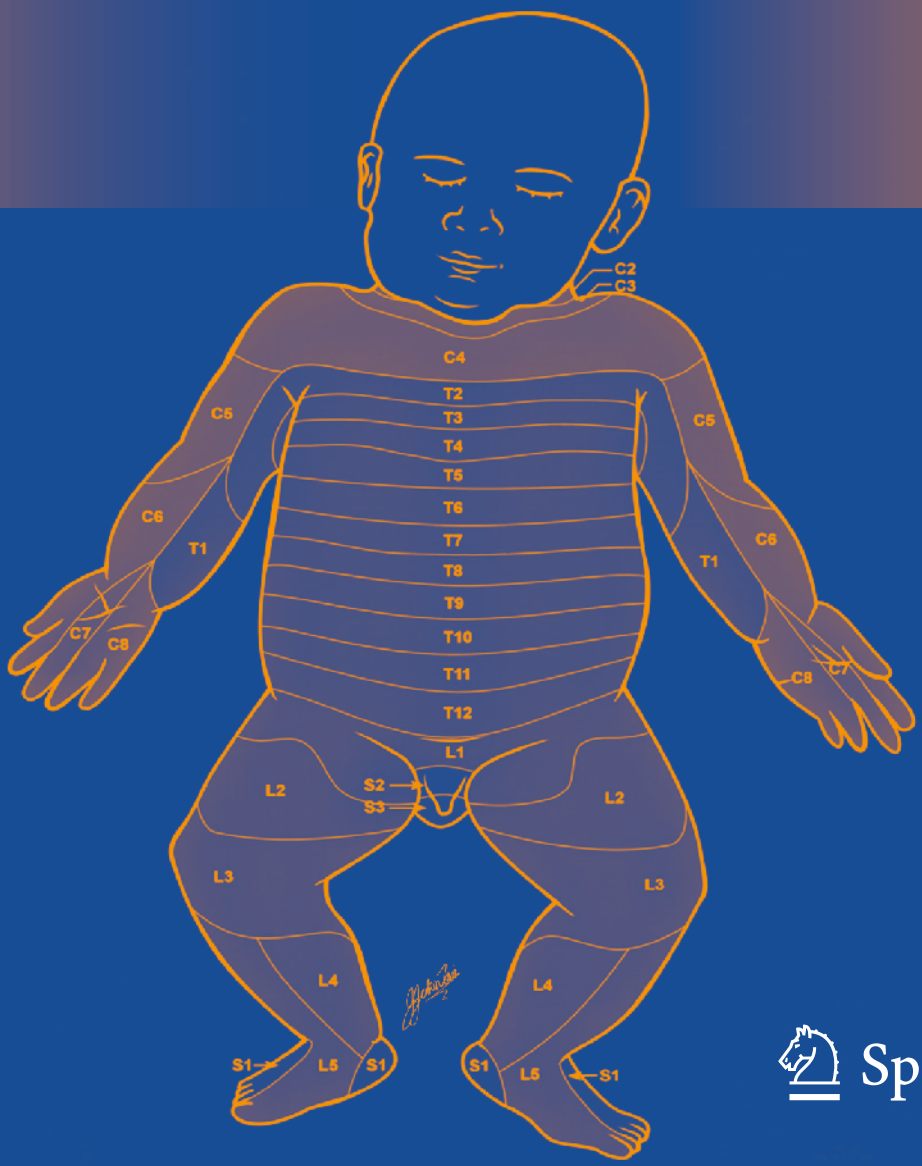
Ban C.H. Tsui
Santhanam Suresh *Editors*

Pediatric Atlas of Ultrasound- and Nerve Stimulation-Guided Regional Anesthesia



Springer

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We would like to dedicate this edition of the book to our patients, our teachers, our students, and our families. In addition, Dr. Tsui would especially like to express his deepest appreciation of the great encouragement provided to him during his academic career by his father, Woon-Tak Tsui, who he lost suddenly during the preparation of this edition.

