Barrel Cortex

The barrel cortex contains the somatosensory representation of the whiskers on the face of the rodent and forms an early stage of cortical processing for tactile information. It is an area of great importance for understanding how the cerebral cortex works because the cortical columns that form the basic building blocks of the cerebral cortex can be seen within the barrel cortex. In this advanced graduate- and research-level text, Kevin Fox explores three main aspects of the barrel cortex: development, sensory processing, and plasticity. Initial chapters introduce the topic, describing those animals that have barrels, the functional anatomy of the system, and the cellular and synaptic physiology of the cortical microcircuit. The book concludes with a chapter covering the numerous fields where the barrel cortex is used as a model system for solving problems in other areas of research, including stroke, angiogenesis, and understanding active touch.

Kevin Fox is currently Professor and Head of Neuroscience, and Head of Research in Biosciences at Cardiff University, as well as Director of the Experimental MRI Centre. He gained his Ph.D. in Neuroscience at the University of London and has worked in the USA at Washington University St. Louis as a McDonnell Fellow, Brown University Rhode Island, and University of Minnesota Medical School Minneapolis as an Assistant Professor.

It is almost 40 years since Thomas Woolsey discovered the barrel field in studies carried out in his father’s laboratory in Wisconsin. His pioneering work with Henrick Van der Loos, Dan Simons and others has given rise to a large and growing community of scientists who find the barrel cortex an ideal system in which to study numerous questions about the brain. He continues to innovate with the barrel cortex, most recently using in-vivo imaging methods such as hyperspectral interferometry, MRI, and microPET. Tom Woolsey is currently the Director of the James L. O’Leary Division of Experimental Neurology and Neurological Surgery at Washington University St. Louis.
The front cover shows “Cerebral Sublime II,” an image made by Karen Ingham as part of her residency with the Neuroscience Research Group at Cardiff University. The image is based on van Gogh’s “The Starry Night” painted in St. Remy mental asylum near the end of Van Gogh’s life. “Even in the midst of mental turmoil Van Gogh was capable of creating works of sublime beauty, an affirmation perhaps, of the complexity of the mind. We study the brain with a ‘cosmic gaze’ looking at increasingly microscopic cellular images in order to ultimately see ‘the bigger picture’.” (Karen Ingham, Cardiff, 2006.)
Barrel Cortex

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This book is dedicated to Richard, William and Anwen
# Contents

- Foreword page xiii
- Preface xv
- Acknowledgements xvii
- Abbreviations xviii

## 1 Introduction to the barrel cortex 1

1.1 Introduction 1

1.2 System overview 2

1.2.1 What animals have barrels? 2

1.2.2 What are barrels? 6

1.2.3 Why are barrels important? 11

## 2 Anatomical pathways 14

2.1 Whisker follicle innervation 14

2.2 Brainstem nuclei and their projections 17

2.2.1 General organization of the trigeminal nuclei 17

2.2.2 Projection patterns of the trigeminal nuclei 19

2.2.3 Receptive field properties of trigeminal nuclei cells 20

2.3 Thalamic circuits 23

2.3.1 General organization of the somatosensory thalamus 23

2.3.2 The ventroposterior medial thalamic nucleus 24

2.3.3 The thalamic reticular nucleus 25

2.3.4 The posterior medial thalamic nucleus 26

2.4 Barrel cortex 29

2.4.1 Thalamic inputs to barrels and septal areas 29

2.4.2 Excitatory intracortical pathways 31

2.4.3 Inhibitory intracortical pathways 40

2.4.4 Non-specific innervation 43
viii  Contents

2.5  Cortical outputs  45
2.5.1  Corticocortical connections  45
2.5.2  Subcortical somatomotor projections  46
2.5.3  Subcortical somatosensory projections  48

