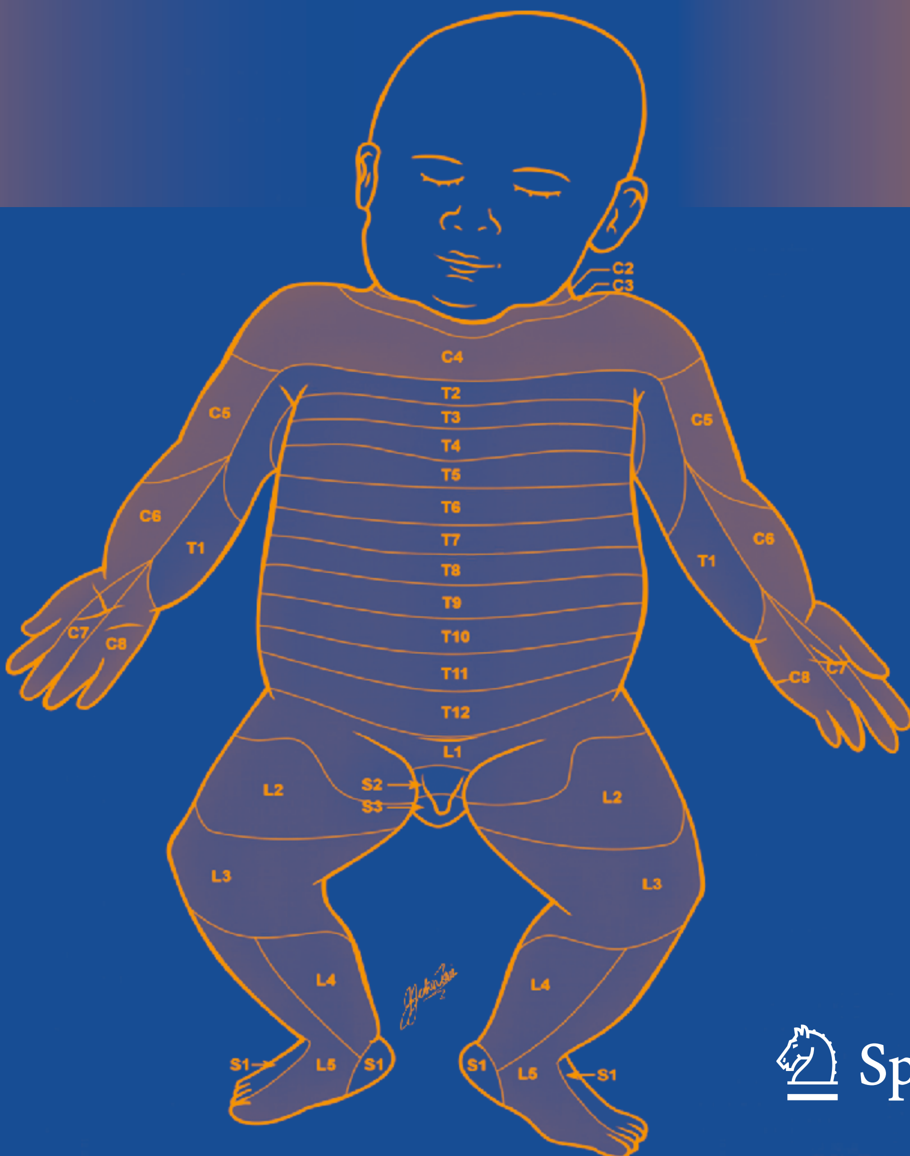
Ban C.H. Tsui
Santhanam Suresh *Editors*

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



Springer

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

Ban C.H. Tsui • Santhanam Suresh
Editors

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

Springer

Editors
Ban C.H. Tsui, Dip Eng, BSc (Math), B Pharm, MSc, MD, FRCPC
Professor and Director of Clinical Research
Department of Anesthesiology and Pain Medicine
University of Alberta
Edmonton, Alberta
Canada

Pediatric and Adult Anesthesiologist
Stollery Children's Hospital/University of Alberta Hospital
Site Chief, Anesthesia, Cross Cancer Institute
Edmonton, Alberta
Canada

Santhanam Suresh, MD
Arthur C. King Professor and Chair of Pediatric Anesthesiology
Department of Pediatric Anesthesiology
Ann and Robert H. Lurie Children's Hospital of Chicago
Chicago, IL
USA

Professor of Anesthesiology and Pediatrics
Feinberg School of Medicine
Northwestern University
Chicago, IL
USA

ISBN 978-0-387-79963-6 ISBN 978-0-387-79964-3 (eBook)
DOI 10.1007/978-0-387-79964-3

Library of Congress Control Number: 2015949112

Springer New York Heidelberg Dordrecht London

Printed on acid-free paper

Springer Science+Business Media LLC New York is part of Springer Science+Business Media (www.springer.com)

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.

Charles Berde, MD, PhD
Professor of Anesthesia (Pediatrics), Harvard Medical School,
Children's Hospital Boston, Boston, MA, USA

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.

Edmonton, Alberta, Canada — Ban C.H. Tsui, MSc, MD, FRCPC
Chicago, IL, USA — Santhanam Suresh, MD

Acknowledgments

We wish to acknowledge the following individuals for their support, hard work, and contributions in preparing this book. Dr. Tsui's research manager, Dr. Gareth Corry, spent many extra hours and worked diligently to contribute toward and assemble the material contained in this book. His continual assistance with editing helped organize and expedite our and our colleagues' writing and editing process. We also wish to thank a group of students, medical students, fellows, and research assistants over the past 5 years, including Natalie Chua, Kim Cochrane, Jason Ha, Sarah Henschke, Alex Kwan, Danika Leung, Paul Li, Jennifer Pillay, and Jenkin Tsui from the University of Alberta, and Dr. Amod Sawardekar from Northwestern University, who assisted in organizing chapter drafts, labeling of the images, and contribution of the written material. The Chair of the University of Alberta Department of Anesthesiology and Pain Medicine, Dr. Mike Murphy, provides ongoing support and encouragement. Dr. Michelle Noga, of the University of Alberta Department of Diagnostic Imaging and Radiology, facilitated access to the institution's MRI technology and operators. We also acknowledge the work done by Teresa Liang, now a radiology resident at the University of British Columbia, who diligently collected the MRI images used in this book. We acknowledge the Ecole Polytechnique Fédérale de Lausanne, Switzerland, Visible Human Web Server (http://visiblehuman.epfl.ch) as the data source for the anatomical slices used throughout the book. Staff members from the University of Alberta Hospital, the Stollery Children's Hospital, and Northwestern University/Lurie Children's Hospital Chicago always provide an excellent environment for patient care, teaching, and research that has directly facilitated the advancement of clinical regional anesthesia practice. A Clinical Scholar Award from the Alberta Heritage Foundation for Medical Research allowed Dr. Tsui to pursue this project by helping to support his academic work. The unrestricted grant from Springer to start this project was a financial help and support, and Shelley Reinhardt and Michael D. Sova from Springer are greatly appreciated for providing their expertise and assistance for this project.

Edmonton, Alberta, Canada — Ban C.H. Tsui, MSc, MD, FRCPC
Chicago, IL, USA — Santhanam Suresh, MD

Contents

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

1 Regional Block Area Setup, Equipment, and Monitoring 3
Vivian H.Y. Ip and Ban C.H. Tsui

1.1 Differences Between the Pediatric and Adult Populations That Affect Regional Blocks 4
1.2 Block Area and Monitoring 4
1.2.1 General Equipment 5
1.2.2 Emergency Drugs and Resuscitating Equipment 5
1.2.3 Resuscitation Equipment 6
1.2.4 Resuscitation Drugs (Intravenous Doses) 6
1.2.5 Monitoring 6
1.2.6 Nerve Block and Catheter Equipment 6
1.2.7 Needles 6
1.2.8 Peripheral Nerve Catheters 9
1.2.9 Neuraxial Nerve Blocks/Catheters 9
1.2.10 Additional Equipment 9
Suggested Reading 10

2 Pediatric Electrical Nerve Stimulation 11
Kelly P.A. Byrne and Ban C.H. Tsui

2.1 Nerve Stimulation Procedure 12
2.2 Electrophysiology 12
2.2.1 Characteristics of Electrical Impulses 12
2.2.2 Current Intensity and Duration 13
2.2.3 Rate of Current Change 13
2.2.4 Polarity of Stimulating and Returning Electrodes 13
2.2.5 Distance-Current Relationship 14
2.2.6 Current Density of Electrodes and Injectates 15
2.2.7 Electrodes 15
2.2.8 Injectates 15
2.2.9 Electrical Impedance 16
2.3 Electrical Epidural Stimulation 17
2.3.1 Test Equipment and Procedure 17
2.4 Mechanisms of the Epidural Stimulation Test 18
2.4.1 Stimulating Epidural Catheter Requirements 19
2.4.2 Effective Conduction of Electrical Current 19
2.4.3 Advancement of the Catheter 20
2.4.4 Considerations for Test Performance and Interpretation 20
2.4.5 Limitations of Epidural Stimulation 20

2.5 Useful Equipment Features in Nerve Stimulation 21
2.5.1 Constant Current Output and Display 21
2.5.2 Variable Pulse Width and Frequency 22
2.5.3 Other Features 22
2.6 Practical Considerations 23
2.6.1 Documentation 23
2.6.2 Population Considerations 23
2.6.3 Does Nerve Stimulation Make a Difference? 23
References 23
Suggested Reading 23

3 Ultrasound Basics 25
Michelle L. Noga, Vivian H.Y. Ip, and Ban C.H. Tsui

3.1 Basic Ultrasound Physics and Technology 27
3.1.1 Basic Principles 27
3.2 Transducers 27
3.2.1 Types of Ultrasound Transducers 28
3.3 Sound Wave Properties in Tissue 29
3.3.1 Speed of Sound 30
3.3.2 Reflection 30
3.3.3 Scattering 30
3.3.4 Resolution 30
3.3.5 Refraction 30
3.3.6 Absorption 30
3.4 Optimization of Image Quality: Knobology 31
3.4.1 Frequency 31
3.4.2 Depth 31
3.4.3 Gain 31
3.4.4 Time Gain Compensation 31
3.4.5 Focal Zone 31
3.4.6 Doppler Ultrasound 31
3.5 Anisotropy and Artifacts 33
3.5.1 Anisotropy 33
3.5.2 Artifacts 33
3.6 Echogenic Appearance of Various Tissues 35
3.7 Equipment Selection 38
3.8 Current Advances for Future Developments 39
3.8.1 Compound Imaging 39
3.8.2 Single-Crystal Transducers 39
3.8.3 Capacitive Micromachined Ultrasound Transducers (CMUT) . . . 39
3.8.4 Sonix GPS (Ultrasonix Medical Corp, Richmond, BC, Canada) . . 39
3.8.5 Power Doppler 39
3.8.6 Robot-Assisted Regional Anesthesia 39
Suggested Reading 40

