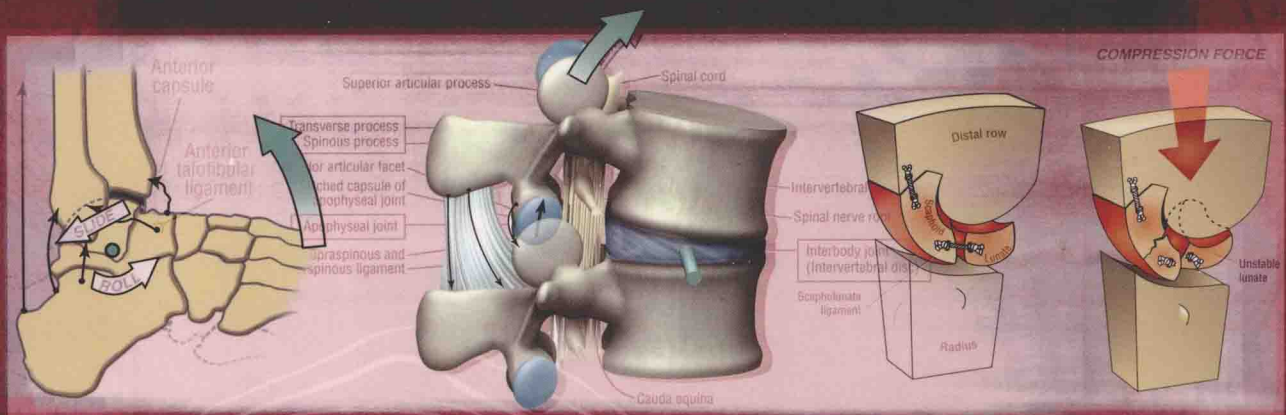


Donald A. Neumann

# KINESIOLOGY of the MUSCULOSKELETAL SYSTEM

Foundations for Rehabilitation

Second Edition



# KINESIOLOGY of the MUSCULOSKELETAL SYSTEM

## Foundations for Rehabilitation

Second Edition

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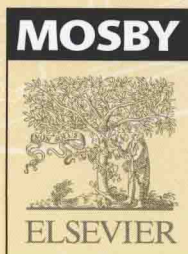
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Artwork introducing the Additional Clinical Connections in Chapters 5-15 from  
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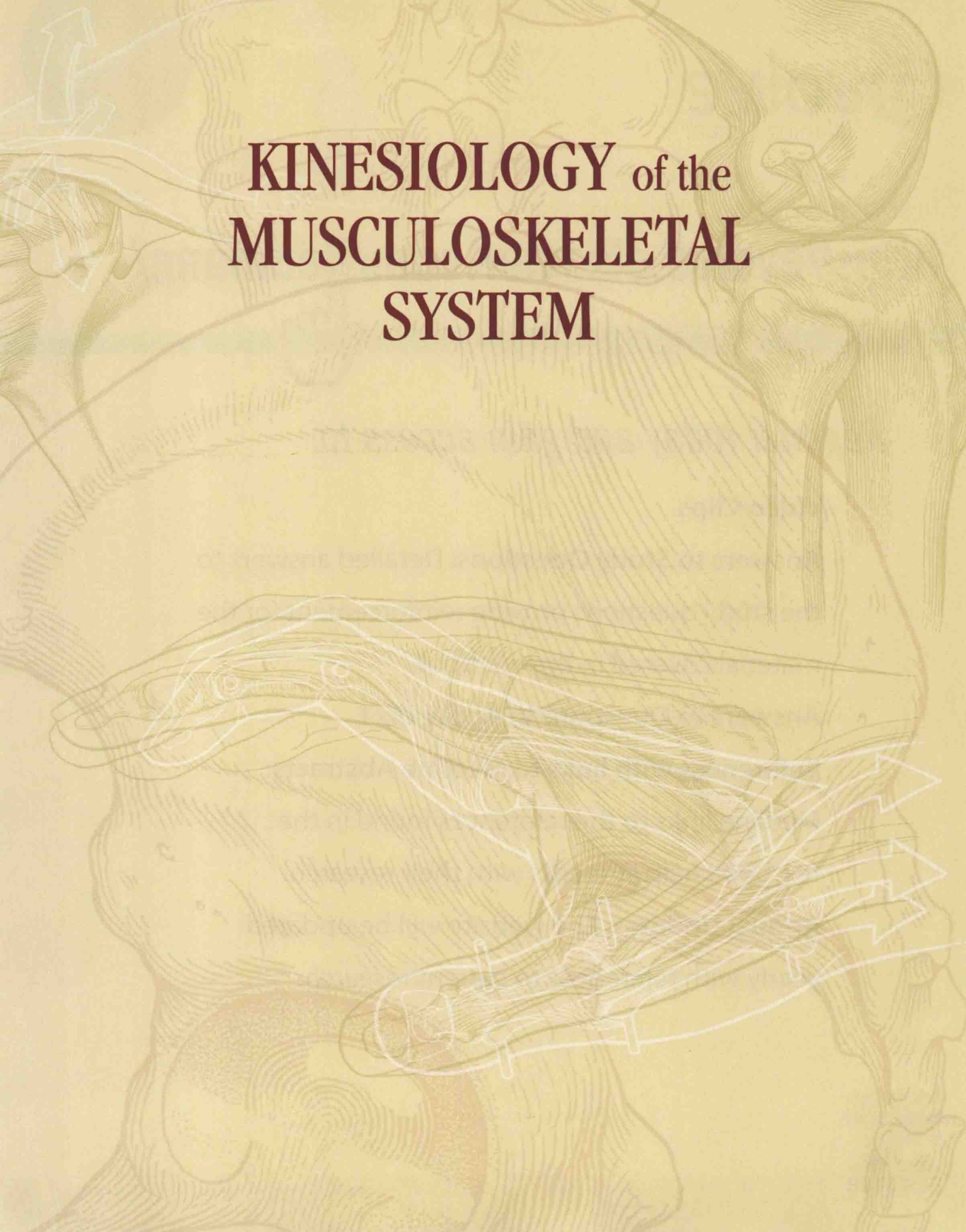
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The background of the cover is a detailed anatomical illustration of a human torso, showing the ribcage, spine, and major muscle groups. Overlaid on this illustration are white lines and arrows. Some arrows point upwards, while others follow the contours of muscles, suggesting movement or force. There are also some white circles and rectangular boxes highlighting specific areas of interest.

