Susceptibility
Weighted Imaging in MRI
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Basic Concepts and Clinical Applications

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WILEY-BLACKWELL
A JOHN WILEY & SONS, INC., PUBLICATION
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Since its inception, magnetic resonance imaging has used tissue properties such as $T_1$, $T_2$, and spin density followed by flow, diffusion characteristics, lipid imaging, and spectroscopy as the technology developed to create images with extraordinary detail of the body and brain; and this list continues to grow. Surprisingly, prior to susceptibility weighted imaging or SWI, the basic property of tissue susceptibility had not been used directly, but rather taken advantage of through local $T_2^*$ effects in magnitude images. The problem with this approach is that many different sources can cause $T_2^*$ signal dephasing. The basic field effects created by susceptibility have generally been recognized as a source of artifacts and the usual first response was to remove them. However, such field effects can be used to separate types of materials such as calcium deposits, which are diamagnetic, from microbleeds, which are paramagnetic. In fact, these field effects were used in the original concept of susceptibility weighted imaging to better image small veins and to enhance contrast in tissues.

Practically, the phase information available in MR imaging carries all the information that is needed to reconstruct the local magnetic source or susceptibility difference between tissues. Although SWI uses phase as a source of contrast, the more advanced concept is to create a susceptibility map that can be used not only to differentiate paramagnetic from diamagnetic substances but also to quantify the amount of a given substance present that is causing the susceptibility difference, such as local iron differences between tissues. In this book, we refer to the combination of SWI filtered phase and magnetic susceptibility mapping as SWIM for susceptibility weighted imaging and mapping. The work on SWI showed the significance of phase in enhancing contrast in tissues and now SWIM opens the door to quantifying susceptibility in tissues. Clinically, SWI makes it possible to image microbleeds and veins more effectively, while SWIM will provide the methods to quantify oxygen saturation and local iron content. These techniques have or will find applications in neurovascular diseases, neurodegenerative diseases, and iron-related diseases. Multi-echo SWI also offers a means to image the
entire vascular system, including arteries and veins alike. The field is still developing, and there are hints that major roadblocks in this area are falling, thanks to technical advances in magnet homogeneity, gradient strengths, and faster imaging methods such as parallel imaging. For example, the need to accommodate or correct air/tissue interfaces is now theoretically possible, high bandwidth imaging avoids geometric distortion, and multi-echo imaging may offer a means to ideally phase unwrap data on a pixel by pixel basis. This book contains nearly every aspect of SWI; however, a number of new developments and new findings are being made at the time this book went into publication. As these new concepts in the field of MRI evolve and develop, some of them may be ready for incorporation into the next edition of the book.

The main aim of this book is to provide clinicians a detailed overview of the basic concepts and applications related to susceptibility weighted imaging. The book has been organized into three parts. In the first eight chapters, we introduce basic concepts that include the definitions and mechanisms of gradient echo imaging, phase, $T_2^*$, and multi-echo imaging. This will enable the reader to have an understanding of the basics of the terms used throughout the book. The next 12 chapters represent the current efforts in clinical translational research using SWI. These chapters cover the basic venous structures in the brain followed by the application of SWI in several diseases, such as cancer, traumatic brain injury, vascular dementia, stroke, hemorrhage, multiple sclerosis, venous malformations, Sturge–Weber syndrome, atherosclerosis, and calcifications in breast cancer. The final 16 chapters cover a variety of technically more advanced concepts, including susceptibility mapping (SWIM), oxygen saturation measurements, technical developments, and animal imaging, as well as a list of references related to SWI up to early 2010. Most of the images used in this book have been adapted from published journal articles. Since most of these were either from Journal of Magnetic Resonance Imaging (JMRI) or Magnetic Resonance in Medicine (MRM), both published by John Wiley & Sons Inc., a blanket permission was acquired for their use in this book. Acknowledgement for the figures adapted from other publications are specifically mentioned in their respective captions.

The increasing clinical applications of SWI were our inspirations to write and produce this book. We believe its recent growth into SWIM and susceptibility mapping will spearhead even more quantitative measures of iron and new applications ranging from neurodegenerative diseases to hemochromatosis. Many colleagues around the world have made efforts in developing clinical applications of SWI and many, if not most of them, have contributed to this book. We acknowledge the contributions of these experts in the field. Without their enthusiasm and continuous support, including numerous meetings at various conferences, this project would not have been possible.

We are indebted to all those people who helped us in bringing out this book, particularly Alexander Boikov, Daniel Haacke, Lisa Hamm, and Judith Farah. Yongquan Ye helped us with his technical expertise in refining several chapters. A very special thanks to Jaladhar Neelavalli for his careful reading of the book, for his meticulous attention to detail, and for coordinating the final efforts that made it possible to get this book to press, in a timely fashion. We acknowledge Wiley for taking on this project and for their expert professional editorial support, particularly that of Dean Gonzalez, Kristen Parrish, and Ms. Sanchari Sil. We are grateful to Thom Moore, editor at Wiley, for his patience and enthusiasm in bringing out this book. A special thanks is due to the people at Siemens Healthcare for having made SWI available as a product for their customers. This was a major
step in taking the methodology into the clinical domain and, in part, is the reason why so many new applications are developing for SWI now. Finally, we would like to thank our families who put up with the added responsibilities during our long hours of work. Their emotional support and patience made this book possible.

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