4 Clinical and Practical Aspects of Ultrasound Use 41
Michelle L. Noga, Vivian H.Y. Ip, and Ban C.H. Tsui

4.1 Image Acquisition 42
4.2 Probe Preparation 42
4.3 Image Optimization 44
4.3.1 Probe Alignment 44
4.3.2 Practical Approach: Traceback Method 46

4.4 Control of Needle Trajectory 49
4.4.1 Visibility of Needles 49
4.4.2 Hand-Eye Coordination 51
4.4.3 Needling Technique 52
References 57
Suggested Reading 57

5 Regional Block Catheter Insertion Using Ultrasonography and Stimulating Catheters 59
Vivian H.Y. Ip and Ban C.H. Tsui

5.1 Indications, Contraindications, and Safety of Peripheral Nerve Catheter Placement 60
5.2 Equipment and Injectates 60
5.2.1 Equipment Required 60
5.2.2 Sterile Transducer Preparation 65
5.2.3 Choice of Injectates 65
5.3 Technique 66
5.3.1 Confirming Catheter Tip Location with Ultrasonography 66
5.3.2 Confirming Catheter Tip Location with Nerve Stimulation 67
5.3.3 Catheter-Over-Needle Assembly Insertion 67
5.3.4 Securing the Catheter 68
5.4 Examples of Common Peripheral Nerve Catheterization Procedures Used in Children 69
5.4.1 Infraclavicular Nerve Block Catheterization 69
5.4.2 Femoral Nerve Block Catheterization 69
5.4.3 Sciatic Nerve Block Catheterization 70
5.5 Summary 71
References 72
Suggested Reading 72

Part II Considerations in Pediatric Regional Anesthesia

6 Pain Assessment in Children Undergoing Regional Anesthesia 75
Bruce D. Dick, Kathy Reid, Michelle J. Verrier, and Alex Baloukov

6.1 Background 76
6.2 Principles of Pain Assessment in Infants and Children 76
6.3 Assessing Pain in Neonates and Infants 77
6.3.1 The Premature Infant Pain Profile (PIPP) 78
6.3.2 Neonatal Pain Agitation and Sedation Scale (N-PASS) 79
6.3.3 CRIES 80
6.3.4 Assessing Postoperative Pain in Infants and Young Children 81
6.4 Assessing Pain in Children and Adolescents 82
6.4.1 Faces Pain Scale-Revised 82
6.4.2 Numeric Rating Scales (NRS) 82
6.4.3 Oucher 82
6.4.4 Pieces of Hurt/Poker Chip Scale 82
6.4.5 Wong-Baker FACES Pain Scale 82
6.4.6 Visual Analogue Scale (VAS) 82
6.4.7 Children's Hospital of Eastern Ontario Pain Scale (CHEOPS) 83
6.5 Assessing Postoperative Pain in Critically Ill Children 84
6.6 Assessing Postoperative Pain in Children with Cognitive Impairments 86
6.7 Summary 88
6.8 Developmental, Familial, and Psychological Factors 90

6.8.1 Age . . . 90
6.8.2 Developmental Delays . . . 90
6.8.3 Psychological Factors . . . 91
6.8.4 Gender . . . 92
6.8.5 Cultural Factors . . . 93
Conclusion . . . 93
References . . . 94
Suggested Reading . . . 96

7 Pediatric Pharmacological Considerations . . . 97
Derek Dillane

7.1 Introduction . . . 98
7.2 Structure and Physiochemical Properties . . . 98
7.2.1 Onset of Action, Potency, and Duration . . . 99
7.2.2 Sodium Channel . . . 100
7.2.3 Physiological Considerations . . . 101
7.3 Pharmacokinetics . . . 102
7.3.1 Absorption . . . 102
7.3.2 Absorption from Epidural Space . . . 102
7.3.3 Absorption from Other Routes of Administration . . . 102
7.3.4 Distribution . . . 103
7.3.5 Plasma Protein Binding . . . 103
7.3.6 Hepatic Metabolism . . . 104
7.4 Toxicity . . . 105
7.4.1 Central Nervous System Toxicity . . . 106
7.4.2 Cardiac Toxicity . . . 106
7.4.3 Treatment of Toxicity . . . 107
7.4.4 Prevention of Toxicity . . . 108
7.5 Dosing . . . 108
References . . . 108
Suggested Reading . . . 110

8 Complications of Regional Anesthesia in the Pediatric Population . . . 111
Adam M. Dryden and Ban C.H. Tsui

8.1 General Principles . . . 112
8.2 Adverse Events Related to Local Anesthetics . . . 115
8.2.1 Allergic Reactions . . . 115
8.2.2 Systemic Toxic Reactions . . . 115
8.3 Complications Related to Regional Anesthesia Equipment . . . 119
8.3.1 Introduction . . . 119
8.3.2 Adverse Events Caused by Needles . . . 119
8.3.3 Adverse Events Caused by Nerve Stimulators . . . 124
8.3.4 Adverse Events Caused by Ultrasound Probes . . . 124
8.3.5 Summary . . . 124
8.4 Block Complications . . . 125
8.4.1 Introduction . . . 125
8.4.2 Complications of Peripheral Nerve Blocks . . . 125
8.4.3 Complications of Neuraxial Blocks . . . 126
8.4.4 Summary . . . 127
Conclusion . . . 127
References . . . 129
Suggested Reading . . . 131

Part III Clinical Anatomy

9 Clinical Anatomy of the Head and Neck . . . 135
Glenn Merritt, Anil H. Walji, and Ban C.H. Tsui
9.1 Clinical Anatomy of Trigeminal Nerve . . . 136
9.1.1 Ophthalmic Nerve (V1 Division of the Trigeminal Nerve, Pure Sensory) . . . 138
9.1.2 Maxillary Nerve (V2 Division of the Trigeminal Nerve, Pure Sensory) . . . 140
9.1.3 Mandibular Nerve (V3 Division of the Trigeminal Nerve, Sensory and Motor to Muscles of Mastication) . . . 142
9.2 Clinical Anatomy of the Cervical Plexus . . . 142
9.3 Clinical Anatomy of Occipital Nerves . . . 145
9.3.1 Lesser Occipital Nerve (C2) . . . 145
9.3.2 Greater Occipital Nerve (C2) . . . 146
9.4 Clinical Anatomy of the Nerve of Arnold . . . 146
Suggested Reading . . . 147

10 Clinical Anatomy of the Brachial Plexus . . . 149
Anil H. Walji and Ban C.H. Tsui
10.1 Brachial Plexus: Overview . . . 150
10.2 Branches of the Brachial Plexus . . . 153
10.2.1 Branches from the Roots (Ventral Rami) . . . 153
10.2.2 Branches from the Trunks . . . 153
10.2.3 Branches from the Cords . . . 154
10.2.4 Terminal Nerves . . . 154
Suggested Reading . . . 163

11 Clinical Anatomy of the Lumbar Plexus . . . 165
Anil H. Walji and Ban C.H. Tsui
11.1 Lumbar Plexus . . . 166
11.1.1 Branches of the Lumbar Plexus . . . 168
11.1.2 Iliohypogastric Nerve . . . 169
11.1.3 Ilioinguinal Nerve . . . 170
11.1.4 Genitofemoral Nerve . . . 170
11.1.5 Lateral Femoral Cutaneous Nerve (Lateral Cutaneous Nerve of Thigh) . . . 170
11.1.6 Femoral Nerve . . . 171
11.1.7 Obturator Nerve . . . 173
Suggested Reading . . . 175

12 Clinical Anatomy of the Sacral Plexus . . . 177
Anil H. Walji and Ban C.H. Tsui
12.1 Sacral Plexus . . . 178
12.2 Direct Muscular Branches of the Sacral Plexus . . . 179
12.2.1 Nerve to the Piriformis . . . 179
12.2.2 Nerve to Obturator Internus and Gemellus Superior . . . 179
12.2.3 Nerve to Quadratus Femoris and Gemellus Inferior . . . 179
12.3 Major Terminal Nerves of the Sacral Plexus . . . 179
12.3.1 Superior Gluteal Nerve . . . 179
12.3.2 Inferior Gluteal Nerve . . . 179
12.3.3 Posterior Femoral Cutaneous Nerve . . . 179
12.3.4 Sciatic Nerve . . . 180
12.3.5 Tibial Nerve . . . 182

12.3.6 Common Peroneal (Fibular) Nerve 183
12.3.7 Pudendal Nerve. 184
12.3.8 Pelvic Splanchnic Nerves 185
Suggested Reading 185

13 Clinical Anatomy of the Trunk and Central Neuraxis 187
Anil H. Walji and Ban C.H. Tsui
13.1 Spinal Nerves and the Vertebral Column 188
13.1.1 Origin of Spinal Nerves 188
13.1.2 Vertebral Column 188
13.2 Development of the Vertebral Column. 190
13.2.1 Developmental Anatomy of the Thoracic and Lumbar Vertebral Column (Spine) 191
13.2.2 Developmental Anatomy of the Sacrum. 193
13.3 Costovertebral Articulations. 194
13.4 Paravertebral Space 196
13.5 Thoracic Spinal Nerves and Intercostal Nerves 196
13.6 Vertebral (Spinal) Canal 201
13.6.1 Vertebral Levels, Spinal Nerve Roots, and Spinal Cord Segments 201
13.6.2 Spinal Nerves Above the Sacrum 202
13.6.3 Termination of the Spinal Cord and Dural Sac. 203
13.6.4 CSF Volume 204
Reference 204
Suggested Reading 204

14 Clinical Anatomy of the Dermatomes and Innervation of the Joints. 205
Anil H. Walji and Ban C.H. Tsui
14.1 Introduction 206
14.1.1 Dermatomes 206
14.1.2 Myotomes 206
14.1.3 Osteotomes 207
14.2 Innervation of the Upper Extremity 207
14.2.1 Dermatomes and Cutaneous Distribution of the Peripheral Nerves 207
14.2.2 Myotomes 209
14.2.3 Osteotomes 210
14.2.4 Innervation of the Major Joints of the Upper Extremity 211
14.3 Innervation of the Lower Extremity 215
14.3.1 Dermatomes and Cutaneous Distribution of the Peripheral Nerves 215
14.3.2 Myotomes 216
14.3.3 Osteotomes 218
14.3.4 Innervation of the Major Joints 219
Suggested Reading 222

Part IV Nerve Blocks of the Head and Neck

15 Trigeminal Nerve Blocks 225
Glenn Merritt and Ban C.H. Tsui
15.1 Indications 226
15.2 Block Techniques 226
15.2.1 Superficial Transcutaneous Approach to Trigeminal Nerve Blocks: Supraorbital, Infraorbital, and Mental Nerve Block. 226