# KINESIOLOGY of the MUSCULOSKELETAL SYSTEM

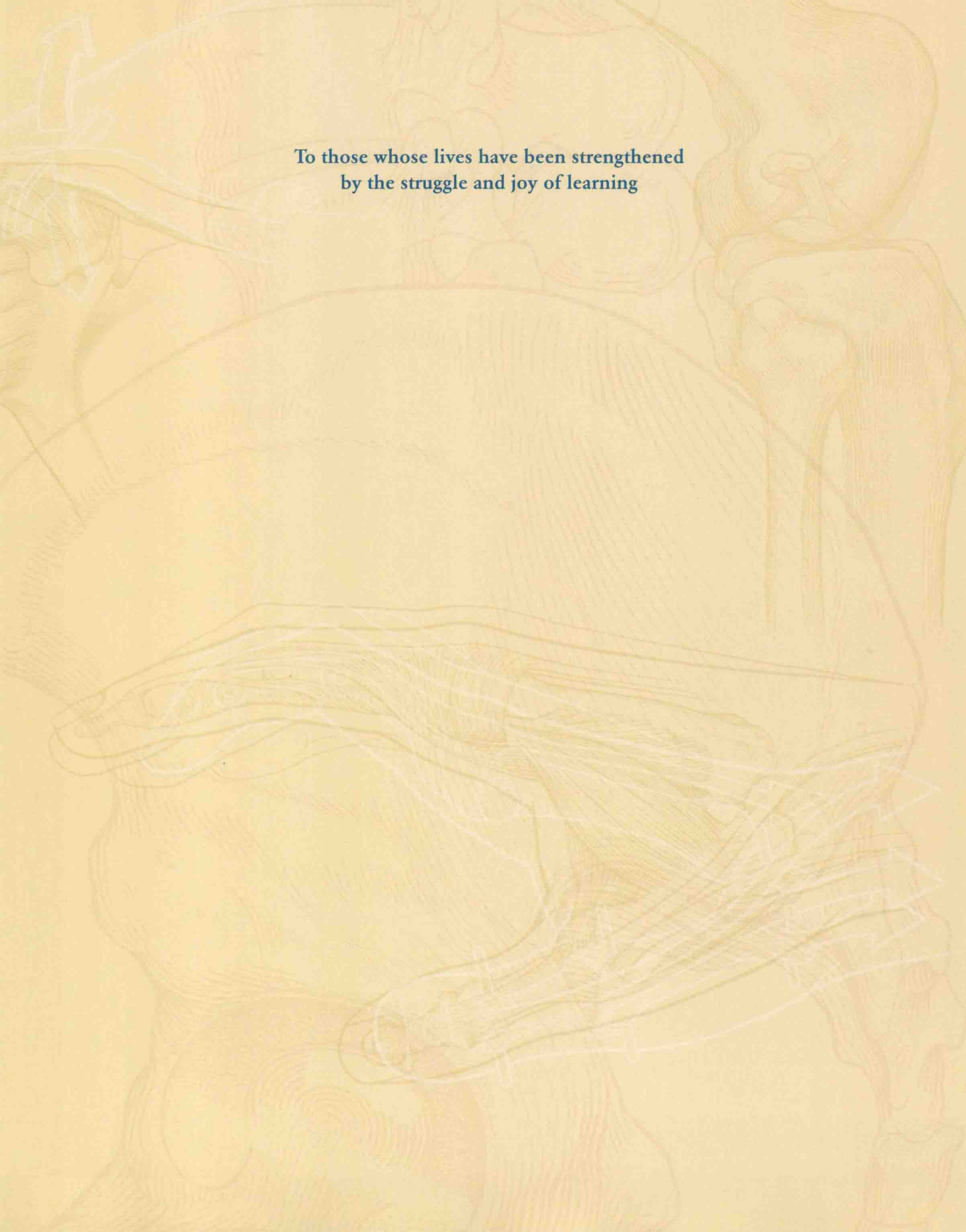
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- **Annual Updates:** The website will be updated yearly with references to current research.



