Comprehensive Electromyography

With Clinical Correlations and Case Studies

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Mark A. Ferrante
Professor, Department of Neurology
Co-Director, Neurophysiology Fellowship
Associate Director, Residency Training Program
University of Tennessee Health Science Center
Section Chief, Neurophysiology
Memphis VA Medical Center, Memphis, TN, USA

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Every effort has been made in preparing this book to provide accurate and up-to-date information which is in accord with accepted standards and practice at the time of publication. Although case histories are drawn from actual cases, every effort has been made to disguise the identities of the individuals involved. Nevertheless, the authors, editors and publishers can make no warranties that the information contained herein is totally free from error, not least because clinical standards are constantly changing through research and regulation. The authors, editors and publishers therefore disclaim all liability for direct or consequential damages resulting from the use of material contained in this book. Readers are strongly advised to pay careful attention to information provided by the manufacturer of any drugs or equipment that they plan to use.

I dedicate this textbook to the memory of my mentor, colleague, and good friend, Dr. Asa J. Wilbourn, whose work in the field has touched so many practitioners of electrodiagnostic medicine, whether they are aware of that contact or not.

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Preface

Although measurements of the muscle response were initially made in the late nineteenth century, motor nerve conduction studies (NCS) were not truly born until the 1940s. At that time, technology was quite limited. As technological advancements occurred over the next 30 years, the ingenuity and depth of thought of our electrodiagnostic (EDX) forefathers slowly advanced this field and addressed most of the technical issues (e.g., instrumentation, ideal electrode placement, the significance of the response parameters, etc.) surrounding EDX medicine. We have gone from analog signals (continuously varying signals), RC circuit filtering (filtering through the use of resistors and capacitors arranged in series), and oscilloscopes to digital signals (composed of a series of on–off pulses representing ones and zeroes), digital filtering, and monitors. As a result, modern-day EDX medicine is much easier to perform. However, as a result of this automaticity, many of the electrical, instrumental, and other technical issues surrounding EDX medicine are unfamiliar to modern-day EDX providers. An understanding of these areas remains mandatory for the proper elicitation and interpretation of the compound electrical potentials recorded during the EDX examination, as well as for the ability to troubleshoot the commonly occurring problem associated with the recording of these electrical signals. Thus, the technical side of EDX medicine must still be learned. Fortunately, the principles and concepts underlying EDX medicine are straightforward and readily mastered once a basic scientific foundation has been established.

The electromyography textbook that had the most profound impact on my early years as an EDX provider was *The Physiological and Technical Basis of Electromyography*. It was the third EDX medicine textbook that I read as a resident. It contained a wealth of information, but, regrettably, my understanding was incomplete due to a lack of knowledge in certain aspects of electricity, electronics, physics, and engineering, as well as unfamiliarity with some of the jargon. At the time, I would have benefited from a pre-EDX medicine textbook that reviewed the core knowledge necessary for a career in this field, including the basic and advanced principles and concepts of the basic sciences, electricity, electronics, and engineering, and that also defined the jargon and *connected the dots*. Such a textbook still does not exist. Although a number of excellent EDX textbooks preface their discussions with electrical principles and concepts, these discussions are often too superficial or, when of the proper depth, do not provide enough explanation.

Consequently, this textbook provides a comprehensive review of the basic and advanced principles and concepts underlying EDX medicine at the beginning of the textbook, defines all jargon and terminology, and errs on the side of oversimplification. It begins with five introductory chapters that provide the core knowledge necessary for a complete understanding of the science pertinent to EDX medicine. All of the technical jargon and EDX terms used in this textbook are defined at their entry into the textbook, and for those interested, the mathematical calculations are solved in a step-by-step manner. The foundational material allows for a complete understanding of the basic and advanced principles and concepts necessary for the performance of quality EDX medicine. By the end of the textbook, the reader will have a full understanding of the measurements we make, how the measurements are generated, what the measurements mean, and how disease affects the measurements. Thus, this textbook addresses the physiological and technical basis of electromyography, as well as the interpretation of the study findings. Because we are providers of EDX medicine, and thus should possess the deepest possible understanding of EDX medicine, the opening two chapters on electricity and electronics are written at a level beyond that required for the performance of quality EDX medicine. The details

included in these two chapters do not require memorization. They are provided to make the principles and concepts under discussion more understandable.

To better understand how the material contained in this textbook is applied in the EMG laboratory, 50 case studies are included in the final section. These case studies not only reinforce the information contained in the textbook, they also introduce other material best taught using a case study format. Finally, a number of appendixes containing useful information for the day-to-day practice of EDX medicine are addended.

Five sections provide the framework for 20 chapters. A review of the core disciplines underlying EDX medicine is provided in Section 1. The integration of this information with the nerve conduction studies (Section 2) and the needle EMG examination (Section 3) follows. Section 4 reviews other topics pertinent to the EDX medicine provider, including lesion characterization, lesion prognostication, common pitfalls and their resolution, safety issues, and details related to the patient encounter and EDX report writing. Following these 4 sections, 50 case studies are provided to reinforce the material presented throughout the text, demonstrate its application, and introduce additional teaching points better conveyed in a case study format. Rather than providing the data and then discussing it, the data is discussed as it is collected so that the reader obtains a better understanding of the orchestration of the various studies composition of the EDX encounter.