3  Cellular and synaptic organization of the barrel cortex  49
3.1  Excitatory cells  49
3.1.1  Spiny stellate cells  49
3.1.2  Star pyramids  50
3.1.3  Pyramidal cells  51
3.2  Inhibitory cells  55
3.2.1  Soma-targeting inhibitory cells (basket cells)  55
3.2.2  Axon-targeting inhibitory cells  56
3.2.3  Dendrite-targeting inhibitory cells  57
3.2.4  Other categories of inhibitory interneuron  57
3.3  Synaptic transmission  59
3.3.1  Excitatory synaptic transmission  60
3.3.2  Inhibitory synapses  62
3.4  Short-term dynamics  64
3.4.1  Regular spiking, fast spiking and low threshold spiking cells  65
3.4.2  Short-term dynamics of excitatory connections on to excitatory cells  66
3.4.3  Factors controlling short-term dynamics  67
3.4.4  Thalamocortical and layer IV inputs on to inhibitory cells  68
3.4.5  Layer IV and layers II/III input to layer II/III inhibitory cells  70
3.4.6  Corticothalamic recurrent collateral to layer IV inhibitory cells  70
3.5  Electrical synapses  71
3.6  Organization of synaptic circuits  73
3.6.1  Single layer cortex  73
3.6.2  Multilayer cortex  75

4  Development of barrel cortex  79
4.1  Premaps and clones  80
4.1.1  Progenitor cells  80
4.1.2  Columnar and layer development  83
4.1.3  Tabula rasa concept  85
4.1.4  Transplant studies  86
4.2  Pattern formation  87
4.2.1  Theories of pattern formation  87
4.2.2  Thalamic afferents  91
4.2.3 Influence of the periphery 93
4.2.4 Activity dependence 94
4.3 Barrel formation 97
4.3.1 Organization of cellular domains 97
4.3.2 Interaction of thalamic afferents with neurons 98
4.3.3 Signaling pathways 99
4.4 Synaptic development 101
4.4.1 Thalamocortical synapses 101
4.4.2 Intracortical synapses 106
4.4.3 Inhibitory synapses 108
4.5 Conclusions 109

5 Sensory physiology 111
5.1 Topography 112
5.1.1 The columnar hypothesis 112
5.1.2 Labeled-line processing versus integration 113
5.2 Intracortical transmission 117
5.2.1 The thalamocortical response transformation 118
5.2.2 Vertical transmission within the column 120
5.2.3 Excitatory transmission between columns 122
5.2.4 Feedforward and feedback inhibition 124
5.2.5 Lateral inhibition 127
5.3 Receptive field organization 129
5.3.1 Receptive field size 129
5.3.2 Dynamic receptive field analysis 131
5.3.3 Cortical and subcortical receptive field components 131
5.3.4 Velocity sensitivity 134
5.3.5 Directional organization 135
5.3.6 Multiwhisker integration 138
5.4 Dynamic sensory processing 141
5.4.1 Whisking and active touch 142
5.4.2 Cortical feedback 145
5.5 Conclusions 148

6 Synaptic plasticity of barrel cortex 150
6.1 Long-term potentiation 151
6.1.1 Historical context and significance 151
6.1.2 Long-term potentiation at the thalamocortical synapse 154
6.1.3 Long-term potentiation at the layer IV to layers II/III synapse 157
6.1.4 Presynaptic long-term potentiation 157
6.1.5 Mechanisms of long-term potentiation and relationship to experience-dependent plasticity 159
x Contents

6.2 Long-term depression 162
  6.2.1 Historical context and significance 162
  6.2.2 Properties and methods of induction 163
  6.2.3 Long-term depression at the thalamocortical synapse 165
  6.2.4 Long-term depression at the layer IV to II/III pathway 166
  6.2.5 Mechanisms of long-term depression and relationship to experience-dependent depression 168

6.3 Conclusions 169

7 Experience-dependent plasticity 171
  7.1 Map plasticity in barrel cortex 172
    7.1.1 The effect of altered tactile experience 172
    7.1.2 The effect of local cortical interactions on plasticity 177
    7.1.3 Two components to depression of sensory responses 178
    7.1.4 Interactive and non-interactive potentiation of sensory responses 179
    7.1.5 Plasticity at different ages 180
  7.2 The locus of experience-dependent map plasticity 183
    7.2.1 Cortical versus subcortical locus 183
    7.2.2 Pathways for plasticity 188
    7.2.3 Traces of plasticity following deprivation 192
  7.3 Early-phase molecular mechanisms of map plasticity 193
    7.3.1 NMDA receptors 194
    7.3.2 Calcium-calmodulin-dependent kinase type II 195
    7.3.3 Protein kinase A 197
    7.3.4 Kinase substrates: glutamate receptor subunit 1 198
  7.4 Late-phase plasticity: gene expression and structural changes 199
    7.4.1 Structural plasticity 201
    7.4.2 Changes in gene expression 206
  7.5 Injury-induced plasticity 210
    7.5.1 Developmental plasticity 210
    7.5.2 Intracortical plasticity beyond the thalamocortical critical period 212
    7.5.3 Subcortical plasticity in adult animals 213
  7.6 Conclusions 215

