Magnetic Resonance Imaging in Stroke

Magnetic resonance imaging (MRI) provides non-invasive information about the brain's blood flow, water movement and biochemical abnormalities following stroke, and advances in MRI are transforming the investigation and treatment of cerebrovascular disease. Echoplanar techniques with diffusion- and perfusion-weighted imaging, together with developments in magnetic resonance spectroscopy and angiography, are replacing CT scanning as the diagnostic modality of choice. In this profusely illustrated book, world leaders in these technologies review the scientific basis and clinical applications of MRI in stroke. It will appeal to a broad readership including stroke physicians, neurologists, neurosurgeons, rehabilitation specialists, and others with a clinical or research interest in cerebrovascular disease.

Stephen Davis is Professor of Neurology at the University of Melbourne. He heads the Stroke Research Group and is Co-Director of the Brain Imaging Laboratory at the Royal Melbourne Hospital, where he is Director of Neurology.

Marc Fisher is Professor of Neurology at the University of Massachusetts, and a leading authority on the use of MRI in the evaluation of stroke therapies.

Steven Warach is Chief of the Section on Stroke Diagnostics and Therapeutics in the Stroke Branch at NINDS, National Institutes of Health, Bethesda, Maryland. He pioneered the use of diffusion and perfusion MRI in the evaluation of stroke and in clinical trials.
Magnetic Resonance Imaging in Stroke

Edited by

Stephen Davis
University of Australia, Adelaide

Marc Fisher
University of Massachusetts Memorial Medical Care, USA

Steven Warach
National Institutes of Health, Bethesda, MD, USA
## Contents

<table>
<thead>
<tr>
<th>List of contributors</th>
<th>Page</th>
<th>Preface</th>
<th>Page vii</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The importance of specific diagnosis in stroke patient management</td>
<td>1</td>
<td>John N. Fink and Louis R. Caplan</td>
<td></td>
</tr>
<tr>
<td>2 Limitations of current brain imaging modalities in stroke</td>
<td>15</td>
<td>P. Alan Barber and Stephen M. Davis</td>
<td></td>
</tr>
<tr>
<td>3 Clinical efficacy of CT in acute cerebral ischemia</td>
<td>31</td>
<td>Rüdiger von Kummer</td>
<td></td>
</tr>
<tr>
<td>4 Computerized tomographic-based evaluation of cerebral blood flow</td>
<td>47</td>
<td>Lawrence R. Wechsler, Steven Goldstein and Howard Yonas</td>
<td></td>
</tr>
<tr>
<td>5 Technical introduction to MRI</td>
<td>55</td>
<td>Rohit Sood and Michael Moseley</td>
<td></td>
</tr>
<tr>
<td>6 Clinical use of standard MRI</td>
<td>69</td>
<td>Brian M. Tress</td>
<td></td>
</tr>
<tr>
<td>7 MR angiography of the head and neck: basic principles and clinical applications</td>
<td>85</td>
<td>Robert R. Edelman and Joel Meyer</td>
<td></td>
</tr>
<tr>
<td>8 Stroke MRI in intracranial hemorrhage</td>
<td>103</td>
<td>Peter D. Schellinger, Olav Jansen and Werner Hacke</td>
<td></td>
</tr>
<tr>
<td>9 Using diffusion-perfusion MRI in animal models for drug development</td>
<td>113</td>
<td>Marc Fisher</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Localization of stroke syndromes using diffusion-weighted MR imaging (DWI)</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>--------------------------------------------------------------------------------</td>
<td>-----</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Max Wintermark, Marc Reichhart, Reto Meuli and Julien Bogousslavsky</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>MRI in transient ischemic attacks: clinical utility and insights into pathophysiology</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jeffrey L. Saver and Chelsea Kidwell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Perfusion-weighted MRI in stroke</td>
<td>147</td>
<td></td>
</tr>
<tr>
<td></td>
<td>William A. Copen and A. Gregory Sorensen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Perfusion imaging with arterial spin labelling</td>
<td>161</td>
<td></td>
</tr>
<tr>
<td></td>
<td>David C. Alsop and John A. Detre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Clinical role of echoplanar MRI in stroke</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stephen Davis and Mark Parsons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>The ischemic penumbra: the evolution of a concept</td>
<td>191</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geoffrey A. Donnan, Peter M. Wright, Romesh Markus, Thanh Phan and David C. Reutens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>New MR techniques to select patients for thrombolysis in acute stroke</td>
<td>207</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vincent N. Thijs and Gregory W. Albers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>MRI as a tool in stroke drug development</td>
<td>223</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Steven Warach</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Magnetic resonance spectroscopy in stroke</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dawn E. Saunders and Martin M. Brown</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Functional MRI and stroke</td>
<td>251</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amy Brodtmann, Leeanne Carey and David G. Darby</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Index</td>
<td>263</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Colour figures between pp. 120 and 121.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Contributors