To those whose lives have been strengthened  
by the struggle and joy of learning



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# About the Author

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## Donald A. Neumann

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Don was born in New York City, the oldest of five siblings. He is the son of Charles J. Neumann, a meteorologist and world-renowned hurricane forecaster, who has lived for 60 years with the affects of polio, which he contracted flying as a “hurricane hunter” in the Caribbean Sea in the 1950s. Don grew up in Miami, Florida, the location of the United States Weather Bureau, where his mother (Betty) and father still live today.

Soon after graduating from high school, Don was involved in a serious motorcycle accident. After receiving extensive physical therapy, Don chose physical therapy as his lifelong career. In 1972, he started his study and practice of physical therapy by earning a 2-year degree from Miami Dade Community College as a physical therapist assistant. In 1976, Don graduated with a bachelor of science degree in physical therapy from the University of Florida. He went on to practice as a physical therapist at Woodrow Wilson Rehabilitation Center in Virginia, where he specialized in the rehabilitation of patients with spinal cord injury. In 1980, Don attended the University of Iowa, where he earned his master’s degree in science education and a PhD in exercise science.

In 1986, Don started his academic career as a teacher, writer, and researcher in the Physical Therapy Department at Marquette University. His teaching efforts have concentrated on kinesiology as it relates to physical therapy, anatomy, and rehabilitation of people with spinal cord injury. Don remained clinically active as a physical therapist on a part-time basis until 2002, working primarily in the area of rehabilitation after spinal cord injury, outpatient orthopedics, and geriatrics. Today he continues his academic career as a full professor at Marquette University.

Dr. Neumann has received many awards for his scholarship in physical therapy ([www.marquette.edu](http://www.marquette.edu)). In addition to receiving several prestigious teaching and research awards from the American Physical Therapy Association, Dr. Neumann received a Teacher of the Year Award at Marquette University in 1994, and in 2006 he was named by the Carnegie Foundation as Wisconsin’s College Professor of the Year. In 2008, Donald was named a Fellow of the American Physical Therapy Association.

Over the years, Dr. Neumann’s research and teaching projects have been funded by the National Arthritis Foundation and the Paralyzed Veterans of America. He has published extensively on methods to protect the arthritic or painful hip from damaging forces. Don has received multiple Fulbright Scholarships to teach kinesiology in Kaunas Medical University in Lithuania (2002), Semmelweis Medical University in Budapest, Hungary (2005 and 2006), and Shinshu University in Matsumoto, Japan (2009 and 2010). In 2007, Don received an honorary doctorate from the Lithuanian Academy of Physical Education, located in Kaunas, Lithuania. Donald also serves as an associate editor of the *Journal of Orthopaedic & Sports Physical Therapy*.

Don lives with his wife, Brenda, and two dogs in Wisconsin; his son Donald, Jr. (“Donnie”) and family, and his stepdaughter, Megann, also live in Wisconsin. Outside of work, Donald enjoys photography, a wide range of music, mountaineering, and paying close attention to the weather.

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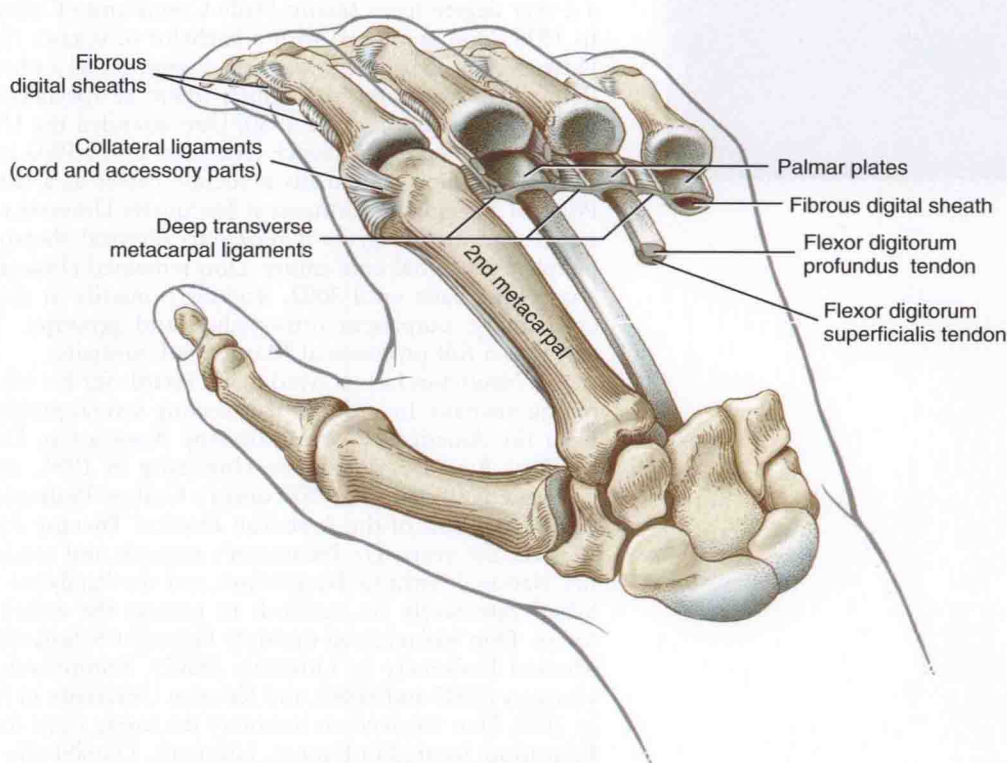
## About the Illustrations