15.2.2 Intraoral Approach to Trigeminal Nerve Blocks: Infraorbital, Mental, and Greater Palatine Nerves 233
15.2.3 Deep Trigeminal Nerve Blocks 237
15.3 Current Literature in Ultrasound-Guided Approaches 239
15.4 Case Study 239
References 239
Suggested Reading 240

16 Cervical Plexus Blocks 241
Ban C.H. Tsui

16.1 Indications for Cervical Plexus Block 242
16.1.1 Indications for Superficial Cervical Plexus Block 242
16.1.2 Indications for Combined Superficial and Deep Cervical Plexus Block 242
16.2 Classic (Deep) Cervical Plexus Block 242
16.2.1 Patient Positioning 243
16.2.2 Landmarks and Surface Anatomy 243
16.2.3 Needle Insertion Technique 243
16.2.4 Nerve Localization and Local Anesthetic Application. 244
16.2.5 Current Literature for Deep Cervical Plexus Block 246
16.3 Ultrasound-Guided Superficial Cervical Plexus Block 247
16.3.1 Patient Positioning 248
16.3.2 Landmarks and Surface Anatomy 248
16.3.3 Scanning Technique 249
16.3.4 Sonographic Appearance 249
16.3.5 Needle Insertion Technique 251
16.3.6 Local Anesthetic Application 252
16.3.7 Current Literature for Superficial Cervical Block 252
16.4 Great Auricular Nerve Blocks 252
16.4.1 Patient Positioning 252
16.4.2 Landmarks and Surface Anatomy 253
16.4.3 Needle Insertion Technique 254
16.4.4 Nerve Localization and Local Anesthetic Application. 254
16.4.5 Current Literature for Great Auricular Nerve Block 254
16.5 Case Study 254
References 254
Suggested Reading 254

17 Occipital Nerve Blocks 255
Ban C.H. Tsui

17.1 Indications 256
17.2 Block Techniques 256
17.2.1 Patient Positioning 256
17.2.2 Landmarks and Surface Anatomy 258
17.2.3 Needle Insertion Technique 258
17.2.4 Local Anesthetic Application 259
17.3 Current Literature in Ultrasound-Guided Approaches 259
17.4 Case Study 259
References 259
Suggested Reading 259

18 Blockade of the Auricular Branch of the Vagus Nerve (Nerve of Arnold) 261
Ban C.H. Tsui
18.1 Indications 262
18.2 Block Technique 262
18.2.1 Patient Positioning 262
18.2.2 Landmarks and Surface Anatomy 262
18.2.3 Needle Insertion Technique 263
18.2.4 Local Anesthetic Application 263
18.3 Current Literature in Ultrasound-Guided Approaches 263
18.4 Case Study 264
Reference 264
Suggested Reading 264

Part V Nerve Blocks Above the Clavicle

19 Interscalene Brachial Plexus Block 267
Ban C.H. Tsui
19.1 Indications 268
19.2 Surface Anatomy 268
19.2.1 Patient Positioning 268
19.3 Nerve Stimulation Technique 269
19.3.1 Needle Insertion 270
19.3.2 Current Application and Appropriate Responses 271
19.3.3 Modifications to Inappropriate Responses 272
19.4 Ultrasound-Guided Technique 273
19.4.1 Preparing the Site 275
19.4.2 Scanning Technique 275
19.4.3 Sonographic Appearance 277
19.4.4 Needle Insertion 278
19.5 Local Anesthetic Application 279
19.5.1 Clinical Pearls: Interscalene Block 279
19.6 Current Literature in Ultrasound-Guided Approaches 279
19.7 Case Study 280
References 281
Suggested Reading 281

20 Supraclavicular Brachial Plexus Block 283
Ban C.H. Tsui
20.1 Indications 284
20.2 Surface Anatomy 284
20.3 Nerve Stimulation Technique 285
20.3.1 Needle Insertion 286
20.3.2 Current Application and Appropriate Responses 287
20.3.3 Modifications to Inappropriate Responses 288
20.4 Ultrasound-Guided Technique 288
20.4.1 Scanning Technique 290
20.4.2 Sonographic Appearance 291
20.4.3 Needle Insertion 292
20.5 Local Anesthetic Application 292
20.6 Current Literature in Ultrasound-Guided Approaches 293
20.7 Case Study 294
References 295
Suggested Reading 295

Part VI Nerve Blocks Below the Clavicle

21 Infraclavicular Brachial Plexus Block 299
Ban C.H. Tsui
21.1 Indications 300
21.2 Surface Anatomy 300
21.3 Nerve Stimulation Technique 301
21.3.1 Needle Insertion 301
21.3.2 Modifications to Inappropriate Responses 303
21.4 Ultrasound-Guided Technique 304
21.4.1 Preparing the Site 306
21.4.2 Scanning Technique 306
21.4.3 Sonographic Appearance 306
21.4.4 Needle Insertion 307
21.5 Local Anesthetic Application 308
21.6 Current Literature in Ultrasound-Guided Approaches 308
21.7 Case Study 309
References 310
Suggested Reading 310

22 Axillary Block of the Brachial Plexus 311
Ban C.H. Tsui
22.1 Indications 312
22.2 Surface Anatomy 312
22.3 Nerve Stimulation Technique 312
22.3.1 Modifications to Inappropriate Responses 314
22.4 Ultrasound-Guided Technique 315
22.4.1 Preparing the Site 315
22.4.2 Scanning Technique 317
22.4.3 Sonographic Appearance 317
22.4.4 Needle Insertion 318
22.5 Local Anesthetic Application 319
22.6 Current Literature in Ultrasound-Guided Approaches 319
22.7 Case Study 320
References 320
Suggested Reading 320

23 Terminal Nerve Blocks of the Upper Extremity 321
Ban C.H. Tsui
23.1 Median Nerve Block 322
23.1.1 Surface Anatomy 322
23.1.2 Nerve Stimulation Technique 323
23.1.3 Ultrasound-Guided Technique 323
23.1.4 Local Anesthetic Application 324
23.1.5 Case Study 325
23.2 Radial Nerve Block 326
23.2.1 Surface Anatomy 326
23.2.2 Nerve Stimulation Technique 327
23.2.3 Ultrasound-Guided Technique 327
23.2.4 Local Anesthetic Application 330
23.2.5 Case Study 330
23.3 Ulnar Nerve Block 330
23.3.1 Surface Anatomy 331
23.3.2 Nerve Stimulation Technique 332

23.3.3 Ultrasound-Guided Technique 332
23.3.4 Local Anesthetic Application 334
23.3.5 Case Study 334
23.4 Current Literature in Ultrasound-Guided Approaches 334
Reference 334
Suggested Reading 334

Part VII Nerve Blocks of the Lumbar Plexus

24 Posterior Lumbar Plexus Block 337
Karen R. Boretsky and Ban C.H. Tsui
24.1 Indications 338
24.2 Surface Anatomy 338
24.3 Nerve Stimulation Technique 339
24.3.1 Needle Insertion 339
24.3.2 Current Application and Appropriate Responses 340
24.3.3 Modifications to Inappropriate Responses 340
24.4 Ultrasound-Guided Technique 342
24.4.1 Scanning Technique 344
24.4.2 Sonographic Appearance 346
24.4.3 Needle Insertion 350
24.5 Local Anesthetic Application 351
24.6 Current Literature in Ultrasound-Guided Approaches 352
24.7 Case Study 352
References 353
Suggested Reading 353

25 Terminal Nerve Blocks of the Lower Extremity 355
Ban C.H. Tsui
25.1 Femoral Nerve Block 356
25.1.1 Indications 356
25.1.2 Surface Anatomy 356
25.1.3 Nerve Stimulation Technique 357
25.1.4 Ultrasound-Guided Technique 359
25.1.5 Local Anesthetic Application 363
25.1.6 Current Literature in Ultrasound-Guided Approaches 363
25.1.7 Case Study 364
25.2 Lateral Femoral Cutaneous Nerve Block 365
25.2.1 Indications 365
25.2.2 Surface Anatomy 365
25.2.3 Nerve Stimulation Technique 365
25.2.4 Ultrasound-Guided Technique 366
25.2.5 Local Anesthetic Application 368
25.2.6 Current Literature in Ultrasound-Guided Approaches 368
25.2.7 Case Study 369
25.3 Obturator Nerve Block 369
25.3.1 Indications 369
25.3.2 Surface Anatomy 370
25.3.3 Nerve Stimulation Technique 370
25.3.4 Ultrasound-Guided Technique 371
25.3.5 Current Literature in Ultrasound-Guided Approaches 373
25.3.6 Case Study 373

25.4 Saphenous Nerve Block . . . 374
25.4.1 Indications . . . 374
25.4.2 Surface Anatomy . . . 374
25.4.3 Nerve Stimulation Technique . . . 375
25.4.4 Ultrasound-Guided Technique . . . 375
25.4.5 Current Literature in Ultrasound-Guided Approaches . . . 378
25.4.6 Case Study . . . 378
References . . . 379
Suggested Reading . . . 379

Part VIII Nerve Blocks of the Sacral Plexus

26 Sciatic and Popliteal Nerve Blocks . . . 383
Heather Y.Z. Ting and Ban C.H. Tsui
26.1 Indications . . . 384
26.2 Posterior Gluteal (Labat) Sciatic Nerve Block . . . 384
26.2.1 Surface Anatomy . . . 384
26.2.2 Nerve Stimulation Technique . . . 385
26.2.3 Ultrasound-Guided Technique . . . 389
26.2.4 Local Anesthetic Application . . . 391
26.3 Infragluteal/Subgluteal Sciatic Nerve Block Approach . . . 393
26.3.1 Surface Anatomy . . . 393
26.3.2 Nerve Stimulation Technique . . . 394
26.3.3 Ultrasound-Guided Technique . . . 397
26.3.4 Case Study . . . 400
26.4 Anterior Sciatic Nerve Block Approach . . . 401
26.4.1 Surface Anatomy . . . 401
26.4.2 Nerve Stimulation Technique . . . 403
26.4.3 Ultrasound-Guided Technique . . . 406
26.4.4 Local Anesthetic Application . . . 409
26.5 Popliteal or Mid-Thigh Sciatic Nerve Block . . . 410
26.5.1 Surface Anatomy . . . 410
26.5.2 Nerve Stimulation Technique . . . 411
26.5.3 Ultrasound-Guided Technique . . . 415
26.5.4 Local Anesthetic Application . . . 419
26.5.5 Case Study . . . 420
26.6 Current Literature in Ultrasound-Guided Approaches . . . 421
References . . . 422
Suggested Reading . . . 422