Stephen M. Davis,
Department of Neurology,
Royal Melbourne Hospital,
Parkville,
Victoria 3050,
Australia

Marc Fisher,
Department of Neurology,
UMACS,
Memorial Health Care,
119 Belmont Street,
Worcester,
MA 01605,
USA

Steven Warach,
National Institutes of Health,
NINDS,
10 Center Drive,
MSC 1063, Room B1D733,
Bethesda,
MD 29892-1063,
USA

Gregory W. Albers,
Stanford Stroke Center,
Stanford University Medical Center,
Palo Alto,
CA 94394,
USA
List of contributors

David C. Alsop,
Department of Radiology,
Beth Israel Deaconess Medical Center and Harvard Medical School,
USA

P.A. Barber,
Department of Neurology,
Royal Melbourne Hospital,
University of Melbourne,
Parkville,
Victoria 3050,
Australia

Julien Bogousslavsky,
Department of Neurology,
University Hospital (CHUV) BH07, 1011 Lausanne,
Switzerland

Amy Brodtmann,
Department of Neurology,
Royal Melbourne Hospital,
Parkville,
Victoria 3050,
Australia

Martin M. Brown,
Stroke Medicine,
Institute of Neurology,
University College London,
The National Hospital for Neurology and Neurosurgery,
Queen Square,
London,
UK

Louis R. Caplan,
Department of Neurology,
Beth Israel Deaconess Medical Center,
Boston,
MA,
USA

Leeanne Carey,
Department of Neurology,
Royal Melbourne Hospital,
Parkville,
Victoria,
Australia

William A. Copen,
Department of Radiology,
Massachusetts General Hospital,
PO Box 9657,
55 Fruit Street,
Boston,
MA 02114,
USA

David G. Darby,
Department of Neurology,
Royal Melbourne Hospital,
Parkville,
Victoria 3050,
Australia

Stephen M. Davis,
Department of Neurology,
Royal Melbourne Hospital,
University of Melbourne,
Parkville,
Victoria 3050,
Australia

John A. Detre,
Departments of Neurology and Radiology,
University of Pennsylvania Medical Center,
3 W Gates,
3400 Spruce Street,
Philadelphia,
PA 19104–4283,
USA

Geoffrey A. Donnan,
National Stroke Research Institute,
Heidelberg,
Victoria,
Australia
List of contributors

Robert R. Edelman,
Department of Radiology, Room 5106
Evanston Hospital,
2650 Ridge Avenue,
Evanston,
IL 60201,
USA

John N. Fink,
Department of Neurology,
Christchurch School of Medicine,
New Zealand

Marc Fisher,
Department of Neurology,
UMACS,
Memorial Health Care,
119 Belmont Street,
Worcester,
MA 01605,
USA

S. Goldstein,
University of Pittsburgh Health System,
Stroke Institute,
Departments of Neurology and Neurosurgery,
200 Lothrop Street,
PA 15213,
USA

Werner Hacke,
Department of Neurology,
University of Heidelberg,
Germany

Olav Jansen,
Department of Neuroradiology,
University of Kiel,
Germany

Chelsea Kidwell,
UCLA Stroke Center,
710 Westwood Plaza,
Los Angeles,
CA 90095,
USA

Rüdiger von Kummer,
Department of Neuroradiology,
University of Technology,
Fetscherstr. 74,
Dresden,
Saxonia D-01307,
Germany

Romesh Markus,
National Stroke Research Institute,
Heidelberg,
Victoria,
Australia

Reto Meuli,
Department of Diagnostic and Interventional Radiology,
University Hospital (CHUV) BH07,
1011 Lausanne,
Switzerland

Joel Meyer,
Department of Radiology,
Evanston Northwestern Healthcare,
Northwestern University School of Medicine,
2650 Ridge Avenue,
Evanston,
IL 60201
USA

Michael Moseley,
Department of Radiology,
1201 Welch Road,
Stanford University,
CA 94305-5488,
USA

Mark Parsons,
Department of Neurology,
Royal Melbourne Hospital,
University of Melbourne,
Parkville,
Victoria 3050,
Australia
Thanh Phan,
National Stroke Research Institute,
Heidelberg,
Victoria,
Australia

Marc Reichhart,
Department of Neurology,
University Hospital (CHUV) BH07,
1011 Lausanne,
Switzerland

David C. Reutens,
National Stroke Research Institute,
Heidelberg,
Victoria,
Australia

Dawn E. Saunders,
Department of Neuroradiology,
The National Hospital of Neurology and
Neurosurgery,
Queen Square,
London,
UK

Jeffrey L. Saver,
UCLA Stroke Center,
710 Westwood Plaza,
Los Angeles,
CA 90095,
USA

Peter D. Schellinger,
Department of Neurology,
University of Heidelberg,
Im Neuenheimer Feld 400,
D69120 Heidelberg,
Germany