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The collection of art in this edition has undergone extensive transformation from the first edition. Some of the art is brand new, some of it has been extensively modified, and nearly all the illustrations have been fully colorized. Most of the more than 700 illustrations are original, produced over the course of compiling the first two editions of this

text. The illustrations were first conceptualized by Dr. Neumann and then meticulously rendered to their pre-colored state through the unique talents of Elisabeth Roen Kelly. Dr. Neumann states, “The artwork really drove the direction of much of my writing. I needed to thoroughly understand a particular kinesiological concept at its most essential level in order to effectively explain to Elisabeth what needed to be illustrated. In this way, the artwork kept me honest; I wrote only what I truly understood.”

Dr. Neumann and Ms. Kelly produced three primary forms of artwork for this text. Elisabeth depicted the anatomy of bones, joints, and muscles by hand, creating very detailed pen-and-ink drawings (Figure 1). These drawings started with a series of pencil sketches, often based on anatomic specimens carefully dissected by Dr. Neumann. The pen-and-ink medium was chosen to give the material an organic, classic feeling. Color was added to these drawings in this edition by a talented and dedicated team of illustrators: Craig Kiefer, Kimberly Martens (from the art studio of Martens & Kiefer), and Claudia Grosz. Craig Kiefer, who led the colorization team, worked diligently with Dr. Neumann to develop a process of adding color that maintained the integrity of Ms. Kelly’s original line art.



**FIGURE 1**

The second form of art used a layering of artistic media, integrated with the use of computer software (Figure 2). Neumann and Kelly often started with a photograph that was transformed into a simplified outline of a person performing a particular movement. Images of bones, joints, and muscles were then electronically embedded within the human outline. Overlaying various biomechanical images further enhanced the resultant illustration. The final design displayed specific and often complex biomechanical concepts in a relatively simple manner, while preserving human form and expression. Final coloring was skillfully provided primarily by the team of Kiefer, Martens, and Grosz.