Part IX Nerve Blocks at the Ankle

27 Ankle Blocks . . . 425
Ban C.H. Tsui
27.1 Indications . . . 426
27.2 Surface Anatomy . . . 426
27.3 Nerve Stimulation Technique . . . 427
27.3.1 Needle Insertion . . . 427
27.3.2 Current Application and Appropriate Responses . . . 427
27.3.3 Modifications to Inappropriate Responses . . . 427
27.4 Ultrasound-Guided Technique . . . 428
27.4.1 Scanning Technique . . . 428
27.4.2 Sonographic Appearance . . . 431
27.4.3 Needle Insertion . . . 431

27.5 Local Anesthetic Application 433
27.6 Current Literature in Ultrasound-Guided Approaches 433
27.7 Case Study 433
References 433
Suggested Reading 433

Part X Nerve Blocks at the Trunk

28 Paravertebral Blocks 437
Heather Yizhen Z. Ting, Karen R. Boretsky, and Ban C.H. Tsui
28.1 Indications 438
28.2 Clinical Anatomy 438
28.3 Block Techniques 438
28.3.1 Landmark-Based Technique 438
28.3.2 Nerve Stimulation Technique 441
28.3.3 Ultrasound-Guided Technique 442
28.4 Current Literature in Ultrasound-Guided Approaches 452
28.5 Case Study 452
References 452
Suggested Reading 453

29 Intercostal Nerve Blocks 455
Ban C.H. Tsui
29.1 Clinical Anatomy 456
29.1.1 Intercostal Nerves 456
29.1.2 Costovertebral Articulations 456
29.2 Landmark-Based Technique 456
29.2.1 Patient Positioning 456
29.2.2 Landmarks and Surface Anatomy 457
29.2.3 Needle Insertion 457
29.2.4 Local Anesthetic Application 458
29.3 Nerve Stimulation Technique 458
29.4 Ultrasound-Guided Technique 458
29.4.1 Scanning Technique 459
29.4.2 Sonographic Appearance 459
29.4.3 Needle Insertion 460
29.4.4 Local Anesthetic Application 460
29.5 Current Literature in Ultrasound-Guided Approaches 460
29.6 Case Study 461
References 461
Suggested Reading 461

30 Rectus Sheath and Transversus Abdominis Plane (TAP) Blocks 463
Bryan J. Dicken and Ban C.H. Tsui
30.1 Rectus Sheath Block 464
30.1.1 Clinical Anatomy 464
30.1.2 Landmark-Based Technique 464
30.1.3 Ultrasound-Guided Technique 465
30.1.4 Current Literature in Ultrasound-Guided Approaches 468
30.1.5 Case Study 469
30.2 Transversus Abdominis Plane (TAP) Block 470
30.2.1 Clinical Anatomy 470
30.2.2 Landmark-Based Technique 470

30.2.3 Ultrasound-Guided Technique . . . 471
30.2.4 Catheter Placement Under Direct Visualization . . . 473
30.2.5 Current Literature in Ultrasound-Guided Approaches . . . 474
30.2.6 Case Study . . . 475
References . . . 476
Suggested Reading . . . 476

31 Ilioinguinal and Iliohypogastric Nerve Blocks . . . 477
Ban C.H. Tsui
31.1 Clinical Anatomy . . . 478
31.2 Landmark-Based Technique (Fascial "Click" Method) . . . 478
31.2.1 Patient Positioning . . . 478
31.2.2 Landmarks and Surface Anatomy . . . 478
31.2.3 Needle Insertion . . . 478
31.2.4 Local Anesthetic Application . . . 479
31.3 Nerve Stimulation Technique . . . 479
31.4 Ultrasound-Guided Technique . . . 479
31.4.1 Scanning Technique . . . 480
31.4.2 Ultrasonographic Appearance . . . 480
31.4.3 Needle Insertion . . . 480
31.4.4 Local Anesthetic Application . . . 481
31.5 Current Literature in Ultrasound-Guided Approaches . . . 481
31.6 Case Study . . . 482
References . . . 483
Suggested Reading . . . 483

32 Penile Blocks . . . 485
Heather Yizhen Z. Ting, Peter D. Metcalfe, and Ban C.H. Tsui
32.1 Clinical Anatomy . . . 486
32.2 Landmark-Based Technique (Subpubic Approach) . . . 488
32.2.1 Patient Positioning . . . 488
32.2.2 Landmarks and Surface Anatomy . . . 488
32.2.3 Needle Insertion . . . 488
32.2.4 Local Anesthetic Application . . . 488
32.3 Ultrasound-Guided Technique . . . 489
32.3.1 Scanning Technique . . . 489
32.3.2 Ultrasonographic Appearance . . . 489
32.3.3 Needle Insertion . . . 490
32.3.4 Local Anesthetic Application . . . 490
32.4 Current Literature in Ultrasound-Guided Approaches . . . 491
32.5 Case Study . . . 491
References . . . 492
Suggested Reading . . . 492

Part XI Neuraxial Blockade

33 Epidural and Caudal Anesthesia . . . 495
Ban C.H. Tsui
33.1 Epidural Anesthesia . . . 496
33.1.1 Introduction . . . 496
33.1.2 Patient Positioning . . . 496
33.1.3 Surface Anatomy . . . 497
33.1.4 Approaches . . . 497

33.1.5 Nerve Stimulation Technique . . . 499
33.1.6 Electrocardiograph (ECG) Monitoring Technique . . . 502
33.1.7 Ultrasound-Guided Technique . . . 503
33.1.8 Needle Insertion Technique . . . 511
33.1.9 Catheter Insertion and Confirmation . . . 512
33.1.10 Case Study: Lumbar Epidural . . . 513
33.2 Caudal Anesthesia . . . 514
33.2.1 Introduction . . . 514
33.2.2 Patient Positioning . . . 515
33.2.3 Surface Anatomy . . . 515
33.2.4 Nerve Stimulation Technique . . . 515
33.2.5 Ultrasound-Guided Block . . . 515
33.2.6 Case Study: Caudal Epidural . . . 519
33.3 Advancing a Catheter to the Lumbar or Thoracic Area from a Caudal Insertion Site . . . 520
33.3.1 Epidural Stimulation Guidance Technique . . . 520
33.3.2 Local Anesthetic Application ("Test") to Confirm Avoidance of Intravascular Placement . . . 521
33.3.3 Ultrasound-Guided Technique . . . 521
33.3.4 Scanning Technique . . . 521
33.3.5 Sonographic Appearance . . . 522
33.3.6 Catheter Insertion and Local Anesthetic Application . . . 522
33.3.7 Case Study: Thoracic Epidural . . . 523
33.4 Current Literature in Ultrasound-Guided Approaches . . . 524
References . . . 525
Suggested Reading . . . 525

34 Spinal Anesthesia . . . 527
Adam O. Spencer, Santhanam Suresh, and Ban C.H. Tsui

34.1 Introduction . . . 528
34.2 Indications . . . 528
34.2.1 Clinical Use and Special Concerns . . . 528
34.2.2 Contraindications . . . 529
34.3 Technique . . . 529
34.3.1 Preparation . . . 529
34.3.2 Patient Positioning . . . 530
34.3.3 Surface Anatomy . . . 530
34.3.4 Sonographic Assessment . . . 531
34.3.5 Nerve Stimulation Technique . . . 531
34.4 Equipment and Spinal Needle . . . 532
34.4.1 Needles . . . 532
34.5 Local Anesthetics . . . 533
34.5.1 Adjuvants . . . 533
34.6 Assessment of the Block Level . . . 534
34.7 Complications . . . 534
34.8 Current Literature in Ultrasound-Guided Approaches . . . 535
34.9 Case Study . . . 536
References . . . 537
Suggested Reading . . . 537

Index . . . 539

Contributors

Alex Baloukov, MPH Faculty of Health Sciences, Simon Fraser University, Burnaby, BC, Canada

Karen R. Boretsky, MD Department of Anesthesia, Perioperative and Pain Medicine, Harvard Medical School, Boston Children's Hospital, Boston, MA, USA

Kelly P.A. Byrne, MB ChB, FANZCA Department of Anesthesia, Waikato Hospital, Hamilton, New Zealand

Bruce D. Dick, PhD, R Psych Division of Pain Medicine, Department of Anesthesiology and Pain Medicine, Stollery Children's Hospital, University of Alberta, Edmonton, AB, Canada

Bryan J. Dicken, MSc, MD, FRCSC Division of Pediatric Surgery, Department of Surgery, University of Alberta Hospital, Edmonton, AB, Canada

Derek Dillane, MB, BCh, BAO, MMedSci, FFARCSI Department of Anesthesiology and Pain Medicine, University of Alberta Hospital, Edmonton, AB, Canada

Adam M. Dryden, MD Department of Anesthesiology and Pain Medicine, University of Alberta Hospital, Edmonton, AB, Canada

Vivian H.Y. Ip, MB ChB, MRCP, FRCA Department of Anesthesiology and Pain Medicine, University of Alberta Hospital, Edmonton, AB, Canada

Glenn Merritt, MD Department of Anesthesiology, University of Colorado Hospital and Children's Hospital Colorado, Aurora, CO, USA

Peter D. Metcalfe, MD, MSc, FRCSC Division of Pediatric Surgery, Division of Urology, Department of Surgery, Stollery Children's Hospital, University of Alberta Hospital, Edmonton, AB, Canada

Michelle L. Noga, MD, FRCPC Department of Radiology and Diagnostic Imaging, University of Alberta, Edmonton, AB, Canada

Kathy Reid, RN, MN, NP Pediatric Anesthesia, Stollery Children's Hospital, Edmonton, AB, Canada

Adam O. Spencer, MSc, MD, FRCPC Vi Riddell Complex Pain and Rehabilitation Centre, Alberta Children's Hospital, Calgary, AB, Canada

Santhanam Suresh, MD Department of Pediatric Anesthesiology, Ann & Robert Lurie Children's Hospital of Chicago, Chicago, IL, USA

Heather Yizhen Z. Ting, MD, FRCPC Department of Anesthesiology and Pain Medicine, University of Alberta Hospital, Edmonton, AB, Canada

Clinical and Practical Aspects of Ultrasound Use

4

Michelle L. Noga, Vivian H.Y. Ip, and Ban C.H. Tsui

Contents

4.1 **Image Acquisition** 42

4.2 **Probe Preparation** 42

4.3 **Image Optimization** 44
4.3.1 Probe Alignment 44
4.3.2 Practical Approach: Traceback Method 46

4.4 **Control of Needle Trajectory** 49
4.4.1 Visibility of Needles 49
4.4.2 Hand-Eye Coordination 51
4.4.3 Needling Technique 52

References 57

Suggested Reading 57

M.L. Noga, MD, FRCPC (✉)
Department of Radiology and Diagnostic Imaging,
University of Alberta, 2A2.41 Walter Mackenzie Centre,
8440-112 Street, Edmonton, AB T6G 2B7, Canada
e-mail: mnoga@ualberta.ca

