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 discoverd 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.)

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This book is dedicated to Richard, William and Anwen

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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

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.

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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
DiI	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_{Kca}	calcium-activated potassium channel current
I_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

PKC	protein kinase C
PLC	phospholipase C
POm	posterior medial thalamic nucleus
RA	rapidly adapting
RS	regular spiking
RSU	regular spike units
SA	slowly adapting
SI	somatosensory cortical area I
SII	somatosensory cortical area II
VPm	ventroposterior medial thalamic nucleus