VASCULAR ACCESS IN CHILDREN - TECHNIQUE AND COMPLICATIONS OF CENTRAL VENOUS CATHETERS

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Abstract
The installation of central venous catheters in children becomes more complex the smaller the patients are. This is less due to the anatomy itself than to the dimensioning of the anatomical structures and the associated vulnerability. While the puncture based on anatomical landmarks CVC (Central Venous Catheter), should not be forgotten, especially for dealing with emergencies, the use of sonography in newborns, infants, and children has become indispensable in everyday clinical practice. While it is important to master the techniques of puncture and placement, one should always keep in mind the special considerations for children, especially younger ones, and be aware of potential undiagnosed anatomical variations. If these points are heeded, the installation of central venous catheters in children can be carried out safely, easily, and with few complications.

Keywords: central venous access, venous cannulation, pediatric venous access, ultrasound-guided cannulation

Introduction
In Germany in 2016, a total of 11,175 pediatric heart surgery procedures were performed in children up to and including 13 years of age. As the Federal Statistical Office of Germany further reported on the “Day of Children with Heart Disease” on May 5th, 2018, that were 5.7% more children than ten years ago. 61% of the children who had heart surgery in 2016 were less than a year old. In addition, according to a projection, 49,000 children with major deformities are born in Germany every year. The affected patients account for approximately one-third of all pediatric inpatient admissions. These children often require not only intensive medical, interdisciplinary, and often lifelong treatment but also surgical interventions. The anesthesiological care of these patients is therefore often time-consuming and complex.

Of course, these patients require extended monitoring and therefore the installation of a central venous catheter (CVC), as part of the intraoperative monitoring in addition to the invasive blood pressure measurement. The anatomical conditions are not different than those of adult patients. However, what makes the installation of central venous catheters difficult and often complicated are the tiny dimensions and the vulnerability of the anatomical structures. In addition, techniques that make puncture easier in adults, for example, do not work in infancy. A further complication for the pediatric anesthetist is that infants are almost completely covered by surgical drapes during the operation. While peripherally introduced venous catheters are usually located in very small, thin-walled veins, this entails the risk of secondary perforation, for example, due to volume administration or the need for transfusion. In addition, it is often essential to replace electrolytes or to initiate catecholamine therapy. These facts require safe, central vascular access.

The widespread use of sonography in vascular punctures has allowed established techniques to be further developed and new access routes to be evaluated in recent years. In the following, standard procedures as well as further developments will be explained, complications will be described and strategies for avoiding them will be presented.

Decision-making on the placement of CVC
A 6-month-old infant is to have a laparotomy for ileus. It is to be expected that fluid and electrolyte shifts will occur after opening the abdominal cavity. In addition, a longer administration of antibiotics is to be expected, as well as frequent blood tests, which make the installation of a central venous catheter (CVC) appear necessary. CVC systems in children in this age group are rare. It is therefore crucial that
the method used should be as simple and safe as possible. The following questions are therefore important. What size should the catheter be? Where and how deep should the CVC be inserted (table 1)?

Table 1. Recommendation for the diameter and length of CVC in newborns, infants, and small children

<table>
<thead>
<tr>
<th>BODY WEIGHT (KG)</th>
<th>DIAMETER (FRENCH)</th>
<th>THE LENGTH OF THE CATHETER (CM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3</td>
<td>3 F</td>
<td>10</td>
</tr>
<tr>
<td>3-5</td>
<td>4 F</td>
<td>13</td>
</tr>
<tr>
<td>5-20</td>
<td>5.5 F</td>
<td>15</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>7 F</td>
<td>20</td>
</tr>
</tbody>
</table>

Access via Internal Jugular Vein (IJV)