Ban C.H. Tsui, MD
Santhanam Suresh, MD

To my wife, Eliza, and my children, Jenkin and Jeremy—the real loves of my life. Without their support and understanding, I could not have completed this demanding project. I would also like to dedicate this opus to my parents, Woon-Tak and Kau-Wan, for their love and guidance throughout my life.

Ban C.H. Tsui, MD

I would like to dedicate this book to my family; my wife, Nina, and my children, Aneesha, Sunitha, and Madhav, who have been my greatest inspiration and love in my life; my mother Chandra Santhanam who has been my avid supporter; and to the memory of my late father R. Santhanam whose extraordinary love and dedication to our family fostered my growth. I want to thank all the members of the Department of Pediatric Anesthesiology at the Ann & Robert H. Lurie Children's Hospital of Chicago, whose support was imperative in getting this book off the ground. Finally to my colleague and friend Ban Tsui whose dedication and commitment is what evolved into this atlas.

Santhanam Suresh, MD

Foreword

Over the past 30 years, pediatric regional anesthesia has come of age. There is now a large and rapidly growing body of information regarding the impact of development on pain responses, local anesthetic pharmacology, and the adaptation of a full range of regional anesthetic techniques for infants and children. There is also a quickly expanding literature on safety and efficacy from registries and clinical trials. Thirty years ago, in most pediatric centers worldwide, regional anesthesia was used for only a small fraction of surgeries. Today, it is an essential part of pediatric anesthetic and analgesic management throughout the world. For children in tertiary centers in highly developed countries, regional anesthesia is recognized as an essential component of multimodal analgesic regimens that seek to provide pain relief with movement; diminish opioid use, with a corresponding reduction in opioid side-effects; and facilitate early mobilization, early enteral feeding, and early hospital discharge. Some preliminary studies in infant humans and infant animals suggest that regional anesthesia may have an impact on preventing prolonged changes in central nervous system responses to surgical trauma. In lower resource settings, pediatric regional anesthesia is more often used as a primary anesthetic approach, based on considerations of cost, safety, and reduced need for postoperative intensive care. In the face of ongoing controversy over the impact of general anesthetics on the developing brain, regional anesthesia has a growing role for neonates, infants, and toddlers as an approach to limiting general anesthetic dosing and overall exposure.

Ban Tsui and Santhanam Suresh have been pioneers in this effort, and it is fitting that they are co-editing this wonderful textbook. Both editors have made fundamental innovations in the field over the past 20 years, and both continue to innovate and to mentor to a new generation of investigators and clinicians.

This book is superb in every way. As an atlas, it is first-rate. Anatomic drawings, diagrams, photos, and ultrasound images are combined in ways that masterfully guide the reader. The introductory sections outline the physics behind nerve stimulation and ultrasound in a way that is both sophisticated and highly practical for the clinician. The chapter entitled "Clinical and Practical Aspects of Ultrasound Use" codifies a set of clinical pearls in a clear and useful manner. The chapters that discuss pain assessment, pharmacology, and complications are practical and up-to-date. Part III covers the clinical anatomy of the various regions of the body with relevance to the conduct of regional anesthesia. Throughout these sections, the illustrations are outstanding, with just the right level of detail and the right points of emphasis. Parts IV, V, VI, VII, VIII, IX, and X build on these foundations to elucidate the "how-to" for the full range of regional anesthetic blocks. No other textbook, adult or pediatric, gives such clear guidance on how to perform a block, how to troubleshoot, how to avoid pitfalls, and how to analyze and solve clinical problems. Throughout these sections, there is a great balance between the science and the art of regional anesthesia. In every chapter, there is an authoritative reference list.

I am left with only one criticism, namely the title. This book is a magnificent atlas, but it is really much more than that: it is by far the definitive textbook on pediatric regional anesthesia.

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Preface

In 2007, Tsui, with Springer, published the first textbook and atlas devoted entirely to ultrasound-guided regional blockade in adults, entitled *Atlas of Ultrasound and Nerve Stimulation-Guided Regional Anesthesia*. Since then, many textbooks and atlases with a similar focus have been written, albeit for the adult population only. Despite the extensive progress made in regional anesthesia over the past decades, there still exists no textbook and/or atlas dedicated to both ultrasound- and nerve stimulation-guided regional blockades for the pediatric population.

