BOOK REVIEW

Human brain connections

The Atlas of Human Brain Connections by Catani and Thiebaut de Schotten (2012) covers the long association, commissural and projection systems of the cerebral hemispheres as studied with diffusion tensor tractography. The atlas begins with an extensive and well-illustrated historical survey of these systems and the disconnection syndromes that result from their interruption. This is followed by chapters on the individual systems, including an atlas of each in serial axial, coronal and parasagittal sections, and an atlas of all the systems combined. The book ends with an overview of diffusion tensor imaging tractography and its applications.

I must have dissected the long association systems of the cerebral hemispheres numerous times during lab courses for students or neurological residents. Blunt dissection of fibre systems is a method of great antiquity, but became more precise with the preservation of the brain in alcohol. The 1840s witnessed an important change in methodology, with blunt dissection of fibre systems replaced by microscopy of serial sections, as introduced by Benedict Stilling in his atlases of the brainstem (1846). This method allowed nuclei and the components of white matter to be distinguished with much greater precision and solved the problem inherent in blunt dissection, namely its inability to trace fibre bundles beyond the point where they merge or are crossed by other fascicles (Voogd and van Baarsen, 2013).

Stilling (1846) used wet unstained sections, relying on the differential refraction of myelin to obtain contrast. However, his method was greatly improved with the subsequent development of fixation and staining techniques. The first systematic microscopic study of the long association systems was published by Déjerine, and was followed by the atlases of Wernicke, and then Jelgersma. Wernicke’s atlas is remarkable because it consists of original photographic prints of sections in the three major planes; however, even before the prints began to fade, the information on the long association systems was scantily. Jelgersma did not even label his illustrations.

An accurate description of the white matter tracts became possible with the development of techniques to trace degenerated tracts, leading ultimately to the tracers commonly used to map retrograde or anterograde axonal transport today. Tracts could now be defined by their origin and termination, their course, their fibre calibre and their neurotransmitter. However, these methods have only rarely been applied to the human brain, thus the ‘gold standard’ in connectional neuroanatomy has yet to be attained. As a second best, Schmahmann and Pandya’s book, The Fiber Pathways of the Brain (2006), provides a complete account of their experimental studies of the association and commissural pathways in the macaque brain. Methods such as fluorescence polarization microscopy of degenerated myelin, or confocal and polarized light microscopy, which provide information about the orientation and structure of long myelinated fibres, have still to be applied to the long association systems.

Nowadays, blunt dissection of white matter tracts has been replaced by diffusion tensor imaging (Conturo et al., 1999). In a sense, the methods are very similar; in tractography the scalpel is replaced by the diffusion of water molecules along the nerve fibres. They share the same limitations, but tractography has the great advantage that it can be applied to the living brain. It is also superior in terms of reproducibility, observer-controlled parameters and the provision of quantitative information.

Illustrations of dissections and reconstructions from diffusion tensor tractography share the same aesthetic quality. Both show the course and the position of tracts but provide only crude information on their origin and termination. Figure 1A and B show reconstructions from Thiebaut de Schotten et al. (2011) and Schmahmann and Pandya (2006) of the human and monkey superior longitudinal fascicle (SLF). Originally this fascicle was included in the arcuate fascicle, the major peri-Sylvian pathway (blunt dissection shown in Fig. 2), but it is now considered to be a separate tract connecting the parietal and frontal lobes. In
humans, and also monkeys, the system is subdivided into three fascicles, SLF1, 2 and 3. It is not clear whether these fascicles exist as separate tracts, or represent local expansions of the white matter in the lobules they occupy. Schmahmann and Pandya (2006) revealed some important properties of the long association systems, including the fact that the superior longitudinal fascicle is a bidirectional system, containing long and short fibre connections, and that true reciprocal connections appear to be rare.

Their description of the superior longitudinal fascicle allowed Catani and Thiebaut de Schotten (2012) to draw some general conclusions about its function. SLF1 and SLF2 are involved in processing the spatial coordinates of the trunk and the inferior limbs, movement planning, oculomotor coordination, visual reaching and, possibly, the voluntary orientation of attention. SLF3 is thought to participate in the functions of the arcuate fascicle, with lesions of this system implicated in disorders of language, writing and the processing of visuospatial information, as well as in the apraxias.

However, to gain a better understanding of function, knowledge of a higher level of organization is required. This is available in the monkey thanks to the electrophysiological analysis of the cortical motor system by Rizzolatti and his collaborators, reviewed by Geyer et al. (2012). In their view, the superior longitudinal fascicle consists of multiple short and long reciprocal loops between posterior parietal and frontal premotor areas involved in the preparation of movement. Catani and Thiebaut de Schotten acknowledge these different levels of connectional anatomy in their chapters on the occipital visual pathways, the commissural connections and the limbic system. The long association and commissural pathways of the frontal, parietal, occipital and temporal association cortex are extensively discussed in relation to the disconnection syndromes and disorders of perception with which they are associated, and which have only scarce equivalents in experimental studies of the monkey brain.

How precise are the atlases contained in this volume? As a neuroanatomist interested in the brainstem and the cerebellum, I was somewhat dismayed by the crude representation of the superior cerebellar peduncle, the corticospinal tract and the corticopontine pathways in sections through the pons and the mesencephalon. Together they fill almost the entire cross section, the corticospinal tract covering a much larger area than the corticopontine pathway. Moreover, the decussation of the superior cerebellar peduncle is lacking in the atlas of the projection systems in Chapter 10 (Fig. 3A). Stilling did much better 170 years ago (Fig. 3B). That tractography is able to overcome the problem of tracing a tract through its decussation was shown in the reconstruction of the superior cerebellar peduncle by Van Baarsen et al. (2013). The illustrations of the long association and commissural pathways in Catani and Thiebaut de Schotten may suffer from a similar overestimation of their size, as a comparison with the histological atlas of Bürgel et al. (2006) in the last chapter suggests. Overestimation may be the consequence of pooling data from different subjects with great individual variability.

This book can be recommended to neurologists who wish to include tractography in their diagnostic repertoire. It may serve as a guide in courses that combine dissection and neurology. For cognitive and more generally interested neuroscientists it offers a
survey of the state of the art in diffusion tensor tractography. I would not advise its use as a primary anatomical text, but its historical introduction and the promises that tractography holds for the future will also make the book of interest to anatomists. There is no doubt that these imaging techniques will be further refined. Once myelin can be visualized, the myeloarchitecture of the cerebral cortex and a detailed topographical anatomy of the white matter will be available for studies using tractography and functional MRI. The tracing of connections, using their neurotransmitters or other molecular markers, should bring the method up to the ‘gold standard’ of connectional neuroanatomy, thus far limited to experimental neuroscience.

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References