The internal jugular vein approach (V. jugularis interna, IJV) is the approach of choice for several reasons. In contrast to the subclavian vein, the diameter of the IJV is variable because it depends on the filling of the vessel, but in the age of ultrasound-assisted vascular puncture, it can be readily accessible and safe for access. Looking at newborns or infants breathing spontaneously, with normal pressure in the left atrium (LA), the IJV collapses during inspiration in almost 50% of patients. If the IJV is dilated or without respiratory variability in these patients, this indicates an increased LA pressure (> 10 mmHg). If no ultrasound device is available, anatomical “landmarks” must be used for orientation. In any case, regardless of the technique used, the patient should be positioned appropriately to facilitate the puncture. The authors recommend using a shoulder roll adapted to the body size. Of course, care must be taken to ensure that the patient’s head is stabilized, e.g. with a gel ring, and is not overstretched. A frequently discussed question is whether the patient’s head should be positioned straight or turned to the left when the right RIJV (Right Internal Jugular Vein). Looking at the anatomical relationship of the IJV, the IJV is located to the right lateral to the common carotid artery (Arteria Carotis Communis, ACC) in over 80% of cases. Since the IJV and the ACC run in a common vascular-nerve layer, the IJV, when the pulse of the ACC is palpated, is in the majority of cases immediately lateral to the palpating finger and indicates the puncture position. However, according to a study by Benter et al, the IJV may run directly on and medial to the ACC in 4% of cases. If one relies on the “landmark technique” alone, there is a risk of accidental arterial puncture. This observation was recently confirmed in a study by Yuan and colleagues. They also found that the vessel diameter correlates little with age, height, and weight. In addition, the distance between the IJV and ACC increases when the ultrasound head is moved from the level of the cricoid caudally or toward the heart, medial. Proponents of head rotation to the left emphasize better exposure of the neck region. However, one can then no longer rely on the carotid pulse as a fixed point, because the rotation leads to a sometimes extreme overlap of the IJV with the ACC. At least for the puncture of the right subclavian vein, it could be shown that the diameter of the vein is larger when the head is in a neutral position.

Some authors therefore always recommend neutral positioning of the head with only slight hyperelevation for punctures without the help of sonography. While an increase in the diameter of the IJV can be achieved in adults by laying the head down, this is of little help in newborns and infants, since from an anatomical point of view the liver and not the venous vascular system represent the blood volume pool. For this reason, either a Valsalva maneuver (rather not recommended, as it is difficult to perform in the age group mentioned) or better liver pressure can be used to help the IJV to fill up better. However, these maneuvers do not help patients with surgically modified anatomy of the head and neck vessels, such as patients with Glenn anastomosis (connection of the superior vena cava to the pulmonary artery).

In most cases, however, an ultrasound device should be available for every puncture of newborns, infants, and small children, so that the landmark technique takes a back seat and is only justified in emergencies. A large number of publications indicate that ultrasound-guided central venous cannulation can be considered the “gold standard”. An overview of the different techniques of sonographically supported puncture of the large veins was presented in earlier work. However, the widespread use of ultrasound does not mean that the anatomical relationships of blood vessels should be ignored. The combination of clinical knowledge about anatomical landmarks with the methods of sonography ultimately leads to a significant reduction in complications and should be taught as such.

The use of ultrasound has also made it possible to explain an old, clinically often made observation that the vessel wall often remains adherent to the needle tip at the moment the needle penetrates and is pressed against the posterior wall of the vein with the penetrating needle. This also explains why we often can aspirate blood only when the needle is withdrawn because the vein reopens (figure 1).

Figure 1. Subtotal occlusion of the vein, when the puncture needle is advanced and only aspiration of blood, is a sign of the intraluminal position of the needle when the needle is withdrawn.
In infants, even slight pressure with the ultrasound head causes the vein to collapse completely. Therefore, a lot of sensitivity and little pressure is required for the puncture.

Patient positioning is key to the success of cannulation of blood vessels in the head and neck region. The use of ultrasound is superior to the “blind method” and allows for more accurate orientation of the vascular structures in the mentioned region.

**Subclavian vein (SCV) access**

In pediatric anesthesia, the subclavian venous approach (SCV) has in a way “gone out of fashion” (been abandoned) because, on the one hand, there is a risk of pneumothorax and consequent insertion of a thoracic drain, and on the other hand, there may large injuries of vital structures in the mediastinum due to their anatomical dimensions. With the establishment of sonography, the puncture of the SCV has gained new importance. The direct visualization of the puncture needle significantly reduces the risk of artificial puncture errors. Thierry Pierot has described the technique of ultrasound-guided puncture of the subclavian vein (SCV) in detail. The ultrasound head must be positioned above the clavicle. In children up to about 10 kg body weight, this technique can be carried out without any problems. While it is important to use a shoulder roller when puncturing the SCV, head positioning may be helpful to prevent the guide wire from deflecting into the IJV. Jung recommends that the patient’s head should face the doctor. This leads to compression of the ipsilateral IJV and is intended to prevent malposition of the CVC. Based on their data, Lukish et al. came to the opposite recommendation. This publication has shown that a neutral head position without shoulder rotation increases the diameter of the SCV, whereas a rotated head with a turned neck leads to a reduction in the circumference of the SCV. However, only 9 school children were included in this study. In my own experience, the neck roll is very helpful and leads to better exposure to SCV, at least in infants. In a very recent publication, Aminnejad and colleagues examined the success rate of the first puncture of the brachiocephalic vein (BCV) in detail. According to these data, the overall success rate for the “first stitch” is 98%, and in the particularly critical group of newborns, it is 73%. According to the same data, there were cases of pneumothorax that required drainage.