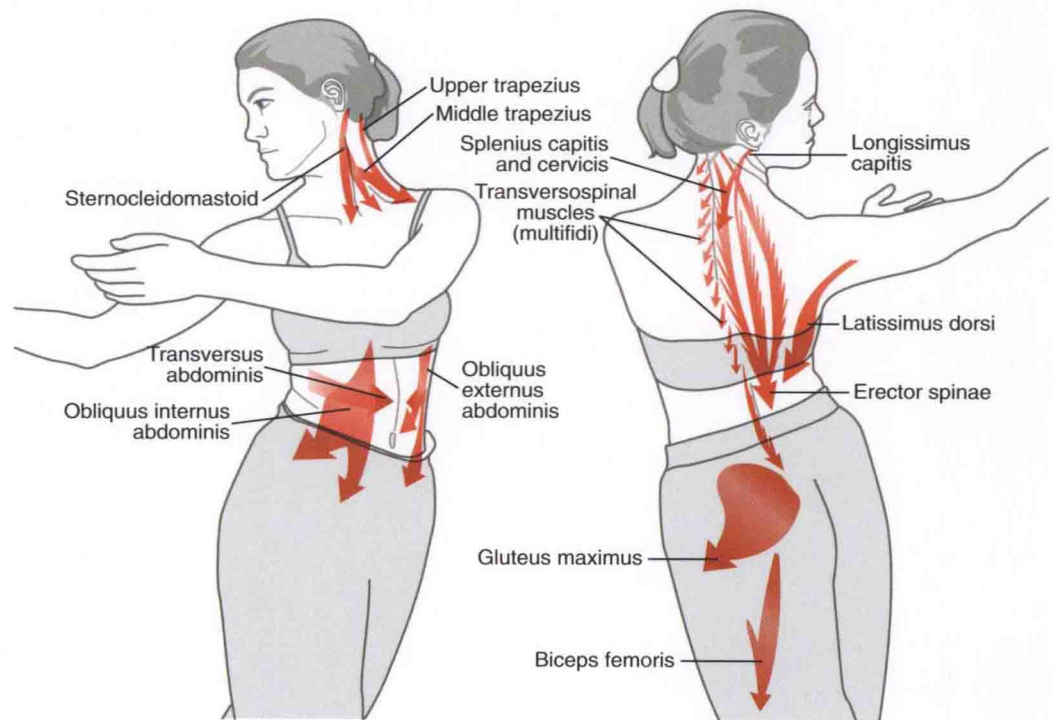


FIGURE 2

A third form of art was specifically developed by Neumann and Kelly for this edition (Figure 3). With the help of software, prepared anatomic specimens were rendered to a textured three-dimensional shape. The depth and anatomic precision of these images provides important insight into the associated kinesiology.

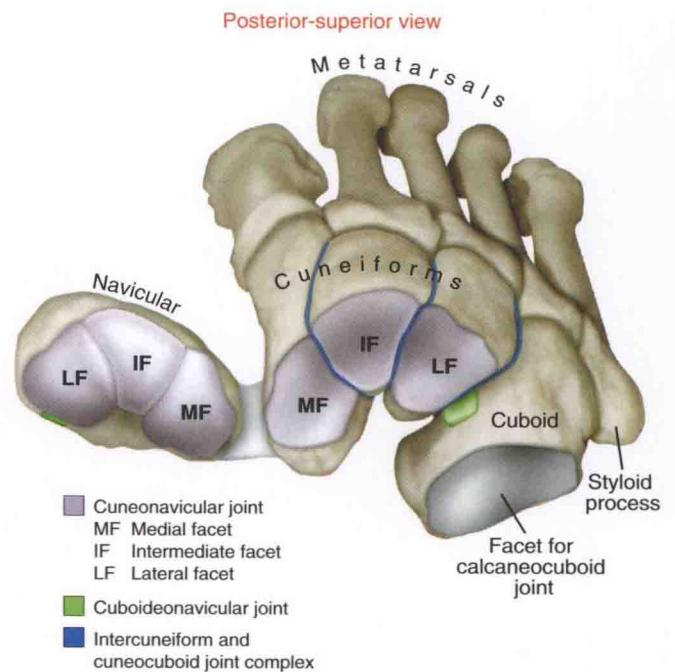


FIGURE 3

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# About the Contributors

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## Peter R. Blanpied, PT, PhD

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Professor, Physical Therapy Department, University of Rhode Island, Kingston, Rhode Island

<http://www.uri.edu/>

Dr. Blanpied received his basic training at Ithaca College, graduating with a bachelor of science degree in physical therapy in 1979. After practicing clinically in acute, adult rehabilitation, and sports settings, he returned to school and completed an advanced master of science degree in physical therapy from the University of North Carolina in 1982, specializing in musculoskeletal therapeutics, and a PhD from the University of Iowa in 1989. Since then, he has been on faculty at the University of Rhode Island teaching in the areas of biomechanics, research, and musculoskeletal therapeutics. In addition to continuing clinical practice, he has also been active in funded and unfunded research and is the author of many peer-reviewed research articles, and national and international professional research presentations. He is an associate editor of the *Journal of Orthopaedic & Sports Physical Therapy*, and is active in the Research Section of the APTA. He lives in West Kingston with his wife Carol (also a physical therapist) and their two sons.

## Sandra K. Hunter, PhD

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Associate Professor, Exercise Science Program, Marquette University, Milwaukee, Wisconsin

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Dr. Hunter received a bachelor of education degree in physical education and health from the University of Sydney, a Graduate Diploma in human movement science from Wollongong University, and a PhD in exercise and sport science (exercise physiology) from The University of Sydney where her research focused on neuromuscular function with aging and strength training. Dr. Hunter moved to Boulder, Colorado, in 1999 to take a position as a postdoctoral research associate in the Neurophysiology of Movement Laboratory directed by Dr. Roger Enoka. Her research focused on the mechanisms of neuromuscular fatigue during varying task conditions. She has been a faculty member in the Exercise Science Program in the Department of Physical Therapy at Marquette University since 2003 where her primary area of teaching is advanced exercise physiology and research methods. Dr. Hunter's current research program focuses on understanding the mechanisms of neuromuscular fatigue and impairment in muscle function in clinical populations under different task conditions. She is the author of several book chapters, many peer-reviewed research articles, and national and international research presentations. Dr. Hunter has received research funding from the National Institutes of Health (NIH), including the National Institute of Aging and

National Institute of Occupational Safety and Health, as well as from many other funding sources. She is on the editorial board for the *Journal of Applied Physiology*. In her free time, Sandra enjoys traveling, camping, hiking, cycling, and the occasional triathlon. She lives in Wisconsin with her husband Jeff and her daughter Kennedy.

