

Preface

A fundamental goal of brain research is to elucidate the functional properties of the structural elements of the brain, at an appropriate organizational scale. One major scientific milestone in this regard was the publication of Korbinian Brodmann's famous map of the cerebral cortex in 1909. This map defines around 40 structural areas in the human cortex based on differences in cytoarchitecture (i.e., size, shape, and topographic arrangement of nerve cells). Subsequent investigators found out that these areas, defined purely anatomically by Brodmann, also correspond to functional entities of the cerebral cortex, so that, for example, Brodmann's area (BA) 4 corresponds to primary motor cortex (M1), and BA 17 to primary visual cortex (V1). Since its publication, Brodmann's map has become a "classic" in the field of neurobiology, and, despite many advances in neuroscience, his nomenclature of cortical areas is still widely used to designate functional regions. Two key problems intrinsic to this mapping strategy, however, are that cytoarchitectonic parcellation requires microscopic analysis of postmortem brain sections and cytoarchitectonic areas vary between individuals in their topography relative to the gyral anatomy of the brain. This means that correlations between microstructure (based on cytoarchitectonic analysis in postmortem brains) and function (based on, e.g., functional magnetic resonance imaging (fMRI) in living brains) have almost always been made probabilistically, with the aid of a computerized brain atlas.

It would be a revolutionary scientific breakthrough if it were possible to map the microstructural correlates of functional activations in the human cortex in a noninvasive and individual-specific way directly in vivo. However, until now, microstructural details of the cerebral cortex have been beyond the resolution of conventional structural MRI, except within the primary visual cortex, where the very prominent Stria of Gennari can relatively easily be detected at the MRI field strength of 3 T. Recently, however, high-field MRI, at a field strength of 7 T and spatial resolution below 0.5 mm, has radically changed this situation by detecting further systematic structural differences within the cerebral cortex. For instance, use of 7 T MRI can resolve the functionally important microanatomical border between primary motor (area 4) and somatosensory (area 3a) cortex in vivo. This opens up the door toward an individual-specific microanatomical brain map with

the enormous potential to make direct correlations between microstructure and function in living human brains.

This brief outline spans an entire century from the publication of Brodmann's postmortem map at the beginning of the twentieth to "in vivo Brodmann mapping" with high-field MRI at the beginning of the twenty-first century. In our book, however, we would like to shed some light also on a few milestones of structural brain mapping that lie between these two "cornerstones". For this reason, the book is divided into three parts.

Part I starts with the world of "classical" cytoarchitectonic brain maps, published in the first half of the twentieth century: the famous parcellation of Korbinian Brodmann (chapter by Guy Elston and Laurence Garey) and the much lesser known map of Constantin von Economo and Georg Koskinas (chapter by Lazaros Triarhou). In contrast to Brodmann, von Economo and Koskinas provide a much more detailed verbal and pictorial description of each area's cytoarchitectonic features. We also bring back to life the almost forgotten myeloarchitectonic map (based on differences in the arrangement of myelinated fibers in preparations stained for myelin sheaths) by Cécile and Oskar Vogt (chapter by Rudolf Nieuwenhuys). Mapping the cortex with high-field MRI shows a renewed interest in myeloarchitecture, since many types of MR image contrast depend on the presence of myelin within the image voxel.

Part II covers more recent approaches that aim at mapping cortical areas noninvasively in living human brains. Bruce Fischl and colleagues use cortical folding patterns to estimate the topography of Brodmann areas in individual brains. Simon Eickhoff and Danilo Bzdok identify functional modules in the cortex in a data-driven fashion by clustering together voxels with similar co-activation patterns and separating them from voxels with different co-activation profiles.

In Part III, we arrive at the second "cornerstone," namely, "in vivo Brodmann mapping" with high-field MRI. The two chapters by Robert Turner argue for the necessity of more realistic functional and structural analysis methods that more effectively exploit the great potential inherent in high-field MRI and, together, should lead to a new understanding of the relationships between structure, function, and connectivity in the living brain. The second chapter also focuses on a discussion about the microstructural origin of the high-field MRI contrast in the cortex. Does it originate from regional variations in the arrangement of cells (cytoarchitecture) or myelin sheaths (myeloarchitecture)? Evidence is provided that the latter (i.e., myelin) is the case. This leads us to the chapter by Nicholas Bock and Afonso Silva on visualizing myeloarchitecture with MRI in the cortex of living marmoset monkeys (*Callithrix jacchus*). We conclude with the first breakthrough in high-field MR mapping in the living human brain (chapter by Stefan Geyer): the detection of the functionally important border between primary motor (area 4) and somatosensory (area 3a) cortex.

Microstructural Parcellation of the Human Cerebral
Cortex

From Brodmann's Post-Mortem Map to in Vivo Mapping
with High-Field Magnetic Resonance Imaging

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