Atlas of Ultrasound-Guided Central Venous Catheter Placement

Neonatal and Pediatric Approach

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Fernando Montes-Tapia
Pediatrics Department
Hospital Universitario "Dr. José Eleuterio González"
Universidad Autónoma de Nuevo Leon
Monterrey, Mexico

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I wish to dedicate this book first to Him, for without His wisdom, this endeavor would not have been possible.

"A truly good wife is the most precious treasure a man can find! Her husband depends on her, and she never lets him down." Her name is Rosario; thank you.

To Félix and Fernando, I hope to have been a good steward.
To my parents, who gave me the chance to exist.
To my siblings, who are always here despite the distance.
To my in-laws, for welcoming me into their family.
To my patients, for whom I have always strived to provide a quality experience, especially warmth when a vascular access was required.

Foreword

Undoubtedly, the placement of a central venous catheter is an essential procedure in the management of hospitalized pediatric patients. Central venous catheters constitute a vital line for fluid volume management, venous access, medication infusion, and provide a safe and consistent means of monitoring the short-, medium-, and long-term treatment of critically ill patients.

Acquiring the skill to place a central venous catheter is therefore of paramount importance in clinical hospital training, both in infants and adults. In the specific case of pediatric patients, the size of the patient and the dimensions of the vessels to be cannulated are distinctive factors in the difficulty of the procedure, presenting an additional challenge to the patient's clinical condition. Evidently, the size and weight of pediatric patients can range widely from neonates to adolescents, making the learning and mastery of techniques across different pediatric ages highly relevant. Precision, assertiveness with the patient, and good judgment complement the operator's knowledge of regional anatomy, the venous system, and nerve branches. All of this must now be integrated with the ability to handle ultrasound equipment, which has facilitated the execution of this meticulous and indispensable procedure.

For the successful execution of this vascular access technique, the guidance, recommendation, and visual support from experienced practitioners are always welcome. This is where a work like the present *Atlas of Ultrasound-Guided Central Venous Catheter Placement: Neonatal and Pediatric Approach* shows its value and relevance. This atlas is a reliable guide that, step by step, image by image, illustrates the path that the operator must follow when placing a central venous catheter in neonates and pediatric patients. The guide in this vascular procedure is the pediatric surgeon Fernando Montes-Tapia, MD, PhD, professor in the Department of Pediatrics at the "Dr. José Eleuterio González" University Hospital of the Universidad Autónoma de Nuevo León, who, through his experience and collaboration with pioneers in pediatric catheterization like Antonio Rodríguez-Tamez, MD, has made the practice of ultrasound-guided vascular access a significant clinical science in hospital practice.

Professor Montes-Tapia guides the operator through the process of placing a central venous catheter, marking each step, each detail, and warning of possible difficulties and causes of errors throughout 23 chapters, organized by vascular access route. In these chapters, he provides a detailed and meticulous overview, supported by 469 photographs of patient positioning, procedures, anatomical access, and ultrasound transducer positioning. Additionally, through 472 ultrasound images parallel to the procedure photographs, he shows in a detailed and schematic manner the vascular structures, nerves, and tissues, presenting the catheter's position within the vascular pathway. In summary, the procedure is illustrated to be performed safely and expertly.

As the author rightly points out, this invasive medical procedure is not a minor one. It demonstrates not only the skills and competence of the individual operator but also the high quality and teamwork capabilities of the clinical services where it is performed. Under certain circumstances, achieving this can become a true challenge for the medical team.

It is a great satisfaction for me and for the academic medical community of the university hospital that our colleague, Dr. Montes-Tapia, publishes this atlas and makes it available to health professionals worldwide who need to perform vascular access from the neonatal stage to adolescence. I conclude by reiterating this atlas as a useful, relevant, accessible work with a didactic format for precise follow-up. Equally and fundamentally important, it will benefit patients undergoing this procedure under reliable and effective guidance.

Dean of the Faculty of Medicine and Hospital Universitario "Dr. Jose E. González"
Universidad Autónoma de Nuevo León
Monterrey, Nuevo León, Mexico
Oscar Vidal-Gutierrez

Preface

Central venous catheter (CVC) placement is the most frequently performed invasive procedure in pediatric and adult patients. The indications for a CVC include hemodynamic monitoring, administration of parenteral solutions, antibiotics, parenteral nutrition, among others.

Traditionally, vascular access is performed using anatomical guides; however, its effectiveness depends on the expertise of the operator. The success of the anatomical guide procedure decreases as the patient's age and weight decrease or the patient has had previous catheterizations or abnormal anatomy. In addition, the risk of associated complications such as hematomas, pneumothorax, cardiac tamponade, or deaths is reported when using this technique.