## Guy G. Simoneau, PT, PhD

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Professor, Department of Physical Therapy, Marquette University, Milwaukee, Wisconsin

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Dr. Simoneau received a bachelor of science degree in physiotherapy from the Université de Montréal, Canada, a master of science degree in physical education (sports medicine) from the University of Illinois at Urbana-Champaign, Illinois, and a PhD in exercise and sport science (locomotion studies) from The Pennsylvania State University, State College, Pennsylvania, where he focused much of his work on the study of gait, running, and posture. Dr. Simoneau has been a faculty member in the Department of Physical Therapy at Marquette University since 1992. His primary area of teaching is orthopedic and sports physical therapy. He has also published several book chapters and research articles on topics related to orthopedic/sports physical therapy and biomechanics. Dr. Simoneau has received research funding from the National Institutes of Health (NIH), the National Institute of Occupational Safety and Health (NIOSH), the Arthritis Foundation, and the Foundation for Physical Therapy, among others. His research and teaching efforts have been recognized through several national awards from the American Physical Therapy Association. In 2007, Guy received an honorary doctorate from the Lithuanian Academy of Physical Education, located in Kaunas, Lithuania. Dr. Simoneau is currently the editor-in-chief of the *Journal of Orthopaedic & Sports Physical Therapy*. In his free time, Guy enjoys traveling and hiking.

## Original Contributors

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### David A. Brown, PT, PhD

Associate Professor and Associate Chair for Post-Professional Education, Department of Physical Therapy & Human Movement Sciences, Feinberg School of Medicine, Northwestern University, Chicago, Illinois

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Dr. Brown is the son of a physical therapist (Elliott). David graduated with a master's degree from Duke University in 1983 and received a PhD in exercise science from the University of Iowa in 1989. He is now the director of the NUPTHMS Locomotor Control Laboratory. His area of clinical expertise



is in neurorehabilitation with an emphasis on locomotion following stroke. In his current role as an educator and scientist, Dr. Brown is a named inventor on four patents, including the KineAssist Walking and Balance System, and has authored many articles in peer-reviewed journals. He has received research funding from the National Institutes for Health, Department of Education, Department of Veterans Affairs, and Foundation for Physical Therapy. Dr. Brown is married, has one child, and enjoys hiking, biking, travel, classical music, theater, and reading American literature.

**A. Joseph Threlkeld, PT, PhD**

Associate Professor, Department of Physical Therapy, Creighton University, Omaha, Nebraska

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A 1976 physical therapy graduate of the University of Kentucky, Lexington, Kentucky, Dr. Threlkeld has been involved in the clinical management of musculoskeletal dysfunctions, particularly arthritis and related disorders. In 1984, he completed his doctoral work in anatomy with a focus on the remodeling of articular cartilage. He is currently Director of the Rehabilitation Science Research Laboratory at Creighton University. Dr. Threlkeld teaches courses on kinesiology and pathomechanics and co-teaches clinical electrophysiology and prosthetics to physical therapy students. His research pursuits include investigating the role of lower extremity loading in the generation, control, and rehabilitation of

pathologic gait patterns. His hobbies include music, remodeling his house, and equine adventure.

**Deborah A. Nawoczenski, PT, PhD**

Professor, Program in Physical Therapy, School of Health Sciences and Human Performance, Ithaca College, Rochester, New York

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Dr. Nawoczenski has both a bachelor of science degree in physical therapy and a master of education degree from Temple University, Philadelphia. She also has a PhD in exercise science (biomechanics) from the University of Iowa, Iowa City. Dr. Nawoczenski is co-director of the Movement Analysis Laboratory at Ithaca College's Rochester Campus. She is engaged in research on the biomechanics of the foot and ankle. Dr. Nawoczenski also holds a position as an Adjunct Assistant Professor of Orthopaedics in the School of Medicine and Dentistry at the University of Rochester, Rochester, New York. She has served as an editorial board member for the *Journal of Orthopaedic & Sports Physical Therapy* and was co-editor of the two-part special issue on the foot and ankle. Dr. Nawoczenski has co-authored and co-edited two textbooks: Buchanan LE, Nawoczenski DA (eds): *Spinal Cord Injury: Concepts and Management Approaches*, and Nawoczenski DA, Epler ME (eds): *Orthotics in Functional Rehabilitation of the Lower Limb*.



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# Preface

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I am pleased to introduce the second edition of *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation*. This edition is a natural offspring of the first, expanding upon many new concepts that have been fueled by a rapidly growing body of knowledge. Over 2000 references are cited in this second edition to support the science and clinical relevance behind the kinesiology. Any respected textbook must continue to grow and keep pace with the expanding knowledge base of the discipline and the professions it helps support.

The overwhelming popularity of the illustrations created in the first edition stimulated the efforts to take the art in the second edition to the next level. Every piece of art was revisited and thoroughly examined, and virtually every piece was revised. Through the full colorization of the existing work as well as the creation of many new or modified illustrations, the artwork in this edition has been significantly upgraded. As in the first edition, the art drives much of the teaching of this textbook.

Many new instructional elements have been added to the second edition, such as Study Questions and a section called Additional Clinical Connections. These clinical connections allow the students to apply their newly learned kinesiology to specific and often complex clinical situations. Furthermore, a more extensive website has been developed to extend the teaching effectiveness of this book.