V.H.Y. Ip, MB ChB, MRCP, FRCA
Department of Anesthesiology and Pain Medicine,
University of Alberta Hospital, 2-150 Clinical Sciences Building,
Edmonton, AB T6G 2G3, Canada
e-mail: hip@ualberta.ca

B.C.H. Tsui, Dip Eng, BSc (Math), B Pharm, MSc, MD, FRCPC
Department of Anesthesiology and Pain Medicine,
Stollery Children's Hospital/University of Alberta Hospital,
2-150 Clinical Sciences Building,
Edmonton, AB T6G 2G3, Canada
e-mail: btsui@ualberta.ca

B.C.H. Tsui, S. Suresh (eds.), *Pediatric Atlas of Ultrasound- and Nerve Stimulation-Guided Regional Anesthesia*,
DOI 10.1007/978-0-387-79964-3_4

4.1 Image Acquisition

Basic Concepts

- It is advisable to perform the block in a stress-free environment with minimal time restraints.
- The target area should be surveyed (scanned) using a generous amount of ultrasound gel prior to sterile preparation. One of the most common reasons for poor visualization is lack of sufficient gel for skin-probe contact.
- Upon location of a suitable puncture site, the probe position is marked on the skin with a sterile marker.
- The images used in this book are those from our everyday practice and are achievable by any newcomer to ultrasound-guided regional anesthesia. We have been mindful not to concentrate on presenting anatomically perfect ultrasound images, which are obtained occasionally; shown are images that are representative of what you will encounter in an average day.
- In order to facilitate learning in identification of the sonoanatomy, unlabelled ultrasound images are placed next to identical but well-labeled images. Our colleagues have found this layout to be the most effective for familiarizing themselves with realistic clinical images as there is no distraction from multiple labels, yet at the same time, they benefit from side-by-side reference to the same image that has been labeled.
- More importantly, the labeling system indicates what structures are normally visualized as well as the expected locations of any clinically relevant and important structures which may not be immediately obvious. Hopefully, this will reduce frustration and failure from unrealistic expectation in an attempt to visualize every structure.

4.2 Probe Preparation

- Both the probe and the patient's skin should be prepared for maximum sterility and optimal imaging.
- Water-soluble conductivity gel is always used to remove the air-skin interface and to allow good reflection of ultrasound waves.
- Probe sterility is paramount in performing real-time, or dynamic, ultrasound-guided nerve block. This can be maintained by standard sleeve covers, although these can be expensive and cumbersome.
- When using a probe with the standard long covers, it is important to avoid air tracking between the probe and cover, as well as between the cover and the skin, which can obscure the ultrasound image.
- For single-shot blocks, we find it practical to use a transparent dressing without the full cover of a sterile sleeve:
  - A sterile transparent dressing (Tegaderm™; 3M Health Care, St. Paul, MN, USA) can be used effectively, but to maintain a smooth surface, it must be stretched before it is adhered to the surface of the probe. The IV3000 dressing (Smith & Nephew Medical Limited, Hull, UK) is marketed for this purpose, but we have observed that, when placed over the probe surface, multiple small adhesive wells trap air underneath the dressing, leading to poor imaging and a limited ability to use the Doppler effect (Fig. 4.1) [1].
  - We also use individual sterile packs of gel.
- For continuous blocks:
  - Complete sterile preparation is required; a complete sterile cover is used for the ultrasound probe. A mask, sterile gown, and gloves should be worn by the operator.
- After completion of the procedure, the probe and related equipment (including all surfaces and cables) should be thoroughly cleaned.

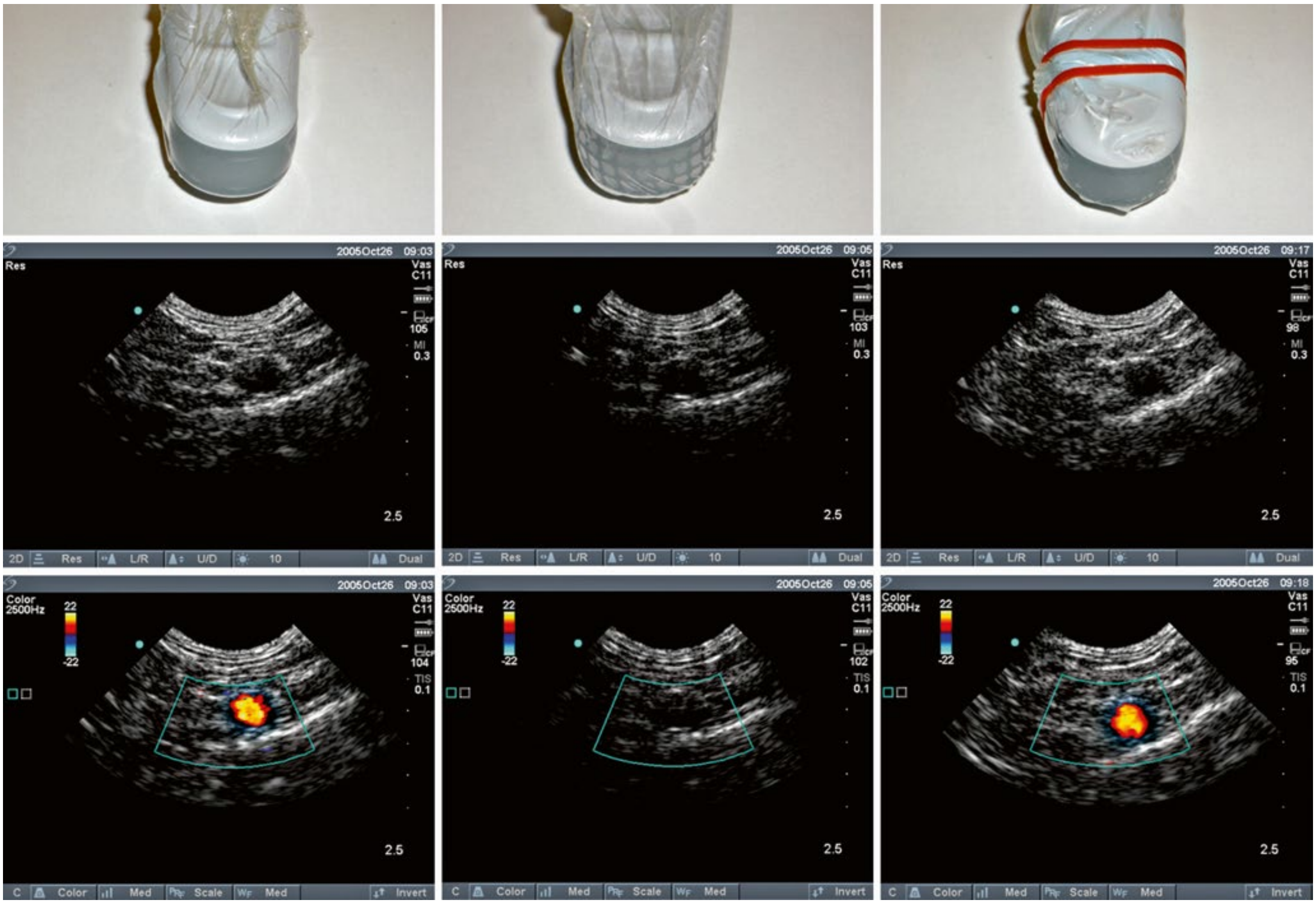


Fig. 4.1 Effects of sterile transparent dressing on image quality and ability to use Doppler ultrasound with curved probes. The Tegaderm dressing maintains image quality and ability to use Doppler as long as it is stretched (*left*). The IV3000 dressing can be used (*middle*), but multiple small adhesive wells containing air may form under the dressing, leading to poor imaging and limited ability to use Doppler. A complete commercial sterile cover (*right*) would be necessary if performing catheter insertion for continuous anesthesia/analgesia (Adapted from Tsui et al. [1]. With permission from Wolters Kluwer Health)

4.3 Image Optimization

- One of the most important factors in ultrasound-guided localization is patient positioning. The patient should be placed in a position such that the target area is well exposed. In the subsequent clinical chapters, patient positioning will be described for each individual block prior to discussing the ultrasound imaging technique.
- The operator position should be optimized to enable both a good view of the ultrasound screen and comfortable hand positioning for needle insertion.
- The reader is referred to Chap. 3 to choose the appropriate frequency of transducer at each peripheral block location; the frequency will partly determine the type of array (linear versus curved) that will be suitable. Often, a high-frequency linear array transducer (10 MHz or more) is the most appropriate for the pediatric population. If the area of interest is relatively deep, such as the gluteal region in teenagers, a lower-frequency transducer (5–7 MHz) may be advantageous with greater penetration. Whether the probe array is curved or linear depends on the region and field of view required (e.g., blocks in the lumbar region benefit from larger fields of view and lower frequencies, which curved array probes offer).

4.3.1 Probe Alignment

- The probe will have a marker or groove to show which way is "up." The marker corresponds to the top of the ultrasound image, and if you slide the probe toward the marker, the image will move in the direction that the probe is moved. Similarly, if you slide the probe away from the marker side, the image will move in the direction opposite the marker.
- In most circumstances, and particularly with transverse planes of viewing, the plane of the transducer beam should intersect the axis of the nerve structures at a perpendicular position. The lateral resolution will be optimal in this situation, and artifacts such as anisotropy (Chap. 3, Sect. 3.6) will be minimized.
- To obtain the best short-axis view in a coronal plane, such as scanning the supraclavicular region, follow these important steps for probe handling (Fig. 4.2):
  – Scan across the relevant area to obtain a transverse view of the vascular structure (e.g., subclavian artery) or nerve since it is easier to capture these structures with an ultrasound beam "transecting" in a short axis rather than obtaining a longitudinal view.
  – The image can be refined by rotating the probe (turn slightly clockwise or anticlockwise) or tilting the probe forward and backward to achieve a perpendicular beam through the target structure in order to sharpen the image.
- Adjust the time gain compensation (TGC) so that the visualized area is of uniform echotexture. Always adjust the TGC to the center when changing transducers during a study.
- Appropriate depth should be adjusted such that the target nerve is in the center of the screen with other relevant structures in view (e.g., in supraclavicular block, one should be able to visualize the subclavian artery, the first rib, and the pleura).
- The focal point should be adjusted to the where the target nerve is.
- A systematic approach allows the best image to be obtained in a timely fashion, increasing the success rate of ultrasound-guided peripheral nerve blocks.
- Most neural structures are accompanied by blood vessels (pulsatile arteries or compressible veins) or bony landmarks, which are readily identifiable using ultrasound. Color Doppler is useful in this situation to identify blood vessels. The color convention is for red to represent blood flowing toward the transducer and blue to represent blood flowing away from the transducer. Therefore, the knowledge of anatomy is always important to identify nerves around these landmarks.
- The "traceback" approach (see below) also aids the identification of a nerve, especially when differentiating between similar-looking structures such as tendons or artifacts.