Ultrasound-guided central venous catheter placement is recognized by the National Institute for Clinical Excellence (2002) recommendations, which state that ultrasound guidance is the preferred method for elective CVC insertion in both adults and children. However, it has not yet become the standard due to lack of training or adequate equipment (ultrasound) to perform it.

This atlas aims to contribute to the development of the knowledge component and, potentially, facilitate the acquisition of skills through the photographic demonstration of techniques within the competence of performing ultrasound-guided vascular access procedures. This atlas is the first in the literature to present a graphic/clinical step-by-step format for each of the 23 types of vascular access in neonatal and pediatric ages.

The decision to share this knowledge stems from a commitment to improving the quality and safety of a procedure often minimized by many physicians as "just vein puncture." However, facing a 0.500 kg newborn or a 100+ kg adolescent presents challenges often associated with complications and fatal incidents.

More than 41 years ago, my mentor Dr. Antonio Rodríguez Taméz began with anatomical guide-based vascular accesses, quickly transitioning to ultrasound-guided placement with the first Site Rite® in Mexico in 1992. His expertise over the years and the use of various ultrasound devices made him a great expert. Thus, in 2002, I started my training in ultrasound-guided vascular access under my mentor, later learning other vascular accesses that I now share with him.

A competitive advantage of ultrasound-guided vascular access lies not only in its quality and safety but also in the psychological impact on the operator. Faced with patients who have multiple previous punctures, difficult vascular access due to weight, clinical condition, or congenital anomalies, the use of ultrasound provides fundamental confidence, ensuring the location of a suitable vein. This confidence gives the operator a decisive initial advantage, approaching the procedure with a mindset of assured success.

Regarding the chapters:

- When the venous access technique is applicable to both neonatal and pediatric stages, we dedicate a chapter to the puncture of the same vein in each age group, acknowledging their unique peculiarities. Conversely, if the technique is strictly for pediatric patients, the description will focus solely on this age group.
- We include chapters illustrating the venous puncture technique from both long-axis (LAX) and short-axis (SAX) views, allowing for the learning of both techniques, and giving the reader the freedom to choose the one they feel more comfortable with and can learn more effectively.

The atlas chapters start with the internal jugular vein access, which I recommend as the first to learn because it is easy to locate and has a direct path to the superior vena cava. In neonates, due to the neck size, the LAX view is impossible, making the SAX view optimal.

Regarding the SAX view technique, described as out of the plane, thus potentially puncturing unvisualized structures (out of the plane), this is mitigated by performing ultrasound-guided dynamic needle-tip positioning (DNTP) to guide the intravenous catheter puncture or the introducer needle; in other words, you must learn to perform a sweep down or up the transducer as you progress with the puncture, ensuring at all times that the needle does not puncture other structures.

We will then describe the puncture technique of the most used vein in my series, the subclavian vein via the infraclavicular route. The puncture is performed in LAX view, which is more difficult to learn, but mastering it will eliminate the major complication described as pneumothorax from my incident scenario. As I always say when teaching this approach, the major incident is not cannulating the vein, but the cervicothoracic region has other veins and other subclavian access routes, such as the supraclavicular route described next, which I only describe in the pediatric stage.

The technique for puncturing the extrathoracic subclavian vein, originally described for pacemaker placement, has a limited margin for location. Anatomically, the subclavian vein starts after the confluence of the cephalic vein with the axillary vein, located in the deltopectoral groove. Thus, there is a short segment of the extrathoracic subclavian vein between this junction and the clavicle before its subclavicular passage. In patients older than 8 years, this segment measures approximately 3 cm in length, increasing as the individual's weight and height increase. Furthermore, the closer the vein is to the clavicle, the larger its diameter. I propose puncturing this specific segment of the subclavian vein, not the axillary vein. Although you will see that the suggested reading for these two chapters only contains literature on pacemaker placement.

Another vein in the cervicothoracic region is the brachiocephalic vein, notable for being a large vessel even in the neonatal stage; I only describe the puncture technique in LAX view.

We continue with the demonstration of femoral vein puncture, particularly in neonatal patients of very low weight (less than 1.5 kg), where many punctures are performed on the iliac vein due to its larger caliber. It can be confirmed in LAX view that the puncture is executed above the femoral head.

Finally, I present the technique for puncturing the upper extremity veins such as the brachial, basilic, and cephalic veins. These are used for the placement of a peripherally inserted central catheter (PICC), which can be punctured using either SAX or LAX views, though I suggest starting with SAX view.