8 New and emerging fields in barrel cortex research 217
  8.1 Cortical blood flow and stroke research 218
    8.1.1 Imaging cortical blood flow and oxygenation levels 219
    8.1.2 Dynamic blood flow in the barrel cortex 221
    8.1.3 Metabolic coupling of neuronal activity and blood flow 223
    8.1.4 Models of cortical ischemia 225
    8.1.5 Angiogenesis 226
8.2 Understanding active touch 227
  8.2.1 Modeling whisker mechanics 228
  8.2.2 Studying natural whisking responses 231
8.3 Studying synaptic physiology 234
  8.3.1 The thalamocortical slice preparation 234
  8.3.2 Intracortical pathways 235
8.4 Modeling cortical function 237
  8.4.1 Modeling barrels 237
  8.4.2 Toward simulation of a cortical column 239
8.5 Genetic analysis of barrel cortex 240
  8.5.1 Forward genetic approaches 241
  8.5.2 Reverse genetic approaches 242
8.6 Conclusions 245

References 247
Index 287

The Plates are between pages 48 and 49.
Foreword

Understanding the brain – its structure, connections, functions and the genetic bases of these properties – remains the central riddle in biology if not science. A number of different strategies to attack this issue have focused on many aspects of the nervous system and have, at an ever-increasing pace, begun to home in on the core questions. In neuroscience, the details of the underlying mechanisms have become tractable in the past decade and a half. But, similar to understanding the relationship of atomic interactions to the weather that they must cause, taking detailed neural mechanisms back to the level of the functioning nervous system has been arduous. Nevertheless, there is great promise that in the not too distant future the problem will be solved. Seemingly complicated behaviors and strategies could be explained entirely from understanding the components, their connectivity, their functions and their cohorts.

This quest could be made easier by focus on a part of the brain that is both easily accessible and straightforward to study and that provides a “standard” context to position data of different sorts from different studies by different laboratories. Further, it would offer greater promise if it could be manipulated genetically, developmentally and behaviorally and was reasonably similar to many other brain regions so as to permit ready translation to them. In this volume, Kevin Fox (whom I have had the good fortune to know since he worked in St. Louis in the late 1980s and early 1990s) has elegantly and concisely summarized the major findings on a region of cortex that we have both studied.

The barrel cortex, the whiskers that activate it and the intervening neural pathways have been increasingly the subject of focus by a growing number of groups for some time. At the time I first described barrels in the context of somatosensory function related to the whiskers, they seemed a kind of curiosity. In 1970, with the late Hendrik Van der Loos, we advanced the hypothesis that they may be a visible form of the functional columnar organization detailed by Mountcastle and subsequently rapidly confirmed this in many cortices of
many species, including humans. It is of interest that Mountcastle cited Lorente de Nó’s summary based in part on original histological studies in Madrid in the 1920s as the anatomical correlate of functional columns. The barrels were quickly proven to be visible parts of columns in the rodent somatosensory cortex.

It has been personally gratifying to me to see the explosion of information that relates in many ways to the barrels and, likely, the cortex in general. However, it has also become more challenging to keep pace with new findings and to place them in a reasonable context. Fortunately, Kevin Fox has picked up this gauntlet and has produced this insightful, succinct and readable volume. It is an excellent summary of a large body of work that will be of use to those familiar with this “field” as well as to those contemplating entering it. It is with considerable personal satisfaction and admiration that I have been asked to write this Foreword. It is a privilege that I did not imagine 40 years ago, much less now.

THOMAS A. WOOLSEY
Washington University in St. Louis
Preface

The field of barrel cortex research has grown rapidly over the past few years. Today, studies are directed not only at understanding the barrel cortex itself but also at understanding issues in related fields using the barrel cortex as a model system. In the three years it has taken to write this book, over 300 papers have been published on barrel cortex. While this rising tide of information has made writing a challenge, the fundamental studies of the preceding 34 years have provided a solid foundation and context in which to place the new work. Fortunately for me, the story has been enhanced by research in recent years and not entirely rewritten by it.