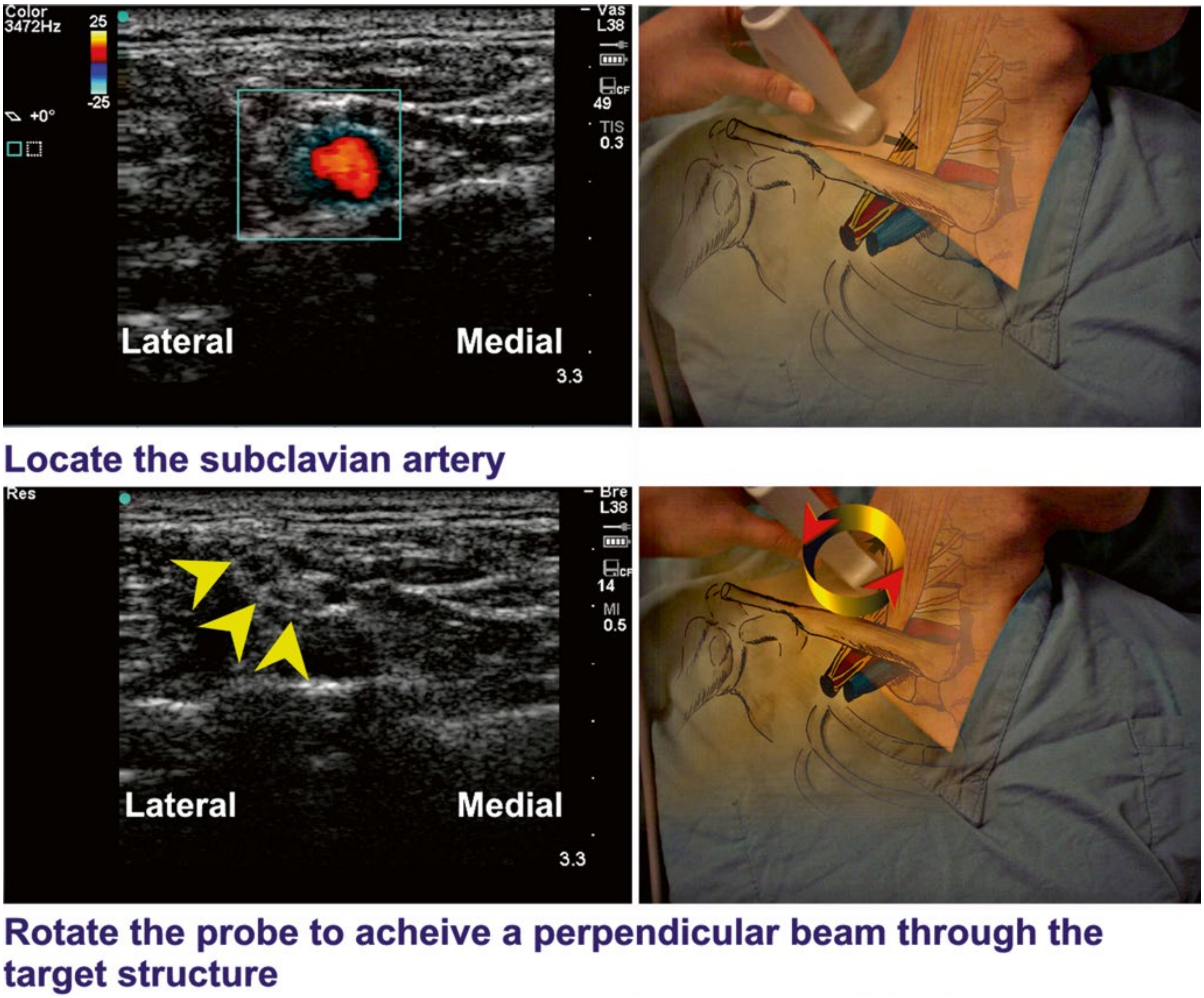


Fig. 4.2 Probe handling during supraclavicular blockade with landmark identification of the subclavian artery. Scan across the relevant area to obtain a transverse view of the vascular structure (in this case the subclavian artery; *top*). To sharpen the image, rotate the probe (*clockwise* or *anticlockwise*) or tilt the probe forward and backward to achieve a perpendicular beam through the target structure (*bottom*)

4.3.2 Practical Approach: Traceback Method

As with the conventional "blind" approach, knowledge of anatomy is of upmost importance when performing peripheral nerve blocks under ultrasound guidance. The spatial appreciation in relation to the surrounding structures is also relevant. In our experience, neural structures are not always easy to identify under ultrasound; they can appear hyper- or hypoechoic and are sometimes confused with artifacts. Nerves are continuous structures, which lend themselves to be "traced" proximally and distally. This enables the differentiation from structures with similar appearance (e.g., tendons). In this section, we will describe a systematic "traceback" approach [2] to help identify the target nerves (within various regions) of commonly used nerve blocks.

- Instead of immediately focusing on locating the target nerve at the commonly used block site, the goal of this exercise is to obtain a clear image of an obvious anatomic landmark (i.e., a blood vessel or bony landmark) not too far removed from one point along the target nerve's path.
- If suitable, it is generally preferred to perform the block at this location due to the dependable anatomical relations.
- Otherwise, the operator focuses on the nerve (often in short axis by adjusting the transducer as described above in probe alignment) and "traces" it toward the block target area by moving the ultrasound probe in a proximal or distal direction along the nerve.
- The appearance of surrounding structures (e.g., muscle and other soft tissues) changes consistently as the probe moves, whereas the appearance of the target nerve does not change in any significant manner and is traceable.
- In this way, we can more easily and reliably identify the corresponding nerve or plexus.

For illustration purposes, see Fig. 4.3, which describes a traceback practice for facilitating identification of the sciatic nerve at the popliteal fossa (using vascular landmark identification). This approach allows the operator to gain confidence in their ability to recognize and locate the nerves. During the training process, we found that the traceback approach is an easy and reliable way to become proficient at identifying neural structures prior to performing regional anesthesia. However, the traceback approach may not be necessary in some locations where the larger nerves are more easily identifiable, for example, the median nerve in the axilla and antecubital fossa and the femoral nerve in the inguinal region.

We strongly recommend that the initial step in performing ultrasound-assisted regional anesthesia is identification of obvious landmarks (usually blood vessels or bony landmarks) in the vicinity of the target nerve. Table 4.1 lists the numerous nerve blocks that can benefit from identification of highly visible and dependable structures (i.e., blood vessels (especially with color Doppler) and bone) for accurate nerve identification. Nonetheless, the traceback technique is useful for popliteal nerve for identification of the bifurcation, identifying the brachial plexus at the interscalene region, or for revealing anatomic anomalies.

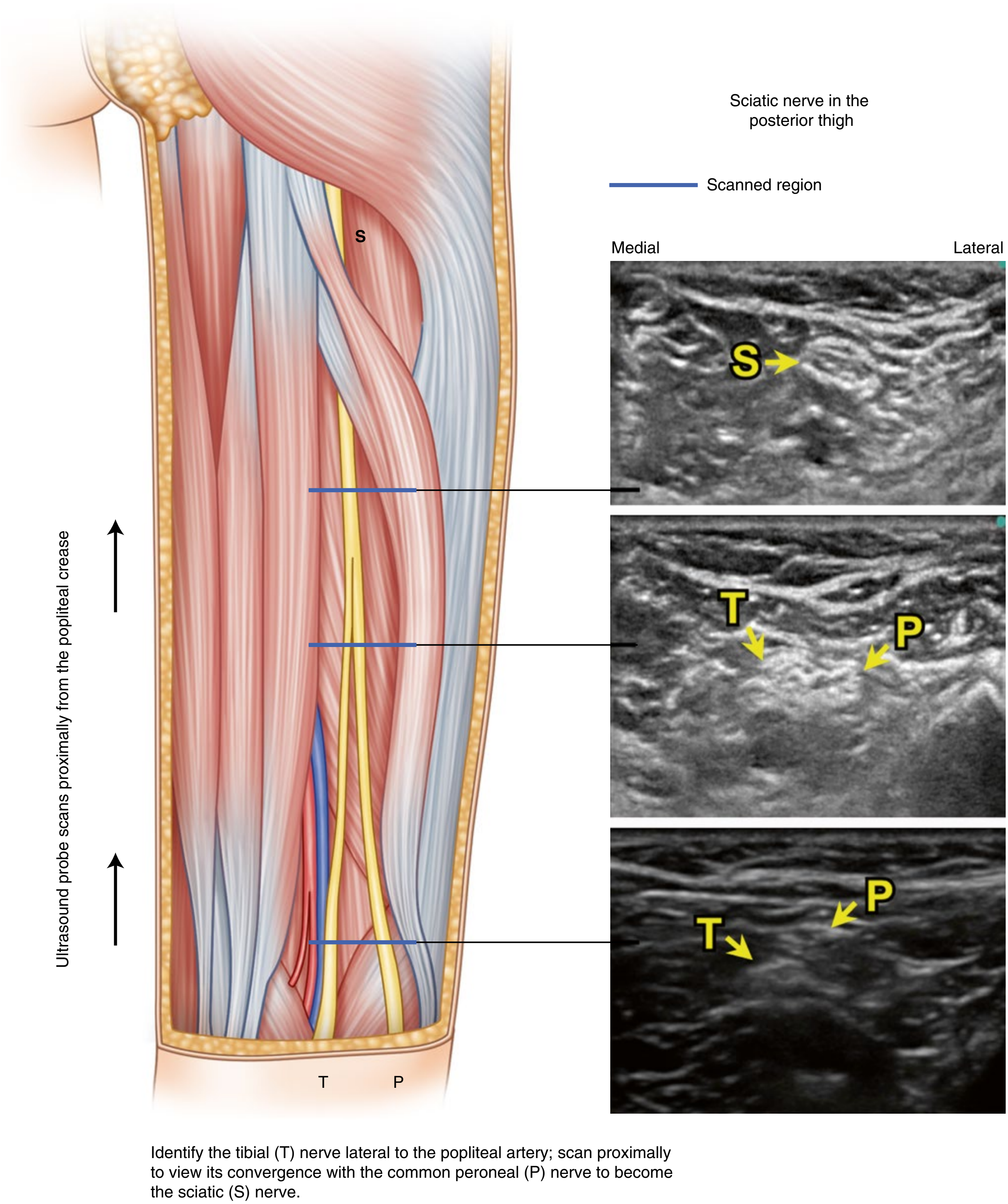


Fig. 4.3 Traceback approach in the posterior thigh for identification of the sciatic nerve at the popliteal fossa (Adapted from Tsui and Finucane [2]. With permission from Wolters Kluwer Health)