It is my hope that this atlas serves as your guide whenever you perform a venous puncture to place a central venous catheter and that you adopt ultrasound-guided puncture as your standard for quality and safety. Our patients, whom we are privileged to serve, deserve nothing less.

Monterrey, Mexico Fernando Montes-Tapia, MD PhD

Acknowledgments

I wish to express my gratitude to the Universidad Autónoma de Nuevo León, through the Hospital Universitario "Dr. José E. González", for providing the setting for most of my professional practice, a place I consider home. To Dr. Oscar Vidal Gutiérrez, for his trust and the anticipation of better things to come. To Dr. Antonio Rodríguez-Taméz, who is undoubtedly my mentor in the field of ultrasound-guided vascular access; without your expertise and, above all, your friendship, I would not have acquired this skill. To my colleagues Dr. Ulises Garza-Luna and Guillermo Martínez-Flores, for their invaluable support and experience in the field of pediatric surgery. To my fellow faculty members in the Department of Pediatrics for considering me a peer. To the various generations of residents from the Department of Pediatrics at the Hospital Universitario "Dr. José E. González", for their valuable assistance during "the catheter time." To my research interns, Antonio Castillo, Zelenia García-Alcudia, Madeline Nuñez-Ku, who inspired me to excel, Evelyn González and Emilia González for believing in my project, and Karen Cantú for continuing the legacy of her colleagues. To Berenice Ricardez, for her invaluable support in photography. To Sergio Lozano M.D., who assisted me in conveying the knowledge contained in this book in English.

About the Book

This atlas provides a detailed illustration of the venous puncture technique under real-time ultrasonographic guidance, specifically for neonatal and pediatric patients for the insertion of central venous catheters. Comprising 23 chapters, it thoroughly covers all documented venous accesses to date. Each chapter is enhanced with clinical images capturing each phase of the procedure, alongside their corresponding ultrasonographic images, offering a detailed, step-by-step guide for executing each technique.

Contents

About the Author

Fernando Montes-Tapia, MD PhD is a pediatric surgeon and chief of the Department of Pediatrics at the Hospital Universitario "Dr. José E. González and professor at the Faculty of Medicine, Universidad Autónoma de Nuevo León, Monterrey, Mexico. He teaches both undergraduate and graduate courses and is a researcher with National Council of Humanities, Science and Technology (Consejo Nacional de Humanidades, Ciencias y Tecnología - CONAHCYT). His research focuses on ultrasound-guided vascular accesses in neonatal and pediatric patients, for which he has won national research awards in this area. He has participated in multiple conferences to promote the use of ultrasound as the standard for vascular access and offers workshops on ultrasound-guided vascular accesses. He has received various grants for his research and the acquisition of ultrasound equipment (Rotary Club International).

Abbreviations

BCV	Brachiocephalic vein
CA	Carotid artery
CV	Cephalic vein
DNT	Dynamic needle tracking
DNTP	Dynamic needle-tip positioning
ETSCA	Extrathoracic subclavian artery
ETSCV	Extrathoracic subclavian vein
FV	Femoral vein
IJV	Internal jugular vein
IVC	Inferior vena cava
LAX	Long axis
LBCV	Left brachiocephalic vein
LBrV	Left brachial vein
LBV	Left basilic vein
LCA	Left carotid artery
LCV	Left cephalic vein
LETSCA	Left extrathoracic subclavian artery
LETSCV	Left extrathoracic subclavian vein
LFA	Left femoral artery
LFV	Left femoral vein
LIA	Left iliac artery
LIJV	Left internal jugular vein
LIV	Left iliac vein
LSCA	Left subclavian artery
LSCV	Left subclavian vein
RBcV	Right brachial vein
RBCV	Right brachiocephalic vein
RBV	Right basilic vein
RCA	Right carotid artery
RCV	Right cephalic vein
RETSCA	Right extrathoracic subclavian artery

RETSCV	Right extrathoracic subclavian vein
RFA	Right femoral artery
RFV	Right femoral vein
RIA	Right iliac artery
RIJV	Right internal jugular vein
RIV	Right iliac vein
RSCA	Right subclavian artery
RSCV	Right subclavian vein
SAT	Subcutaneous adipose tissue
SAX	Short axis
SCA	Subclavian artery
SCM	Sternocleidomastoid
SCV	Subclavian vein
SVC	Superior vena cava

Chapter 1
General Principles

Due to the nature of this atlas, indications and contraindications are not covered. However, every time a decision is made to perform vascular access, these details must be analyzed and discussed with the attending physician to evaluate the best venous access according to the intended use.