In preparing this, the first textbook focused on ultrasound and nerve stimulation for pediatric regional anesthesia; we had the privilege of gathering friends and colleagues as contributing authors. Similar to the situation for the adult population, pediatric regional anesthesia has long been regarded as an "art," and success with these techniques is perceived widely to be the domain of a few skilled pediatric anesthesiologists. Around 30 years ago, the introduction of nerve stimulation technology began to nudge regional anesthesia closer toward a "science." However, nerve stimulation has its limitations; the technique relies on electrical impulses to elicit a physiological response from nerves, and considerable variation exists among individuals with respect to this phenomenon. Nerve stimulation guidance is also limited by a number of other factors, including the properties of injectates, physiological fluids (e.g., blood), and disease. Nevertheless, it proved to be a useful and objective method to place, with some reliability, the needle tip close to a target nerve. Surprisingly, the introduction of nerve stimulation did not spark a renewed interest in regional anesthesia, although it proved quite a benefit to those of us who were performing nerve blocks on a regular basis. This is particularly true in the case of pediatric patients, who are usually unable to provide feedback since their blocks are administered under heavy sedation and/or general anesthesia.

Ultrasound imaging is one of the most exciting technological advancements to be applied to regional anesthesia. For the first time in over 100 years, we can visualize the nerve which we intend to block. Unlike nerve stimulation, we foresee ultrasound being a catalyst to draw anesthesiologists toward devoting more of their practice to regional anesthesia. We must remember, however, that the images ultrasound provides us are indirect and open to individual interpretation, depending on the user's experience level, training, and where they received that experience and training. While some practitioners have a natural gift for interpreting ultrasound images, this is not the case with the majority. There is a significant learning curve that goes with mastering ultrasound-guided regional anesthesia. What is more, it has been shown that combining ultrasound and nerve stimulation can improve block success, meaning that two techniques must be learned and mastered to be used to achieve a common goal. This was the main reason for describing and covering the advantages of both technologies in the adult atlas.

It is our hope that the adult atlas spurred readers to incorporate ultrasound (and nerve stimulation) technology into their practice and become better regional anesthesiologists. As with that book, the main objective of this one is to shorten the learning curve associated with regional anesthesia—this time for use in pediatric patients. For those practitioners who are already adept and experienced with pediatric regional anesthesia, this book may serve to increase their knowledge and provide new insights into this field. The ultimate goal of this book is to continue to develop and uncover new knowledge by amalgamating landmark, nerve

stimulation, and ultrasound guidance techniques in regional anesthesia, thereby improving patient care.

This atlas follows a layout similar to the one in the adult atlas. The book begins with several chapters providing information on both ultrasound and nerve stimulation. Equipment and setup, with a focus on needs for pediatric regional anesthesia, are also discussed. Chapter 4 provides perhaps the most important information, including many practical ideas and approaches for using ultrasound during pediatric regional blockade. As with the adult book, we have also included a chapter discussing the fundamental ideas and physical tenets underlying electrical stimulation for regional blockade. In the clinical chapters, the reader will find helpful tables and flowcharts which describe step-by-step procedures for finding a nerve using electrical stimulation as well as troubleshooting tips in case of unexpected or unwanted responses during nerve stimulation. This atlas also includes a chapter on the use of ultrasound for placement of perineural catheters for continuous nerve blocks; many readers will find this chapter applicable to blocks in adults as well.