Table 4.1 Useful landmarks for identification of nerves using ultrasound; many can be used in "traceback" approaches

Block	Ultrasound landmark	Comments
Interscalene	Subclavian artery	Trace nerve proximally from the distal supraclavicular location where the artery lies medial to the nerve
Supraclavicular	Subclavian artery	Brachial plexus lies lateral and often superior to the artery
Infraclavicular	Subclavian artery and vein	Brachial plexus cords surround the artery
Axillary	Axillary artery	Terminal nerves surround the artery
Peripheral nerves		
Median at antecubital fossa	Brachial artery	Nerve lies immediately medial to the artery
Radial at posterior elbow	Humerus at spiral groove	Groove is found on posterolateral surface of humerus inferior to the deltoid insertion, and the nerve can be located (also adjacent to the deep brachial artery) and traced to the anterior elbow
Ulnar at medial forearm	Ulnar artery	The nerve lies medial and adjacent to the artery at the midpoint of the forearm
Lumbar plexus	Transverse process	Lies between and just deep to the lateral tips of the processes
Femoral	Femoral artery	Nerve lies lateral to artery (vein most medial). Insert needle above the bifurcation of the deep femoral artery
Sciatic		
Labat	Ischial bone	Nerve lies lateral to the ischial bone
Subgluteal	Greater trochanter and ischial tuberosity	Nerve lies between the two bone structures
Popliteal	Popliteal artery	Trace back from the popliteal crease where the tibial nerve is adjacent to the artery. Scanning proximally to the sciatic bifurcation, the artery becomes deeper and at a greater distance from the tibial nerve where it is joined by the peroneal nerve
Ankle		
Tibial (posterior tibial)	Posterior tibial artery	Nerve lies posterior to the artery
Deep peroneal	Anterior tibial artery	Nerve lies lateral to the artery

4.4 Control of Needle Trajectory

4.4.1 Visibility of Needles

- Common small-bore, 22G insulated block needles are adequate to perform ultrasound-guided blocks in children.
- Since neural structures are superficial in children, there is generally good needle visibility since the increased angles of penetration tend to reduce visibility.
- A larger-gauge needle, such as the 17G–20G Tuohy needles used in peripheral nerve block catheterization, can also improve visibility.
- Manufacturers are constantly improving needles for visibility, and echogenic needles are commercially available (Chap. 1).
- It is important to be able to visualize the tip of the needle. Tilting (Fig. 4.4a), rotating (Fig. 4.4b), and manipulating the transducer alignment (Fig. 4.4c) is necessary to ensure that the image of the needle includes the tip. This is particularly important for the out-of-plane approach, since the image of the needle is a hyperechoic dot which could be interpreted as either the shaft or the tip of the needle on the screen (see below).

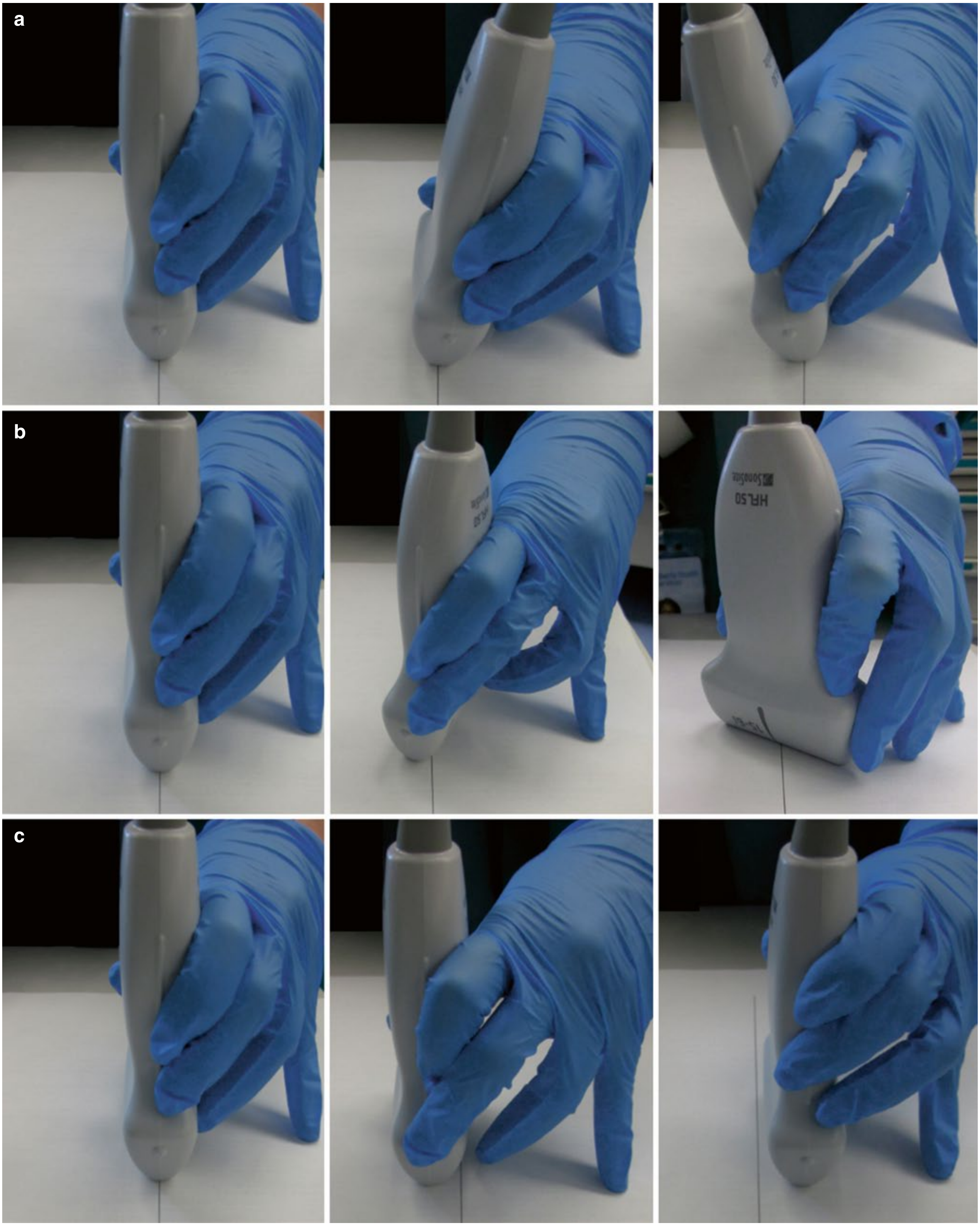


Fig. 4.4 Tilting (**a**), rotating (**b**), and manipulating (**c**) the alignment of the ultrasound probe is necessary to visualize the tip of the needle. The *line* on the paper indicates the original axis of the probe

4.4.2 Hand-Eye Coordination

One of the most common errors of the beginner learning ultrasound-guided regional anesthesia is to focus their attention on the needle in their hand, instead of observing the needle position changes on the screen. This is a cardinal error, as important information relating to the needle position and the corresponding image will be missed by concentrating on the actual needle. Today's teenage population illustrates this point by focusing on the onscreen action rather than on the controller when playing a video game (Fig. 4.5). Similarly, an experienced laparoscopic surgeon may look directly at their instruments upon initial insertion but will transfer their focus to the screen for all subsequent instrument manipulation. Although it sounds trivial to stress good hand-eye coordination, mastering it has been extremely helpful for staff at our institution.

Fig. 4.5 Children demonstrating hand-eye coordination focusing on the video game screen rather than their hand movements on the controller (Reprinted from Tsui BC, Dillane D. Practical and clinical aspects of ultrasound and nerve stimulation-guided peripheral nerve blocks. In: Tsui BC, editor. Atlas of ultrasound and nerve stimulation-guided regional anesthesia. New York: Springer; 2007. p. 35–48. With permission from Springer Verlag)

4.4.3 Needling Technique

4.4.3.1 In-Plane Technique (Fig. 4.6)

- Aligning the needle to the ultrasound plane is an important concept to grasp and practice.
- In-plane (IP, long-axis, longitudinal, or axial) needling approaches with the needle parallel to the ultrasound scanning plane have the advantage of allowing continuous control of the needle trajectory due to clear visualization of both needle tip and shaft.
- The nerve structure is often placed at the edge of the ultrasound screen to ensure shallow insertion angle of the needle and, therefore, a better visualization.
- Good alignment of the needle shaft and scanning plane is required and can be attained by paying close attention when viewing the needle and probe from above or in an axial view.
- For practical reasons, it is often advisable to use a small footprint linear (e.g., hockey stick) probe or curved array probe (e.g., C11) in compact areas, such as the supraclavicular fossa. It is critical to use in-plane technique at this location (to adequately view the needle to prevent pleural puncture), and smaller probes will be beneficial for more space to maneuver the needle.
- Most commercial needle-guiding tools involve physical fixation of the needle aligned in-plane with respect to the ultrasound beam; such an apparatus is not only expensive and cumbersome to use but often limits fine adjustment of needle placement and requires extra long needles (Fig. 4.7).
- A GPS needle tracking device is available which provides real-time information of where the needle should be maneuvered for the target area (Chap. 3).
- In contrast, the freehand technique requires excellent coordination to align and maintain the needle in plane to the ultrasound beam in order to visually track the advancement of the needle toward the target in real time; accordingly, the freehand technique often requires a steep learning curve.
- Tsui [3] developed a method of needle-probe alignment using a laser attachment for the probe (Fig. 4.8); the laser line will project onto both the needle shaft and the midline of the probe, indicating an in-plane position. Alternatively, a commercially available laser attachment for the needle (SonoGuide, Pajunk, Geisingen, Germany) is also available and operates with a similar concept (Fig. 4.9).
- It should be noted that the in-plane approach can be performed as a single shot or catheter insertion when the target nerve is scanned both in a short-axis (cross-sectional view) or a long-axis (longitudinal view).