1.1 Informed Consent

- It should be obtained from all patients or legal guardians before performing the procedure.
- This process is carried out with each family member and patient who is mature enough to understand the purpose of the procedure and the benefits, risks, and complications according to the patient's clinical condition.

1.2 Universal Protocol

- Since it is an invasive procedure, all patients should be considered for the pre-procedure, time-out, and post-procedure evaluation.

F. Montes-Tapia, *Atlas of Ultrasound-Guided Central Venous Catheter Placement*, https://doi.org/10.1007/978-3-031-61887-1_1

1.3 Patient Monitoring

- Vascular access is an invasive and high-risk procedure which is performed in the operating room but that can be performed outside the operating room. Quality and safety during the procedure must be guaranteed, so all patients must have at least the following:
  - Cardiac monitoring.
  - Pulse oximeter.
  - Oxygen therapy.
  - Equipment for invasive airway management.

1.4 Sedation

- Our hospital protocol uses the following drugs: midazolam associated with ketamine, fentanyl, or propofol. The combination of these is administered according to the patient's clinical status.
- In infants and anxious patients, start with a dose of midazolam when starting positioning and pre-procedure scanning.
- In patients who do not have vascular access, sedation can be provided intranasally, intramuscularly, intraosseously, or with a combination of these routes, according to the biosorption of each drug.
- In our institution, more than 95% of vascular accesses are performed under sedation outside the operating room.

1.5 Sterile Procedure

- Antiseptic solutions such as chlorhexidine-alcohol or chlorhexidine are used to disinfect the area chosen for the procedure.
- Operator cap and mask.
- Operator handwashing.
- Sterile gown and gloves.
- Protection barriers such as sterile cloth or synthetic fiber fields. These should cover a large area so that they can be placed over a 50-cm guidewire.
- Central venous catheter placement kit: See Fig. 1.1.

Fig. 1.1 The set we use at our institution

1.6 Anesthesia

- In all patients, local infiltration with 1% lidocaine is performed at the puncture site, catheter route, and fixation site. This procedure can be done under ultrasonographic guidance in real time or after previous ultrasound marking.
- In premature patients, local infiltration with lidocaine can cause a hyperechoic area in the tissues that later prevents visualization of the vessels or intravenous catheter below the infiltration. Therefore, the patient is sedated in these cases, and the vessel is punctured with a 24-G intravascular catheter. Once the vein is cannulated, and the guidewire is inserted into the vessel, lidocaine is infiltrated to perform the following steps, which are more painful, such as dilation of the trajectory and fixation with skin suture.

1.7 Ultrasound-Guided Vascular Access

- This atlas only presents the real-time ultrasound-guided vascular access technique.
- It is recommended to use a linear array probe, especially high frequency with a range of more than 10 Mhz. The high frequency allows the visualization of structures close to the skin with greater clarity. In this atlas, we used 13–6 MHz.
- Type of footprint (contact area of the transducer with the skin). There are different sizes according to the brand. The smallest is in the shape of a hockey stick

(with which most of the procedures presented in this atlas were performed), and there are others with a larger footprint of up to 6 cm. However, the choice will depend on the size of the patient. For example, if a patient weighs less than 1500 g, a 5-cm transducer would be too large for the neck or supraclavicular fossa. In contrast, a hockey stick would not be suitable for a teenager weighing 80 kg.

- Transducer and cable coverage equipment. There are covers designed for each type of transducer with suitable alternatives that each hospital designs. In our institution, we usually use a condom or a sterile glove to cover the transducer and a cloth or synthetic fiber field to cover the cable, which you hold with gauze or garters. The objective is that the equipment in contact with the sterile area should also be sterile.
- It is convenient to wash the transducer and the cable to keep them clean, according to the handling standards of each piece of equipment.
- The ultrasound screen is placed ergonomically. It is preferred to place it in front of the operator. Sometimes the patient's position does not allow it, so it is necessary to know how to adapt the screen position, so it does not impede adequate visualization and comfort for the procedure.
- In knobology, we must identify and know how to modify the following parameters:

  – *Position indicator or orientation marker* refers to a reference point on the body of the transducer that serves as a reference point to orient the image on the monitor, that is, which side of the transducer corresponds to the side of the monitor.