Rohit Sood,
Department of Radiology,
Stanford University,
CA 94305-5488,
USA

A. Gregory Sorensen,
Massachusetts General Hospital,
NMR Center,
149 13th Street,
Charlestown,
MA 02129,
USA

Vincent N. Thijs,
Department of Neurology,
U2 Gasthuisberg,
Herestraat 49,
3000 Leuven,
Belgium

Brian M. Tress,
The University of Melbourne Department of
Radiology,
c/o Post Office,
Parkville,
Victoria 3050,
Australia

Steven Warach
National Institutes of Health,
NINDS,
10 Center Drive,
MSC 1063, Room B1D 733
Bethesda
MD 29892–1063,
USA

Lawrence R. Wechler,
University of Pittsburgh Health System,
Stroke Institute,
Departments of Neurology and Neurosurgery,
200 Lothrop Street,
PA 15213,
USA

Max Wintermark,
Department of Diagnostic and Interventional
Radiology,
University Hospital (CHUV) BH07,
1011 Lausanne,
Switzerland
List of contributors

Peter M. Wright,
National Stroke Research Institute,
Heidelberg,
Victoria,
Australia

H. Yonas,
University of Pittsburgh Health System,
Stroke Institute,
Departments of Neurology and Neurosurgery,
200 Lothrop Street,
PA 15213,
USA
Stroke is a leading cause of death in Western countries, with a mortality rate higher than most forms of cancer and now the commonest cause of long-term adult disability. Stroke diagnosis and management were revolutionized by the widespread introduction of computed tomographic (CT) scanning in the 1970s. CT scanning sensitively excludes cerebral hemorrhage, but early ischemic changes can be subtle. In the first few hours after stroke onset, when acute therapies such as thrombolysis are being considered, CT is often normal, although acute ischemic changes have become better recognized in recent years. Conventional magnetic resonance imaging (MRI) became widely available in most countries a decade after the advent of CT scanning, but has had a limited role in stroke diagnosis and management. Although MRI provides far better imaging of posterior fossa structures and facilitated non-invasive angiography (MRA), its sensitivity in acute stroke is not much better than CT. Other functional imaging techniques such as single photon emission computed tomography (SPECT) and positron emission tomography (PET) have been valuable research tools, but have not been of routine clinical use in the management of stroke.

Since the 1990s, the increasingly widespread availability of echoplanar MRI technology facilitated the introduction of diffusion-weighted imaging (DWI), perfusion imaging (PWI) and magnetic resonance spectroscopy (MRS). Diffusion-weighted imaging allows the hyperacute evaluation of the ischemic core within minutes of stroke onset and the distinction between acute and chronic
ischemic lesions. It represents an extraordinary advance in stroke imaging, specifically in the region of ischemic tissue that is usually destined for infarction. PWI provides a measure of the hypoperfused tissue at risk, particularly in the ischemic penumbra, where acute therapies are targeted. Currently, PWI is dependent on contrast injection, but arterial spin labelling may well supersede this technique. These new MRI methods also permit topographic analysis of acute infarcts and some insights into stroke pathophysiology and prognosis. Concurrent MRA allows analysis of acute arterial occlusion and monitors recanalization. Magnetic resonance spectroscopy provides insights into metabolically deranged cerebral tissues and provides information that is complementary to DWI and PWI. These new techniques are transforming the diagnosis and management of acute stroke. We believe that CT is likely to be widely replaced by these new MR techniques within the next few years. This has already occurred in many expert stroke centres.

In this book we have aimed to provide a comprehensive and up-to-date summary of the dramatic developments that have occurred in this field in the last few years and have also tried to predict likely advances. The scope of the text includes background on the importance of precise stroke diagnosis, the current uses of CT including perfusion imaging and an introduction to standard and echoplanar MRI techniques. Recent advances in MRI permit exclusion of intracerebral hemorrhage and this is currently being tested in randomized trials. A series of chapters details the diagnostic advances facilitated by MRA, DWI, PWI and MRS. Following a review of the pathophysiology and clinical importance of the ischemic penumbra, our contributors illustrate the role of MRI in drug development and selection of acute therapies. Recent studies provide insights into the use of MRI in individualization of the time window, providing a ‘tissue clock’ for therapeutic interventions such as thrombolysis. Currently, MR-based studies are testing the hypothesis that perfusion–diffusion mismatch, the postulated MR signature of the ischemic penumbra, can suggest the benefit of thrombolysis beyond the clinically established 3-hour time window. Finally, functional brain imaging using brain activation studies and MRI are leading to a better understanding of brain processing and brain recovery after stroke.

In this book, we have targeted neurologists, other stroke physicians, neuroradiologists and other clinicians involved in stroke diagnosis, imaging and management. We have aimed to encapsulate the development, current and emerging clinical role of MRI in stroke. We are grateful for the contributions of our chapter authors, all leaders in the field of MRI and stroke. A few years ago, experts debated whether MRI, in acute stroke diagnosis, was ready for ‘prime time’. After reading this book, we suspect you will agree that it is.

Stephen Davis, Marc Fisher and Steven Warach, 2002