**Brachiocephalic vein (BCV) approach**

A very interesting alternative to the subclavicular puncture is the supraclavicular puncture. In the opinion of the authors, this technique should only be performed with ultrasound guidance. When using the in-plane technique, the needle can be well visualized over the entire course deep into the vessel. Another advantage is that even in cardiac anesthesia when using a thoracic retractor, there is no compression of the catheter between the clavicle and the first rib so the supraventricular puncture can also be performed in cardiac surgery. One of the pioneers of this technique is Christian Breschan from Graz. Some publications not only describe the technique in neonates and premature babies but also discuss complications. However, apart from case reports, there are still no studies with large numbers of cases that allow a conclusive assessment of access via BCV in children. While the risk of pneumothorax appears to be very low, it is possible to injure the thoracic duct, which opens into the BCV close to the potential needle entry point, with subsequent chylothorax. In addition, it seems very important to pay attention to the correct positioning depth, especially with venous catheters inserted on the left side. Depending on the manufacturer, the flexibility of the plastic material varies and can lead to incorrect positioning on the right lateral wall of the SCV. The position close to the heart also causes continuous friction on the endothelium, which can lead to increased thrombogenicity (figure 2). The right-sided BCV can also be shown well in the ultrasound image and can be considered as an alternative to the left side.

**Femoral vein (FV) approach**

The femoral vein (FV) is a blood vessel that is very easy to access and easy to visualize in sonography. The puncture technique is sonographically supported, easy, and quick to learn, with a low puncture-related, complication rate.
However, access through the FV is only recommended to a limited extent due to multiple reasons. If the frequency of thrombosis is considered, numerous data show an increased incidence of thrombosis in systems when placing CVC via the FV\textsuperscript{15}. In addition, the mentioned region is potentially moist and contaminated in children who are wearing diapers. In situations where establishing venous access is difficult and when there are reasons that prevent access to the neck, placement of a CVC through the femoral vein may be considered, but the CVC must be removed as soon as possible.

**Control of catheter tip positioning**

Regardless of the existence of alternative methods for verifying the position of the CVC tip, chest radiography is still considered the gold standard. In the field of pediatric medicine, imaging should be based on avoiding ionizing radiation as far as possible. While the exclusion of the pneumothorax after puncture using sonography is not a problem and is even more sensitive compared to conventional radiographs, position control is technically far more difficult\textsuperscript{17}. For example, numerous studies in neonatology and newborns have examined control using sonography\textsuperscript{18}. In the field of anaesthesiology, Kim and co-workers were able to show that transthoracic echocardiography can also provide satisfactory results for experienced examiners\textsuperscript{19}. In one meta-analysis that included 2,548 patients from 25 studies in adult medicine, the combined specificity for detecting malposition was 98.9\%\textsuperscript{20}, while the sensitivity was only 68.2\%\textsuperscript{20}, which supports the mandatory radiographic verification that cannot be omitted. Looking at the X-ray image, the tip of the catheter should be at about the level of the lower edge of the carina, which roughly corresponds to the confluence of the superior vena cava with the right atrium\textsuperscript{21,22}.

**Complications and failures of the CVC**

During catheter placement, it is essential to have a clear idea of the position and depth of the catheter. There are numerous recommendations from different authors (such as the “rule of the thumb”) and formulas (table 2) that can be used for estimating the depth of the catheter. Yamamoto conducted a retrospective study of data from 386 patients during the placement of right-sided CVC via IJV, BCV and left-sided placement via BCV. For right IJV and left BCV, a simplified principle is used where the catheter length is calculated as 10\% of the body length + 1 cm. This applies to patients shorter than 100 cm in height. For patients over 100 cm in height, 1 cm is subtracted from the calculated length (info box location depth).

When placing a central venous catheter (CVC) in children, it is important to anticipate the correct position and depth of the catheter. If the CVC is placed too deeply, there is a risk of cardiac arrhythmias and perforation with pericardial effusion. Conversely, if the CVC is placed too shallow, the risk of thromboembolic complications increases.