In the same way that a sound knowledge of anatomy forms the basis of success in regional anesthesia, anatomy forms the core of this book. As Gaston Labat, the father of modern regional anesthesia, stated, "Anatomy is the foundation upon which the entire concept of regional anesthesia is built. Anyone who wishes to be an expert in the art of regional anesthesia must be thoroughly grounded in anatomy." This advice remains as true today as when it was given a century ago. Thus, there are six consecutive chapters discussing pediatric anatomy with relevance to regional anesthesia, each supplemented with diagrams and illustrations to provide the reader with a comprehensive rendering of the anatomy associated with blocks in a particular region of the body. In the clinical chapters, there is a brief description of relevant anatomy with illustrations. In the absence of a readily available pediatric cadaver, we utilized an adult cadaver software program to obtain cross-sectional images showing gross anatomy, and we have used MRI and ultrasound, in pediatric subjects where possible, to capture detailed images of the corresponding block location. This is followed by a clinical description of how to perform ultrasound imaging during regional blockade. These sections describe and illustrate the positioning of the probe, the specific needling technique used, how to use nerve stimulation, and pre- and post-local anesthetic application. This sequential format gives the reader a realistic simulation of the management of each clinical situation.

The images used in this book are those from our everyday practice and are achievable by any newcomer using ultrasound for regional anesthesia. We have been mindful not to concentrate on anatomically perfect ultrasound images—which can be obtained occasionally—but instead show images that are representative of those encountered on an average day. As with the adult atlas, MRI images were captured from consenting patients to further illustrate the neuroanatomy and relationship to surrounding anatomical structures. Where possible, we have also provided schematic drawings to show the relationship between nerves, vessels, bone, muscle, and other structures that one must contend with when using ultrasound to guide nerve blocks. For the ultrasound images, we have again provided unlabeled and labeled images along with a diagram showing the location of the ultrasound probe footprint. The unlabeled image allows the reader to familiarize themselves with a realistic clinical image without the distraction of labels. In our experience, the side-by-side presentation of unlabeled and labeled ultrasound images acts as a helpful learning tool for novice users.

Since ultrasound-guided regional anesthesia is still an emerging field, the literature is constantly being updated with new ideas about how to best apply this technology. In this book, we focus on the most common approaches used and supplement these by including, in clinical pearls and notes, alternative approaches as described in the literature or by the chapter authors. This allows the reader to attempt and select the most suitable approach for his/her own needs. Throughout the book, dynamic and systematic scanning techniques are emphasized. As with adults, ultrasound-guided visualization of obvious nearby landmarks (i.e., blood vessels) is recommended as a first step in identifying target nerves in pediatric patients. From there, shifting the view to the associated neural structures and "tracing back" to the desired block site is,

in our experience, a more user-friendly method than "hunting" for the target nerve and block site without the guidance of any familiar subcutaneous landmarks. In this way, the dynamic method reemphasizes the importance of anatomical knowledge as the foundation for successful regional anesthesia.

It is almost certain that when they are first beginning to use ultrasound for regional blockade, anesthesiologists will encounter difficulty in learning how to use the technology to identify neural structures and place the needle tip accurately. In many cases, this will result in frustration and failure, which likely deters many anesthesiologists from persisting in improving their technique and adopting the technology for their practice. This is especially pertinent to pediatric regional anesthesia since the patients are, in general, uncooperative and the anatomy is that much smaller and, in some cases, underdeveloped compared to adults. We anticipate that the concepts and methods described in this textbook will ease the learning curve for pediatric anesthesiologists wishing to incorporate regional blockade into their repertoire. Finally, the contents of this book provide a useful refresher and resource for all regional anesthesiologists wishing to hone their skills and adapt cutting-edge techniques into their practice.

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Part I

Equipment and Technique for Nerve Stimulation and Ultrasound Guidance in Regional Anesthesia

Regional Block Area Setup, Equipment, and Monitoring

1

Vivian H.Y. Ip and Ban C.H. Tsui

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1.1 Differences Between the Pediatric and Adult Populations That Affect Regional Blocks

It is important to recognize that there are distinct differences between the pediatric and adult populations that can affect regional block technique. In order to understand the setup and equipment used for children in regional anesthesia, one must appreciate that:

- Children do not understand the importance of lying still for a procedure.
- Children are not able to communicate or differentiate paresthesia, pain, or pressure on injection.
- Anatomical structures are smaller and are situated more closely to each other and to the adjacent vessels.
- Target nerves are more superficial to the skin.
- There is a lower concentration of plasma protein binding, especially in young children.

