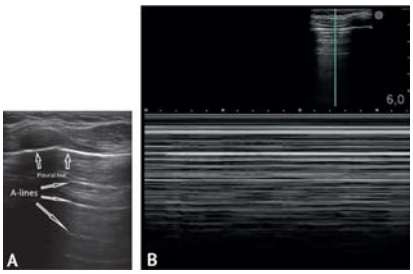

Fig. 6. Lung scanning in B- and M-mode, pneumothorax profile: A — B-mode, absence of pleural sliding, presence of multiple A-lines; B — M-mode, barcode sign

Thus, the use of ultrasound makes it possible to refuse radiographic verification of the location of the catheter and thereby reduce patient exposure to radiation. As for complications, the incidence of pneumothorax was statistically significantly higher in the first group: 17 (0.8%) vs. 0 cases ($p<0.0001$). Accidental puncture of the artery was noted in 34 cases (1.6%) in the first group and 12 cases (1%) in the second one ($p<0.01$). These figures indicate the high efficiency and safety of the method used.

DISCUSSION

Despite the fact that ultrasound machines are gradually appearing in hospitals even in the most remote regions of the country, many doctors do not seek to master new technologies and introduce them into routine practice, continuing to mistakenly consider the anatomical landmark blind technique as the "gold standard" for CVC placement. This approach significantly reduces the quality of medical care and can lead to serious iatrogenic complications, many of which could be avoided using modern methods of catheterization based on evidence-based medicine.

Currently, there are a limited number of studies that do not support the benefits of ultrasound navigation for central venous catheterization. For example, C.R. Grebenik et al. in 2004 conducted a study challenging the 2002 National Institute for Health and Care Excellence clinical guidelines that called US navigation the preferred method for central jugular vein catheterization in children and adults. In their study, success rates were statistically significantly higher when anatomical landmarks were used (89.3% vs 78%, $p<0.002$), and arterial puncture rates were lower (6.2% vs 11.9%, $p<0.03$) compared with the results of ultrasound use [20]. Such data have a right to exist, and, in our opinion, they can be explained by the great experience of operators who routinely use the anatomical landmark blind technique, as well as relatively recent emergence of high-precision ultrasound machines. In turn, C.D. Froehlich et al. also believe that ultrasound guidance does not increase success rates and does not reduce the duration of catheter placement, however, the number of attempts to successful puncture, as well as complications in the form of arterial puncture, were statistically significantly less when using ultrasound, which also indicates in favor of ultrasound control [4].

Thus, ultrasound navigation is an important aspect of fast and safe catheterization, and therefore the widespread use of this technique among clinicians can be the key to improving the quality of medical care.

CONCLUSION

Summarizing the above, it should be noted that ultrasound-guided subclavian vein catheterization via supraclavicular access is an effective and safe procedure in comparison with the traditional technique when CVC placement is performed blindly using anatomic landmarks. We recommend this method for widespread use in clinical practice.

FINDING

1. The technique described by us provides a number of significant advantages: firstly, the ability to see anatomical structures which reduces the risk of their unintentional damage; secondly, the ability to visualize the position of the catheter directly during the procedure; and thirdly, ultrasound navigation makes it possible to exclude the presence of complications associated with catheterization, without resorting to the use of radiation diagnostic methods.

2. Our analysis of statistical data demonstrates the advantage of the ultrasound guided technique over the anatomical landmark method: the number of attempts prior to successful catheterization was statistically significantly less in the group with ultrasound guidance compared to the group where anatomical landmarks were used (1.2 ± 0.4 vs. 2.6 ± 1.3, $p<0.001$); blind installation of the central venous catheter more often than ultrasound guided catheterization entails complications in the form of catheter malposition (14% vs. 0%, $p<0.0001$), arterial puncture (1% vs. 0.8%, $p<0 .01$) and pneumothorax (1.6% vs. 0%, $p<0.0001$).

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