    In the procedures demonstrated in this atlas, the mark is placed on the left side of the screen, indicating the tip of the hockey stick probe or the mark on the linear transducer with the largest footprint. The mark on the screen can be of different types. In this atlas, with the equipment we use, it appears as an aqua-colored dot in the upper left corner (Fig. 1.2).

    Before starting to scan, the probe's orientation must be checked, placing gel on the transducer and moving it over the patient to confirm if it moves to our left or right. Another way is by touching one of the ends of the footprint and identifying if the left and right of the transducer correspond to the left or right of the screen and the right and left of the operator.

  – *Depth:* This parameter should allow the chosen vessel to be displayed as close to the top of the screen because the top of the screen is the patient's skin. When using the short-axis (SAX) view, the vessel to be punctured is intended to be displayed in the center of the screen. In the images in this atlas, which are ultrasound screen images, the depth in centimeters (1,9, 2,2, etc.) appears in the lower right corner (Fig. 1.2).

    Certain equipment has the zoom function. It is identified in the upper left of the monitor as an indicator on the side of the probe in the equipment we use for the procedures. In zoom mode, it is a "z" within an aqua circle (Fig. 1.3).

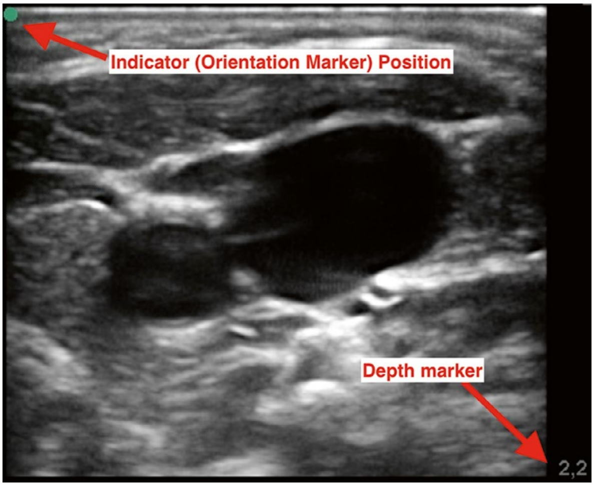

Fig. 1.2 Indicator position and depth marker

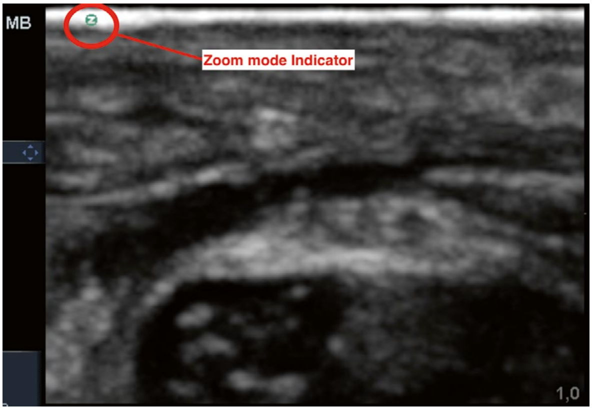

Fig. 1.3 Zoom mode indicator

Although zoom mode allows better visualization of vessels less than 0.5 cm, movements are also magnified, and it is necessary to know how to move when scanning. Movements and displacements must be short and slow.

– *Gain:* This will cause the scanned structures to appear darker in the monitor image (low gain) or the structures to be whiter (high gain).

  This setting is important when the puncture is performed in the SAX view since the tip of a needle is normally displayed as hyperechoic. If we have a high gain (very white image), the tip of the intravenous catheter or the introducer needle will not be recognized. Therefore, the gain must be lowered (to see the image darker), and contrast the needle tip with the surrounding tissue to dynamic needle tip positioning (DNTP).

1.8 Pre-Procedure Scan

- The choice of the vein is made after performing:
  - Rapid central vein assessment (RaCeVA) of the cervicothoracic region for the jugular, subclavian, extrathoracic subclavian, or brachiocephalic veins.
  - RaCeVA of the brachial region for the basilic, brachial, or cephalic veins.
  - Rapid femoral vein assessment (RaFeVA) for the femoral/iliac vein.

1.9 Puncture Technique

- Non-sterile ultrasound gel is placed between the transducer and the sterile cover. Then, to achieve good contact with the skin, saline solution is used since, especially in patients punctured with a very small intravenous catheter, such as 24 G, it can become occluded with gel and obstruct the intravascular cannula.
- In-plane technique. The scan is performed in long-axis (LAX) view (Fig. 1.4); the vessel is visualized longitudinally (Fig. 1.5). In the puncture with this

Fig. 1.4 Transducer in longitudinal position on the right arm