

Contents

Foreword by <i>Emanuel Kanal</i>	vii
Why This Book?	ix
A User's Guide	xi
Acknowledgments	xv

Part I In the Beginning: Generating, Detecting, and Manipulating the MR (NMR) Signal

1 Laying the Foundation: Nuclear Magnetism, Spin, and the NMR Phenomenon	3
<i>The Overall Aim</i>	3
<i>Where Does the MRI Signal Come From?</i>	4
<i>Interaction of Protons with a Static Magnetic Field (B)</i>	10
<i>The Energy Configuration Approach: A Painless (Really!) Bit of Quantum Mechanics</i>	12
<i>One More Thing . . . What Exactly Is the MRI Signal That We Measure?</i>	18
2 Rocking the Boat: Resonance, Excitation, and Relaxation	19
<i>Introduction: How Can We Find a Signal to Measure?</i>	19
<i>Generating Net Transverse Magnetization</i>	20
3 Relaxation: What Happens Next?	27
<i>What Happens When the Radiofrequency Is Shut Off?</i>	27
<i>Separate, but Equal (Sort of): Two Components of Relaxation</i>	27
<i>The Spin Echo</i>	32
4 Image Contrast: T1, T2, T2*, and Proton Density	38
<i>T2/T2* Contrast</i>	38
<i>T1 Contrast</i>	40
<i>Proton Density Contrast</i>	44
<i>Putting Things Together to Control Image Contrast</i>	45

5	Hardware, Especially Gradient Magnetic Fields	47
	<i>Why This Chapter?</i>	47
	<i>The B₀ Magnetic Field</i>	47
	<i>Radiofrequency Transmission</i>	55
	<i>The Gradient Magnetic Field</i>	55
	<i>The RF Coils</i>	60
	<i>The Receiver (A2D)</i>	65
	<i>The Computer</i>	66
	<i>Shielding</i>	68
	<i>The Prescan Process</i>	71

Part II User Friendly: Localizing and Optimizing the MRI Signal for Imaging

6	Spatial Localization: Creating an Image	75
	<i>What Is an Image?</i>	75
	<i>Understanding and Exploiting B₀ Homogeneity</i>	77
	<i>Slice Selection Using the Gradient Magnetic Field</i>	78
	<i>Localizing Signal Within the Plane of the Slice:</i>	
	<i>Background for Frequency and Phase Encoding</i>	82
	<i>Frequency Encoding: The Next Stage</i>	84
	<i>Phase Encoding and the Two-dimensional Fourier Transform</i>	90
	<i>Some Comments Regarding k-Space</i>	97
7	Defining Image Size and Spatial Resolution	101
	<i>How Much Area Will Be Included in the Image?</i>	101
	<i>Specifying the Field of View</i>	102
	<i>Aliasing and Its Fixes</i>	103
	<i>Refining the Field of View</i>	107
	<i>A Footnote Regarding Receiver Bandwidth</i>	109
8	Putting It All Together: An Introduction to Pulse Sequences	110
	<i>Putting It All Together</i>	110
	<i>What Exactly Is a Pulse Sequence?</i>	110
	<i>The Pulse Sequence Diagram</i>	111
	<i>Building the Pulse Sequence</i>	113
	<i>The Spin Echo Pulse Sequence: A First Example</i>	113
	<i>What Happens After TE: Multiple Echoes and Multiple Slices</i>	116
	<i>The Gradient Echo Pulse Sequence</i>	119
	<i>Contrast Modification in SE and GRE Imaging</i>	127

9	Understanding, Assessing, and Maximizing	
	Image Quality	128
	<i>What Is the Measure of a Good Image?</i>	128
	<i>What Is Noise?</i>	129
	<i>Signal-to-Noise Ratio: Measuring Image Quality</i>	129
	<i>What Affects Signal to Noise?</i>	131
	<i>Contrast-to-Noise Ratio: Measuring</i>	
	<i>Diagnostic Utility</i>	134
	<i>Quality Assurance</i>	135
10	Artifacts: When Things Go Wrong, It's Not Necessarily	
	All Bad	139
	<i>Things Do Go Wrong . . . but It's Not All Bad News</i>	139
	Motion	139
	<i>Undersampling (Wraparound Artifact)</i>	141
	<i>Susceptibility Effects: Signal Loss and</i>	
	<i>Geometric Distortion</i>	144
	<i>Truncation (Gibbs Artifact)</i>	146
	<i>Radiofrequency Leak (Zipper Artifact)</i>	149
	<i>k-Space Corruption: (Corduroy, Herringbone, and</i>	
	<i>Spike Artifacts)</i>	150
	<i>Chemical Shift Artifact</i>	151
	<i>Slice Profile Interactions (Cross-Talk Artifact)</i>	153
11	Safety: First, Do No Harm	154
	<i>Who Cares?</i>	154
	<i>The Safety of MRI Versus Iatrogenic Injury</i>	154
	<i>Types of MRI Risk</i>	155
	<i>Keeping It Safe: S⁴</i>	159
 Part III To the Limit: Advanced MRI Applications		
12	Preparatory Modules: Saturation Techniques	165
	<i>Inversion-Recovery Imaging</i>	165
	<i>Spectral Saturation Techniques</i>	169
	<i>Hybrid Techniques</i>	170
	<i>Selective Excitation</i>	170
	<i>Spatial Saturation</i>	171
	<i>Magnetization Transfer Contrast</i>	172
13	Readout Modules: Fast Imaging	174
	<i>Gradient Echo Approaches</i>	174
	<i>Steady-State Free Precession</i>	177
	<i>Manipulating k-Space</i>	177
	<i>Hyperspace: Echoplanar Imaging</i>	182
	<i>Further Exploits in k-Space</i>	185