Naturally, I used the first edition of the text to teach my classes on kinesiology to students at Marquette University. The close working relationship among the textbook, students, and I generated many practical ideas on ways to improve the writing, the organization or flow of topics, and clarity of images. Many improvements in both the text and illustrations are a result of the direct feedback I have received from my own students, as well as from other students and instructors around the United States and in other countries. As the second edition finds its way into the classrooms of universities and colleges, I look forward to receiving continued feedback and suggestions on improving this work.

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## Background

Kinesiology is the study of human movement, typically pursued within the context of sport, art, or medicine. To varying degrees, *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation* relates to all three areas. This textbook is intended, however, primarily to provide kinesiology foundations for the practice of rehabilitation, which strives to optimize functional movements of the human body. Although worldwide the subject of kinesiology is presented from many different perspectives, I and my contributing authors have focused primarily on the mechanical and physiologic interactions between the muscles and joints of the

body. These interactions are described for normal movement and, in the case of disease, trauma, or otherwise altered musculoskeletal tissues, for abnormal movement. I hope that this textbook provides a valuable educational resource for a wide range of health- and medical-related professions, both for students and clinicians.

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## Approach

This textbook places a major emphasis on the anatomic detail of the musculoskeletal system. By applying a few principles of physics and physiology to a good anatomical background, the reader should be able to mentally transform a static anatomic image into a dynamic, three-dimensional, and relatively predictable movement. The illustrations created for *Kinesiology of the Musculoskeletal System* are designed to encourage this mental transformation. This approach to kinesiology reduces the need for rote memorization and favors reasoning based on mechanical analysis, which can assist students and clinicians in developing proper evaluation, diagnosis, and treatment related to dysfunction of the musculoskeletal system.

This textbook represents the synthesis of nearly 35 years of experience as a physical therapist. This experience includes a rich blend of clinical, research, and teaching activities that are related, in one form or another, to kinesiology. Although I was unaware of it at the time, my work on this textbook began the day I prepared my first kinesiology lecture as a brand-new college professor at Marquette University in 1986. Since then, I have had the good fortune of being exposed to intelligent and motivated students. Their desire to learn has continually fueled my ambition and love for teaching. As a way to encourage my students to listen actively rather than to transcribe my lectures passively, I developed an extensive set of kinesiology lecture notes. Year after year, my notes evolved, forming the blueprints of the first edition of the text. Now, eight years later, I present the second edition of this text.

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## Organization

The organization of this textbook reflects of the overall plan of study used in my two-semester kinesiology course sequence as well as other courses in our curriculum. The textbook contains 15 chapters, divided into four major sections. *Section I* provides the essential topics of kinesiology, including an introduction to terminology and basic concepts, a review of basic structure and function of the musculoskeletal system, and an introduction to biomechanical and quantitative aspects of kinesiology. *Sections II* through *IV* present the specific anatomic details and kinesiology of the three major



regions of the body. *Section II* focuses entirely on the upper extremity, from the shoulder to the hand. *Section III* covers the kinesiology of the axial skeleton, which includes the head, trunk, and spine. A special chapter is included within this section on the kinesiology of mastication and ventilation. *Section IV* presents the kinesiology of the lower extremity, from the hip to the foot. The final chapter in this section, “Kinesiology of Walking,” functionally integrates and reinforces much of the kinesiology of the lower extremity.

This textbook is specifically designed for the purpose of *teaching*. To that end, concepts are presented in layers, starting with *Section I*, which lays much of the scientific foundation for chapters contained in *Sections II* through *IV*. The material covered in these chapters is also presented layer by layer, building both clarity and depth of knowledge. Most chapters begin with *osteology*—the study of the morphology and subsequent function of bones. This is followed by *arthrology*—the study of the anatomy and the function of the joints, including the associated periarticular connective tissues. Included in this study is a thorough description of regional kinematics, from both an arthrokinematic and osteokinematic perspective.

The most extensive component of most chapters in *Sections II* through *IV* highlights the *muscle and joint interactions*. This topic begins by describing the muscles within a region, including a summary of the innervations to both muscles and joint structures. Once the shape and physical orientation of the muscles are established, the mechanical interplay between the muscles and the joints is discussed. Topics presented include: strength and movement potential of muscles; muscular-produced forces imposed on joints; intermuscular and interjoint synergies; important functional roles of muscles in movement, posture, and stability; and the functional relationships that exist between the muscles and underlying joints. Multiple examples are provided throughout each chapter on how disease, trauma, or advanced age may cause reduced function or adaptations within the musculoskeletal system. This information sets the foundation for understanding many of the evaluations and treatments used in most clinical situations to treat persons with musculoskeletal as well as neuromuscular disorders.