One of the reasons for writing this book has been the realization that barrel cortex research has matured to a point where a survey and a summary has become possible. The field has been characterized by classic studies that illuminate this and other areas of neuroscience and by a constant innovation in techniques and ideas. In fact, the barrel cortex has served as a test-bed system for several new methodologies, partly because of its unique and instantly identifiable form, and partly because the species that have barrels, the rodents, are the most commonly used laboratory mammal. The classic studies on the basic anatomy and physiology of this cortical area have certainly facilitated subsequent studies on barrel cortex. Two fundamental innovations have driven the field further. One is the invention of the thalamocortical slice, which has enabled detailed synaptic and cellular studies of barrel cortex. The other is the development of genetic manipulation in the mouse, which has enabled a host of new questions to be addressed, either about the function of the molecules involved in cortical processes or, by using the expression of fluorescent proteins, about the life of dendrites, spines and cellular subtypes.

As the innovation continues, many new laboratories are using barrel cortex as a system in which to explore their own particular questions without necessarily having access to, or time to research, the literature on the area being used in

xv
their experiment. A further reason for writing this book now is to provide an
easy way of learning about the barrel cortex for those new to the field and to
provide an easy route into the literature on which it is based. I hope that the
book will be of benefit not only for those embarking for the first time on studies
on barrel cortex but also for those who are already experts but need a rapid
reference to direct them toward the numerous seminal discoveries that have
been made in this field over the past 37 years.

Kevin Fox
Cardiff, UK

xvi Preface
Acknowledgements

I am most grateful to my colleagues and friends for help with this book at various stages of its gestation. I would like to thank Asaf Keller and Egbert Welker for early discussions on the genesis of the book and for reading some of the first chapters produced. I should also like to thank Randy Bruno, Barry Connors, Peter Kind, Neil Hardingham and John Isaac for detailed comments on individual chapters. A number of people have either wittingly or unwittingly contributed to the book by discussing scientific issues with me over the years, or by carefully answering what must have seemed like bizarre emails on esoteric points of barrel cortex research. Thanks then also to Tom Woolsey, Reha Erzurumlu, Ehud Ahissar, Dirk Feldmeyer, David Kleinfeld and Mark Jacquin. Last but not least I would also like to thank Gavin Swanson for asking me to write the book, Martin Griffiths for helpful discussion and patience during its genesis and Karen Ingham for her beautiful front cover.
Abbreviations

2-DG 2-deoxyglucose
5-HT 5-hydroxytryptamine (serotonin)
ACI adenylyl cyclase type 1
AMPA alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid
APV 2-amino-5-phosphonovaleric acid
BDNF brain-derived neurotrophic factor
CaMKII calcium-calmodulin kinase type II
CO cytochrome oxidase
Dil 1,1′-dioctadecyl-3,3,3′,3′-tetramethylindocarbocyanine perchlorate
DSI depolarization-induced suppression of inhibition
EPSP excitatory postsynaptic potential
FS fast spiking
FSU fast-spike units
GABA gamma aminobutyric acid
GluR glutamate receptor
HRP horseradish peroxidase
\(I_{\text{Kca}}\) calcium-activated potassium channel current
\(I_{\text{t}}\) low-threshold calcium channel current
IB intrinsic bursting
IPSP inhibitory postsynaptic potential
LTD long-term depression
LTP long-term potentiation
LTS low-threshold spiking
mGluR metabotropic glutamate receptors
MI motor cortical area I
NMDA N-methyl-D-aspartate
PHA-L *Phaseolus vulgaris* phytohemagglutinin
PKA protein kinase A
### List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>PKC</td>
<td>protein kinase C</td>
</tr>
<tr>
<td>PLC</td>
<td>phospholipase C</td>
</tr>
<tr>
<td>POm</td>
<td>posterior medial thalamic nucleus</td>
</tr>
<tr>
<td>RA</td>
<td>rapidly adapting</td>
</tr>
<tr>
<td>RS</td>
<td>regular spiking</td>
</tr>
<tr>
<td>RSU</td>
<td>regular spike units</td>
</tr>
<tr>
<td>SA</td>
<td>slowly adapting</td>
</tr>
<tr>
<td>SI</td>
<td>somatosensory cortical area I</td>
</tr>
<tr>
<td>SII</td>
<td>somatosensory cortical area II</td>
</tr>
<tr>
<td>VPm</td>
<td>ventroposterior medial thalamic nucleus</td>
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