14	Volumetric Imaging: The Three-dimensional Fourier Transform.....	187
	<i>Multislice Versus Volumetric Imaging:</i> <i>Three-dimensional Versus Two-dimensional</i>	187
	<i>Two-dimensional Imaging: How Do We Do It?</i>	187
	<i>Three-dimensional Imaging: How Do We Do It?</i>	188
15	Parallel Imaging: Acceleration with SENSE and SMASH.....	194
	<i>Why Another Imaging Technique?</i>	194
	<i>So What's New?</i>	194
	<i>Basics of Parallel Techniques</i>	195
	<i>Sensitivity Encoding: SENSE</i>	197
	<i>Simultaneous Acquisition of Spatial Harmonics:</i> <i>SMASH</i>	198
	<i>What Do We Actually Gain and at What Cost?</i>	198
16	Flow and Angiography: Artifacts and Imaging of Coherent Motion	200
	<i>What Is Magnetic Resonance Angiography</i> <i>Anyway?</i>	200
	<i>Basic Principles of Flow for Students of MRI</i>	201
	<i>Impact of Flow on the MR Signal</i>	203
	<i>Time-of-Flight MRA</i>	212
	<i>Something Different: Contrast-Enhanced MRA</i>	221
	<i>Don't Forget This Pitfall!</i>	225
	<i>Phase-Contrast MRA</i>	226
	<i>Where Do We Go from Here?</i>	232
17	Diffusion: Detection of Microscopic Motion	233
	<i>Introduction</i>	233
	<i>What Is Diffusion?</i>	233
	<i>Effect of Diffusion on the MR Signal</i>	234
	<i>Making the MR Image Sensitive to Diffusion</i>	234
	<i>What Do Diffusion-Sensitized Images Look Like?</i>	236
	<i>Quantitative Diffusion Imaging: The ADC</i>	238
	<i>Directional Information: DTI</i>	239
18	Understanding and Exploiting Magnetic Susceptibility	245
	<i>What Is Magnetic Susceptibility (χ) Anyway?</i>	245
	<i>Proton-Electron Dipole Interactions: The Other Face of</i> <i>Paramagnetism</i>	248
	<i>Susceptibility-Related Effects I: Artifacts</i>	248
	<i>Susceptibility-Related Effects II: Hemorrhage</i>	249
	<i>Susceptibility-Related Effects III: Contrast Agents</i>	254

	<i>Susceptibility-Related Effects IV: Perfusion Imaging</i>	255
	<i>Susceptibility-Related Effects V: Functional MRI</i>	259
19	Spectroscopy and Spectroscopic Imaging: <i>In Vivo</i>	
	Chemical Assays by Exploiting the Chemical Shift	263
	<i>Introduction</i>	263
	<i>The Chemical Basis of MRS</i>	263
	<i>What Then Is Spectroscopy (MRS) and How Is It</i>	
	<i>Different from MRI?</i>	264
	<i>Abundance, Resolution, and Detection</i>	265
	<i>The Importance of Field Homogeneity</i>	266
	<i>Localization: Single-Voxel Methods</i>	267
	<i>Localization: Chemical Shift Imaging</i>	270
	<i>Brain Chemistry: Brief Overview of</i>	
	<i>the Proton Spectrum</i>	272
	 Appendices	
	Appendix 1 Understanding and Manipulating Vectors	277
	Appendix 2 Glossary of Terms.	279
	Appendix 3 Glossary of Common MRI Acronyms, Abbreviations, and Notations.	291
	Appendix 4 Resources for Reference and Further Study	297
	 Index	299