To overcome these differences, regional anesthesia is usually performed in children under deep sedation or general anesthesia. There is ongoing debate regarding performing regional anesthesia in anesthetized adults, but such practice is well accepted in pediatric patients, primarily due to the differences outlined above. This encourages development of other techniques to minimize the incidence of nerve damage, namely, nerve stimulators, ultrasonography, and injection pressure monitoring.

When performing a regional block, the equipment should be appropriate for the size of the patient. In particular, the size of the needle must be adapted to the size of the child. This allows for improved control of the needle while performing the blocks, which are often superficial. The SLA "hockey stick" (25 mm, 13–6 MHz) is a good example of an ultrasound transducer that provides good resolution for superficial structures and has a small footprint. These are essential characteristics when using ultrasound to guide regional blocks in the pediatric population.

1.2 Block Area and Monitoring

Performing regional anesthesia in children requires meticulous attention to detail and concentration. Having a quiet environment with all of the drugs and equipment needed to perform regional anesthesia and resuscitation on hand is of paramount importance. An induction room is an ideal place where the patient can be sedated or anesthetized away from surgical staff and where the regional block could be performed before entering into the operating room. Available space and setups will, however, vary between hospitals. In adults, a designated block area can be used to provide the ideal environment while speeding up turnover time; however, this type of area may be unnecessary for pediatric patients, as the majority will receive a general anesthetic before regional anesthesia is performed. Also, since the regional block is for analgesia, the time for the block to take effect is not as essential as compared to its application for surgical anesthesia.

An assistant trained in regional anesthesia, with experience in monitoring pediatric patients under sedation or general anesthesia, should be present. This is important not only for monitoring the child during the procedure but also to handle the nerve stimulator and to help with the injectate.

Regardless of the area, it is critical to have all equipment, drugs, and monitoring available in the room where the block is to be performed. The best way to gather all the necessary equipment and drugs is to use a well-labeled storage cart (Fig. 1.1) where the supplies are organized and easily identifiable.

The following outlines the contents of this cart:

Fig. 1.1 Equipment storage cart with clear identification of equipment, supplies, and medication

1.2.1 General Equipment

- Sterile skin preparation solution.
- Sponges/gauze.
- Drape.
- Marking pen and ruler for landmark identification.
- Selection of different sizes of syringes.
- A variety of needles with a selection of gauges for skin infiltration, drawing up 5 % dextrose, local anesthetics, sedation, or induction of general anesthetic.
- In pediatric patients, most regional blocks are performed under general anesthesia without a muscle relaxant. However, selections of sedatives and hypnotics can be used for cooperative mature pediatric patients as follows:
  - Midazolam (IM/IV: 0.1–0.15 mg/kg up to 0.5 mg/kg, IV infusion with loading dose of 0.05–0.2 mg/kg over 2–3 min. Continuous infusion initiated at a rate of 0.06–0.12 mg/kg/h)
  - Propofol (IV: 1–2 mg/kg for sedation, then 100–150 μg/kg/min infusion)
  - Short-acting opioids:
    - Fentanyl (IV sedation: 1–2 μg/kg, then 0.5–1 μg/kg/h IV infusion).
    - Remifentanil (IV: 2–18 years: 1 μg/kg over 30–60 s, then 0.05–0.1 μg/kg/min IV infusion). All sedation medication should be titrated to response.
  - Several commonly used local anesthetics with different concentrations, as well as 50 mL bags or ampules of normal saline for drug dilution if necessary.
  - *All local anesthetics should be stored separately from the intravenous drugs*.

1.2.2 Emergency Drugs and Resuscitating Equipment

- Although the use of ultrasound allows reduced volumes of local anesthetic to accomplish a successful nerve block, it is pertinent to have resuscitation equipment and drugs available.
- Children have a higher tolerance to local anesthetic on a weight-dependent basis owing to a greater volume of distribution; this increases the threshold in reaching the toxic dose. However, in newborns less than 6 months, the threshold in reaching the toxic dose is reduced due to the lower concentration of serum protein for local anesthetic binding, namely, alpha-1 acid glycoprotein. This results in a higher plasma concentration of unbound local anesthetic.