Finally, although EDX studies are sensitive and reliable, the accurate localization and characterization of lesions involving the peripheral neuromuscular system require that the EDX procedures be performed properly. For this reason, the EDX techniques used in our EMG laboratories, along with their age-related normal control values, are provided in Appendix 5 and Appendix 6, respectively.

A fuller understanding of this material, along with the material presented in the instrumentation and troubleshooting chapters and the appendix addressing EMG machine settings, will yield better EDX techniques that allow the EDX provider to collect more easily the various compound electrical potentials despite an environment of unfriendly electrical signal. Those topics with a greater impact on the *practical* aspects of EDX medicine, such as enhancing the signal-to-noise ratio and eliminating stimulus artifact, are given greater attention than the topics with lesser clinical application. Chapter 1 functions as a stepping-stone to Chapter 2, which reviews instrumentation pertinent to an EMG laboratory. Once these electrical concepts are understood, membrane electrophysiology, including the resting membrane potential and the generation and propagation of action potentials, is straightforward.

Section 2 of this textbook, which consists of 7 chapters, focuses on the NCS, including motor NCS, sensory NCS, mixed NCS, late responses, and repetitive nerve stimulation studies. How we collect these responses and the measurements we make from them are reviewed in detail. This is followed by a comprehensive discussion of the various pathologies and pathophysiologies affecting the peripheral nervous system (PNS) and the EDX manifestations associated with each. The final chapter of this section discusses our approach to lesion localization and characterization.

Section 3, which consists of 3 chapters, discusses the needle EMG examination, the pathological manifestations observed during needle EMG, single-fiber EMG, and macro EMG.

Section 4, composed of 5 chapters, reviews a number of topics important to the practitioner of EDX medicine, including a chapter on prognostication, a chapter overviewing the EDX manifestation of lesions at different levels of the neuromuscular axis, a chapter on EMG laboratory pitfalls and their resolution, a chapter on EMG laboratory safety, and a chapter discussing the patient encounter, tips to avoid patient discomfort, and report writing.

Section 5 uses a case study approach to reinforce the information provided in the textbook and to introduce new material best illustrated through such an approach. Each EDX case is discussed in a step-by-step manner, with an interpretation of the study data as it is collected rather than all at once at the end. Each case study begins with the reason for referral, an abbreviated history and focused neurological examination, and a discussion of the NCS that should be employed initially. The focus of each case is lesion localization and lesion characterization, including temporal information regarding the chronicity of the lesion and its rate of progression. Each case study provides at least one unique teaching point and, when instructive, concludes with an impression written in the report format of the author. Although the discussions associated with some of these cases are partially repetitive, they should be considered akin to the scales

and arpeggios of musical practice. The basic concepts are introduced in the earlier cases and the more advanced ones in the subsequent ones.

The final section of this textbook contains a number of appendixes. They are intended to provide immediately available data pertinent to the day-to-day practice of EDX medicine. These appendixes include: (1) anatomical information, such as the SNAP, CMAP, and muscle domains of the various nerve and plexus elements; (2) the routine and nonroutine NCS techniques used by the author, and their age-dependent normal values; and (3) proper EMG machine settings. Other important information is also included here.

In some sections of this textbook, the information conveyed is necessarily redundant. This maintains the coherence of the current material without forcing the reader to return to a previous section of the text. In these instances, however, the material is abridged. The chapters are organized so that simple concepts beget more complicated concepts, thereby permitting self-learning to proceed as effortlessly as possible. Through the 20 didactic chapters and the reinforcing case studies, the reader will gain a mastery over the basic and more complicated aspects of EDX medicine and their clinical application. For explanatory purposes, the textbook includes a large number of illustrations.

Acknowledgments

There are many individuals that I would like to thank for their contributions throughout my career. First and foremost, I would like to thank my children, Nicole, Kristen, and John, and my wife, Jung, for their sacrifices and patience and for their understanding and acceptance of the time commitment required of a career in academic medicine. In addition, I am thankful to Nicole and Kristen for creating some of the illustrations contained within this textbook.

I also wish to express my thanks to my many mentors through the years. Among these individuals, the most influential person in my training and my career was Dr. Asa J. Wilbourn. He provided me with numerous academic opportunities and shared his early brachial plexus research with me, thereby allowing it to become our research. Ultimately, we advanced from a mentor–mentee relationship to a special friendship, as exemplified by his insistence that I allow him and his wife, Eileen, to care for me during my battle against cancer. Asa and I often spoke of authoring an EMG textbook together, but his untimely death eliminated that opportunity. Although this textbook would have been better with his involvement, I am hopeful that he would have been pleased with it nonetheless. I also wish to give special thanks to Dr. Randall B. King, my good friend, who introduced me to the EMG laboratory during my residency and, through his engineering background, has furthered my understanding of electricity and electronics through the years. I especially wish to pay homage to my close friend, Edward J. Milcarsky, MD, for proofing the first two chapters of this textbook for errors. His engineering background and his electronics laboratory provided valuable insights for both of these chapters. In addition, I thank Dr. Olivia Yambem for reviewing the case studies and Dr. Grace Madeiros for reviewing Chapters 1–20 for errors and for those areas needing further explanation.

I would like to extend a special thanks to my EDX technicians, Billy Seay and Teresa James, for all of their long hours and extra effort, and to all of my predecessors who created and contributed to this field. Finally, I am especially thankful to all of the greater than 35,000 patients who have permitted me to perform EDX studies on them and for their willingness to allow small numbers of residents and fellows to be present in the EMG laboratory during their EDX testing.