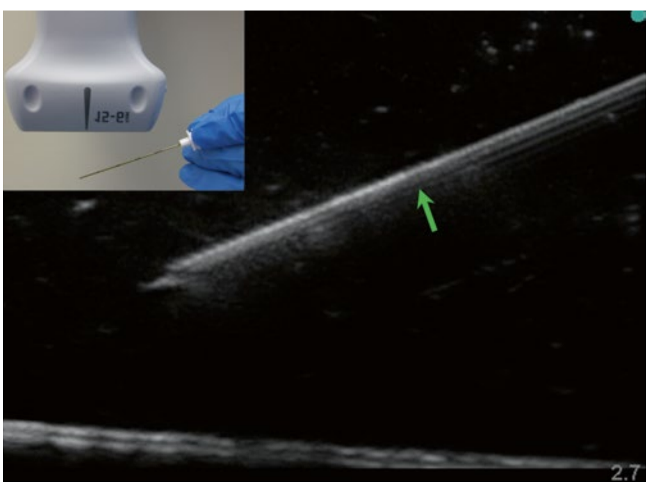


Fig. 4.6 Needle (*green arrow*), including tip and shaft during an in-plane approach

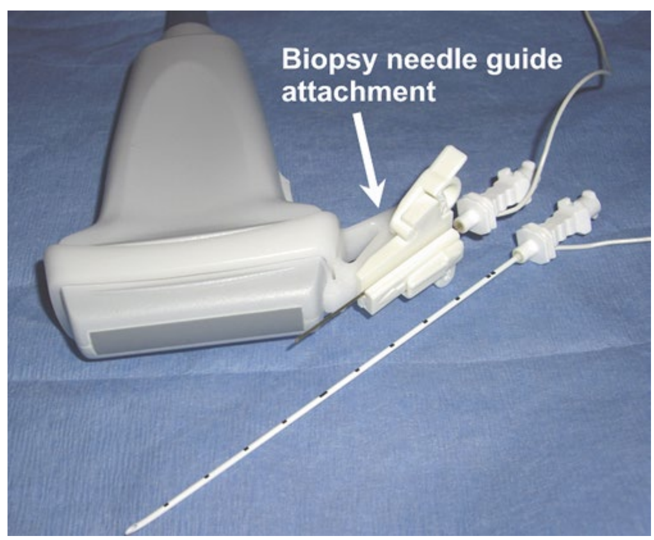


Fig. 4.7 Commercial biopsy needle attachment. The fixed needle has a limited trajectory and has to be extra long (Reprinted from Tsui BC, Dillane D. Practical and clinical aspects of ultrasound and nerve stimulation-guided peripheral nerve blocks. In: Tsui BC, editor. Atlas of ultrasound and nerve stimulation-guided regional anesthesia. New York: Springer; 2007. p. 35–48. With permission from Springer Verlag)

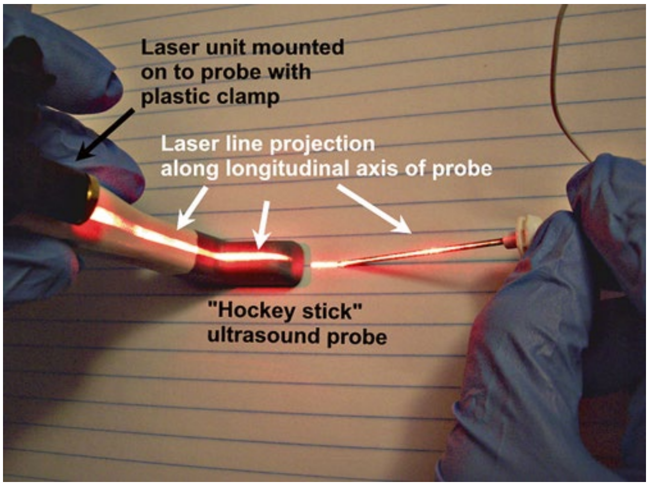


Fig. 4.8 Alignment of the block needle and ultrasound beam using a laser line (Reprinted from Tsui [3]. With permission from Wolters Kluwer Health)

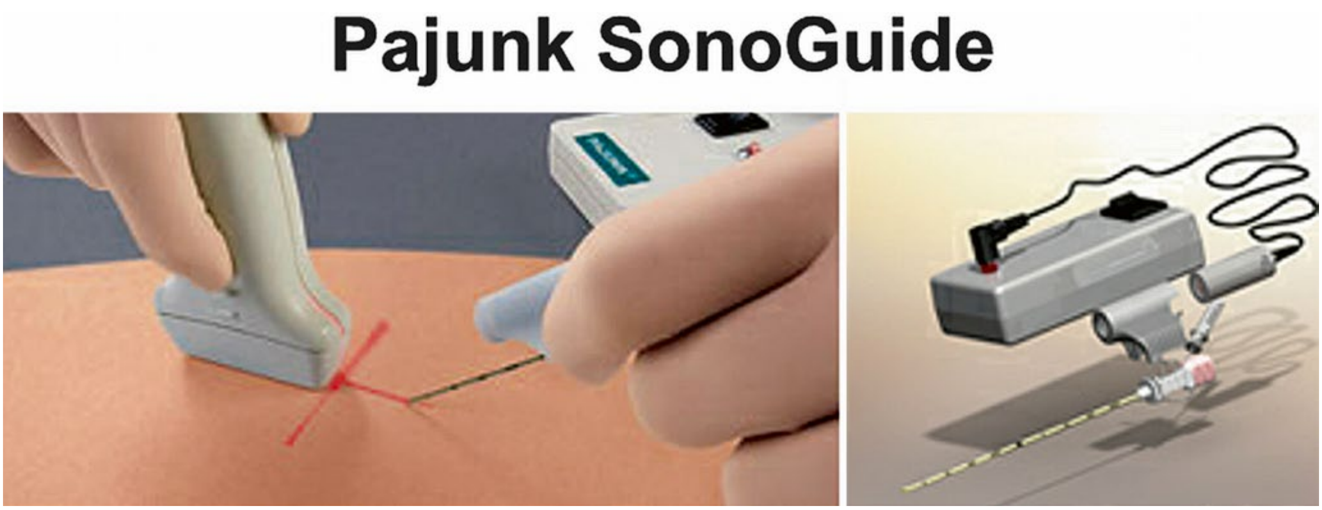


Fig. 4.9 Commercially available laser attachment for block needle

4.4.3.2 Out-of-Plane Technique: Walkdown Approach

- Out-of-plane (OOP; tangential, short-axis) alignment of the needle to the scanning plane can be useful in several block locations (e.g., popliteal, terminal nerves of the forearm, ankle blocks), but the separation between the needle tip and proximal shaft can be poorly defined.
- OOP needling can be difficult since the needle shaft can easily be mistaken for the needle tip (Fig. 4.10).
- Needle tip imaging can be improved by using shallow initial puncture angles since the tip appears as a bright dot at these angles.
- An approach that can improve needle tip visibility when using OOP approaches with linear probes involves calculating the required depth of puncture (with measurement to the related neural structure recorded using ultrasound prior to the block) and using trigonometry with the shaft angle and length to calculate a "reasonable" distance to place the initial needle puncture site (Fig. 4.11) [4].
- The initial shallow puncture will be easily seen, and the needle tip can be followed as it is *walked down* to the final calculated depth. For example, if the final depth of penetration for the block is 2 cm, the needle will ultimately obtain a 45° angle if the initial puncture site is 2 cm from the probe and the needle is incrementally angled to this level [5]. This approach works best for structures that are ≤2 cm deep.
- For target nerves deeper than 2 cm, a long needle is required. It is impractical to have the needle insertion site greater than 2 cm away from the probe since there will be a relatively large "blind" needling area. In this situation, the needle should be inserted almost perpendicularly (i.e., the needle placed just adjacent to the probe which means that in reality, it will be 0.5 cm away from the ultrasound beam). Again, applying the principles of trigonometry, a distance ≤1 cm between the needle and the ultrasound beam becomes negligible as the target depth increases, and the needle insertion depth becomes comparable to the target depth (Fig. 4.12). For instance, the difference between the depth of needle insertion and the actual depth of the target is minimal when the needle is directly adjacent to the transducer with a maximum distance of 1 cm away from the ultrasound beam:

$$\sqrt{\left((2\text{cm target depth})^2 + (1\text{cm insertion distance})^2\right)} = 2.2\text{cm needle length required}$$

  Therefore, this approach helps clinicians to determine if the hyperechoic dot on the ultrasound image is the needle tip by correlating it to the length of the needle inserted.
- The nerve structure is often placed in the center of the screen to guarantee that aligning the needle puncture with the center of the probe will ensure close needle tip-nerve alignment.
- The choice of probe, whether linear or curved, can be altered depending on the anatomical situation.
- The OOP approach usually works well when the target nerve is scanned in a short-axis (cross-sectional view) for both single shot and catheter insertion.

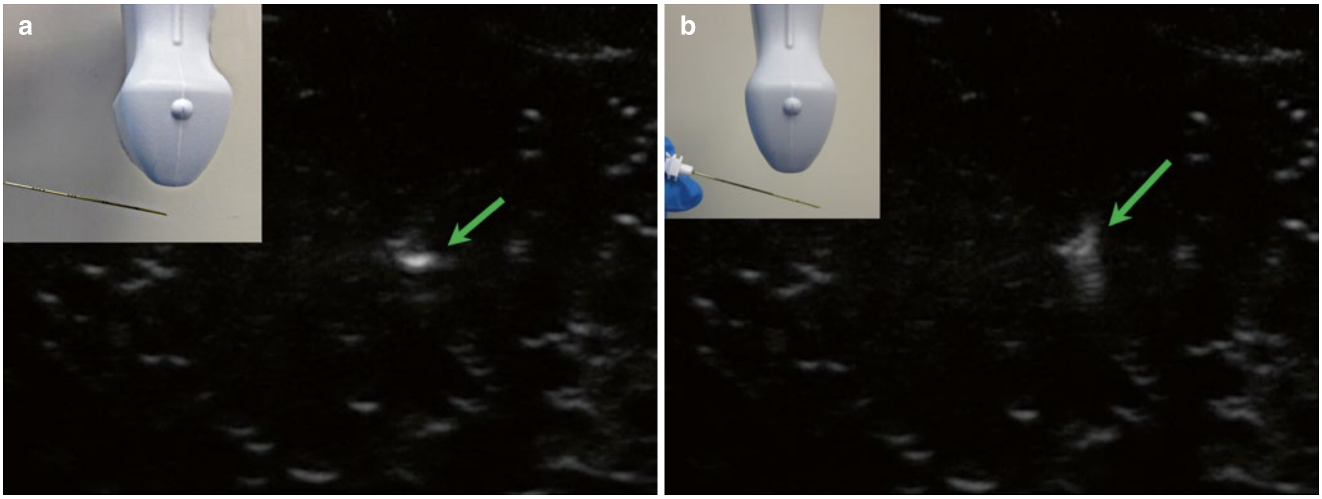


Fig. 4.10 Needle tip (**a**) and shaft (**b**) in an out-of-plane approach. *Green arrows* indicate needle position

Fig. 4.11 Walkdown approach to optimize out-of-plane needle visibility and tracking. The steep angles (*left*) often used limit the visibility of needle tips, while shallower angles (*right*) improve visibility. Incremental needle angulation (with two to three insertion angles from shallow to final 45°) can improve needle tracking. The trigonometric relationship, using an ultrasound-measured target depth, will allow an estimate of the target needle insertion site, directing the needle to the target location at a final angle of 45° (Adapted from Tsui and Dillane [4]. With permission from Wolters Kluwer Health)