**Table 2. Insertion depth of CVC in children via formula**

<table>
<thead>
<tr>
<th>VEIN</th>
<th>THE FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>IJV right and BCV left</td>
<td>Up to 100 cm body size 10% penetration depth +1 cm (example: body size 50 cm = CVC fixation at 7 cm)</td>
</tr>
<tr>
<td></td>
<td>Over 100 cm (up to 140 cm) height 10% -1 cm (example height 120 cm = fixation CVC at 11 cm)</td>
</tr>
<tr>
<td>BCV right</td>
<td>Up to 100 cm body size 10% penetration depth -1 cm (example: body size 70 cm = CVC fixation at 6 cm)</td>
</tr>
<tr>
<td></td>
<td>Over 100 cm (up to 140 cm) height 10% -2 cm (e.g. height 120 cm = fixation CVC at 10 cm)</td>
</tr>
</tbody>
</table>

Legend: H - Height; IJV - Internal Jugular Vein; BCV - Brachiocephalic Vein

In addition to the classic complications of installing central venous catheters such as pneumothorax bleeding and infections, there are some special features, especially

![Figure 3. CVC position in a left superior vena cava (A) and folding of a left-sided, supraclavicular CVC into the confluence of the subclavian vein in the area of the right superior vena cava](image)
in pediatrics. Neonates and premature babies are particularly vulnerable. Nadroo and colleagues have demonstrated that the tip of a CVC placed through a peripheral vein in the hand of premature infants can be moved several centimeters simply by moving the hand. While vascular and myocardial injuries with guidewire are rare in adults, cases of death caused by pericardial tamponade during CVC placement in premature babies have been reported.

Before puncturing the left-sided veins, an overview of the anatomy of the jugular veins should be obtained with the help of sonography. A persistent left superior vena cava is found in about 0.5% of the population, while this is even more common in children with congenital heart defects (up to 5%). If the left superior vena cava persists, about 80% of patients have two superior vena cavae, and in about 20% the right superior vena cava regresses. In this case, there is often an even more pronounced dilatation of the coronary sinus, with an increased tendency to arrhythmias. Accompanying congenital cardiac defects such as atrial and ventricular septal defects are also often found (figure 3).

Normally, from about the 8th week of embryonic development, the upper vena cava, which was initially created on both sides, begins to regress on the left side, where it remains as part of the brachiocephalic vein. Much less common is the missing right superior vena cava with simultaneous persistence of the left superior vena cava, which is then connected to the right side via a dominant brachiocephalic vein. A venous catheter inserted there appears as a rare malposition in the X-ray image (figure 4).

Before proceeding to the puncture, all lumens should be flushed with saline and evacuated. Small lumens such as 4F and less tend to close quickly due to clot formation and can no longer be operated if they are not evacuated. The number of lumens in the catheter not only depends on the intraoperative use but should also be based on subsequent needs, e.g. during an intensive care stay, so consultation with pediatric intensive care specialists is useful.

In patients with known congenital malformations, previous operations, intensive care stays, and/or even ECMO (Extracorporeal Membrane Oxygenation) therapy, a sonographic evaluation of the region to be punctured should always be carried out. Figure 5 shows an example of a patient with thrombotic occlusion of the right superior vena cava and the formation of numerous venovenous collaterals. Figure 5 shows an example of a patient with thrombotic occlusion of the superior vena cava and the formation of numerous venovenous collaterals.

Difficult implementation of wire guidance - examples from practice

When puncturing the IJV of a 3-month-old infant, the needle appears to be in the correct blood vessel. Sonography clearly shows the intraluminal position of the needle tip. Despite this, the guide wire cannot be advanced. A common mistake in such small patients is that when the syringe is removed from the needle for aspiration, the same is moved. Just a few millimeters are enough here to decide whether the puncture was successful or not. One way to avoid this and to securely fix the puncture needle is to fix the wrist to the patient's chin to minimize possible movement.

Figure 4. A very rare case of a right-sided CVC in the absence of a right superior vena cava and position of the catheter tip coming via the brachiocephalic vein (BCV) into a persistent left superior vena cava (Persistent left superior vena cava, PLSVC).

Figure 5. Left-sided installation of a CVC in the IJV due to an occlusion of the right superior vena cava associated with the formation of venovenous collaterals.
Conclusion

Ultrasound-guided puncture of the internal jugular vein (IJV) in children is the method of choice compared to all other vascular approaches due to the lower incidence of thrombosis and infection. The technique of puncturing the brachiocephalic vein is easily learned, has few complications, and provides an alternative to standard approaches even in conditions of difficult vascular anatomy. Complications that arise during CVC placement in children, related to malposition of the catheter, can be avoided. Ultrasound examination can exclude the presence of pneumothorax even before a chest X-ray, but it cannot be used to verify the position of the catheter tip in all patients.

Literature


Declaration of interest statement: None

Received: 17. 03. 2023.
Accepted: 18. 04. 2023.
Online: 01. 06. 2023.