## Distinctive Features

Key features of the second edition include the following:

- Full-color illustrations
- Special Focus boxes
- Chapter at a Glance boxes
- Additional Clinical Connections boxes
- Study questions
- Evidence-based approach

## Ancillary Materials

An Evolve website has been created specifically to accompany this textbook and can be accessed via the following link: <http://evolve.elsevier.com/Neumann>. A wealth of resources is provided to enhance both teaching and learning, as follows:

## For the Instructor

- **Image Collection:** All of the textbook’s artwork is reproduced online for download into PowerPoint or other presentations.
- **Lab Ideas**

## For the Student and Instructor

- **Video Clips:** Video segments are provided to highlight kinesiology concepts discussed in the text. These include videofluoroscopy of joint movements, demonstrations of persons with partial paralysis showing how to substitute for muscle weakness, and various methods of teaching concepts of kinesiology.
- **Answers to Study Questions:** Detailed answers to the study questions provide reinforcement for the material covered in the textbook.
- **Answers to Biomechanical Problems contained in Appendix I**
- **References with links to Medline Abstracts:** Medline links to the references found in the textbook help students with their research.
- **Yearly Citation Updates:** The website will be updated yearly by the author with references on current research related to kinesiology.

## Acknowledgments

I welcome this opportunity to acknowledge a great number of people who have provided me with kind and thoughtful assistance throughout the evolution of this textbook to its second edition. I am sure that I have inadvertently overlooked some people and, for that, I apologize.

The best place to start with my offering of thanks is with my immediate family, especially my wife Brenda who, in her charming and unselfish style, supported me emotionally and physically during both editions. I thank my son, Donnie, and stepdaughter, Megann, for their patience and understanding. I also thank my caring parents, Betty and Charlie Neumann, for the many opportunities that they have provided me throughout my life.

Many persons significantly influenced the realization of *Kinesiology of the Musculoskeletal System: Foundations for Rehabilitation*. Foremost, I wish to thank Elisabeth Roen Kelly, the primary medical illustrator of the text, for her years of dedication, incredible talent, and uncompromisingly high standard of excellence. I also thank Craig Kiefer and his colleagues for their care and skill with transitioning the art into full color. I also extend a thank you to the Elsevier staff and affiliates for their patience, in particular Melissa Kuster Deutsch, Sarah Wunderly, and Jeannie Robertson.

I to wish express my sincere gratitude to Drs. Lawrence Pan and Richard Jensen, present and past directors, respectively, of the Department of Physical Therapy at Marquette University, as well as Drs. Jack Brooks and William Cullinan, past and present deans of the College of Health Sciences at Marquette University. These gentlemen unselfishly provided me with the opportunity and freedom to fulfill a dream.



I am also indebted to the following persons who contributed special chapters to this textbook: Peter R. Blanpied, Sandra K. Hunter, Guy G. Simoneau, David A. Brown, Deborah A. Nawoczenski, and A. Joseph Threlkeld. They provided an essential depth and breadth to this textbook. I am also grateful to the many persons who reviewed chapters, who did so without financial remuneration. These reviewers are listed elsewhere in previous sections.

Several people at Marquette University provided me with invaluable technical and research assistance. I thank Dan Johnson, Chief Photographer, for most of the photography contained in this book. I also wish to thank Ljudmila ("Milly") Mursec, Martha Gilmore Jermé, and other fine librarians at Raynor Library for their important help with my research.

Many persons affiliated directly or indirectly with Marquette University provided assistance with a wide range of activities throughout the evolution of this edition. This help included proofreading, listening, verifying references or concepts, posing for or supplying photographs, taking x-rays, and providing clerical or other technical assistance. For this help, I am grateful to Santana Deacon, Caress Dean, Kerry Donahue, Rebecca Eagleeye, Kevin Eckert, Kim Fowler, Jessica Fuentes, Gregg Fuhrman, Mary Beth Geiser, Barbara Haines, Douglas Heckenkamp, Lisa Hribar, Erika Jacobson, Davin Kimura, Stephanie Lamon, John Levene, Lorna Loughran, Christopher Melkovitz, Melissa Merriman, Preston Michelson, Alicia Nowack, Michael O'Brien, Ellen Perkins, Gregory Rajala, Janet Schuh, Robert Seeds, Elizabeth Shanahan, Bethany Shutko, Jeff Sischo, Pamela Swiderski, Michelle Treml, Stacy Weineke, Andy Weyer, Sidney White, and David Williams.

I am very fortunate to have this forum to acknowledge those who have made a significant, positive impact on my professional life. In a sense, the spirit of these persons is

interwoven within this text. I acknowledge Shep Barish for first inspiring me to teach kinesiology; Martha Wroe for serving as a role model for my practice of physical therapy; Claudette Finley for providing me with a rich foundation in human anatomy; Patty Altland for emphasizing to Darrell Bennett and myself the importance of not limiting the functional potential of our patients; Gary Soderberg for his overall mentorship and firm dedication to principle; Thomas Cook for showing me that all this can be fun; Mary Pat Murray for setting such high standards for kinesiology education at Marquette University, and Guy Simoneau for constantly reminding me what an enduring work ethic can accomplish.

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