II. Summary of Adult Rat Brain Structure

Much more is known, and is being learned, about the structure and chemistry of the brain in the rat than in any other animal. Many of the reasons for the popularity of the rat in neurobiological and behavioral work have been summarized in a delightful book written by S.A. Barnett (1963), but economy and small size are important factors, along with the fact that these animals have a relatively smooth cerebral cortical mantle, as opposed to the highly convoluted mantle found in many larger species.

Two major disadvantages associated with the use of rats come readily to mind. First, the organization of the rat brain is obviously not identical to that of the human brain. Therefore, the clinical relevance of neuroanatomical information obtained in the rat in principle should be confirmed in human material, which often may not be possible for ethical reasons; and conversely, certain important problems like the neurobiology of language may be difficult if not impossible to study in the rat. And second, the types of genetic analyses that can be carried out in mice will not be possible anytime soon in rats for practical reasons. On the other hand, the mouse brain is often too small for critical analysis with available experimental neuroanatomical techniques.

Broadly speaking, the nervous system of all *vertebrates* has two major divisions, central and peripheral (front cover illustration; yellow and black, respectively). The peripheral division (PNS) consists of sensory, autonomic, and enteric neurons, along with the various nerves that are attached to the central division. Topologically, the latter is a tube that is closed at both ends, and the wall of the tube is highly differentiated along its longitudinal axis. Based on embryological considerations (see Swanson 1992a; Alvarez-Bolado and Swanson 1996) the central division of the nervous system (CNS) has traditionally been divided into a massive rostral part within the skull, the brain; and a smaller caudal part within the vertebral column, the spinal cord. Furthermore, the peripheral division is derived from the embryonic neural crest, whereas the central division is derived from the neural tube. Early on, the neural tube displays three rostrocaudal swellings, the forebrain, midbrain, and hindbrain vesicles; and somewhat later the forebrain vesicle is divided into paired endbrain vesicles and an interbrain vesicle, whereas the hindbrain vesicle is divided vaguely into a rostral pontine and a caudal medullary vesicle.

The general organization of the adult *rat* nervous system, as well as the parts of the body that it innervates, has been summarized thoroughly by Greene (1968) and by Hebel and Stromberge (1986), and the work of Donaldson (1924) contains a wealth of information about the changing size of various organs and major subdivisions of the CNS during the course of development.

Dorsal and ventral external views of rat brain gross anatomy are illustrated in fig. 1 (top). It is obvious that the brain is dominated by right and left *cerebral hemispheres* (derived from the endbrain vesicles) and the *cerebellum* (which is continuous across the midline and derived from the dorsal or rhombic lip of the pontine vesicle). The cerebral and cerebellar hemispheres are attached to a much smaller *core* or *brainstem* that is derived from the interbrain, midbrain, and hindbrain vesicles and extends caudally as the spinal cord.

The major parts of the adult rat brain are more easily appreciated in a midsagittal or bisected view (fig. 1, bottom). While the nomenclature and groupings of these parts has changed over the centuries (sections VI and VIII), it is convenient from a functional systems perspective to regard the cerebral hemispheres (cerebrum, endbrain, or telencephalon) as consisting of *cortex* and *basal nuclei* (or ganglia); the cerebellum (parencephalon) as consisting of *cortex* and *deep nuclei* (not shown in fig. 1 because they do not reach the midline); and the brainstem as consisting

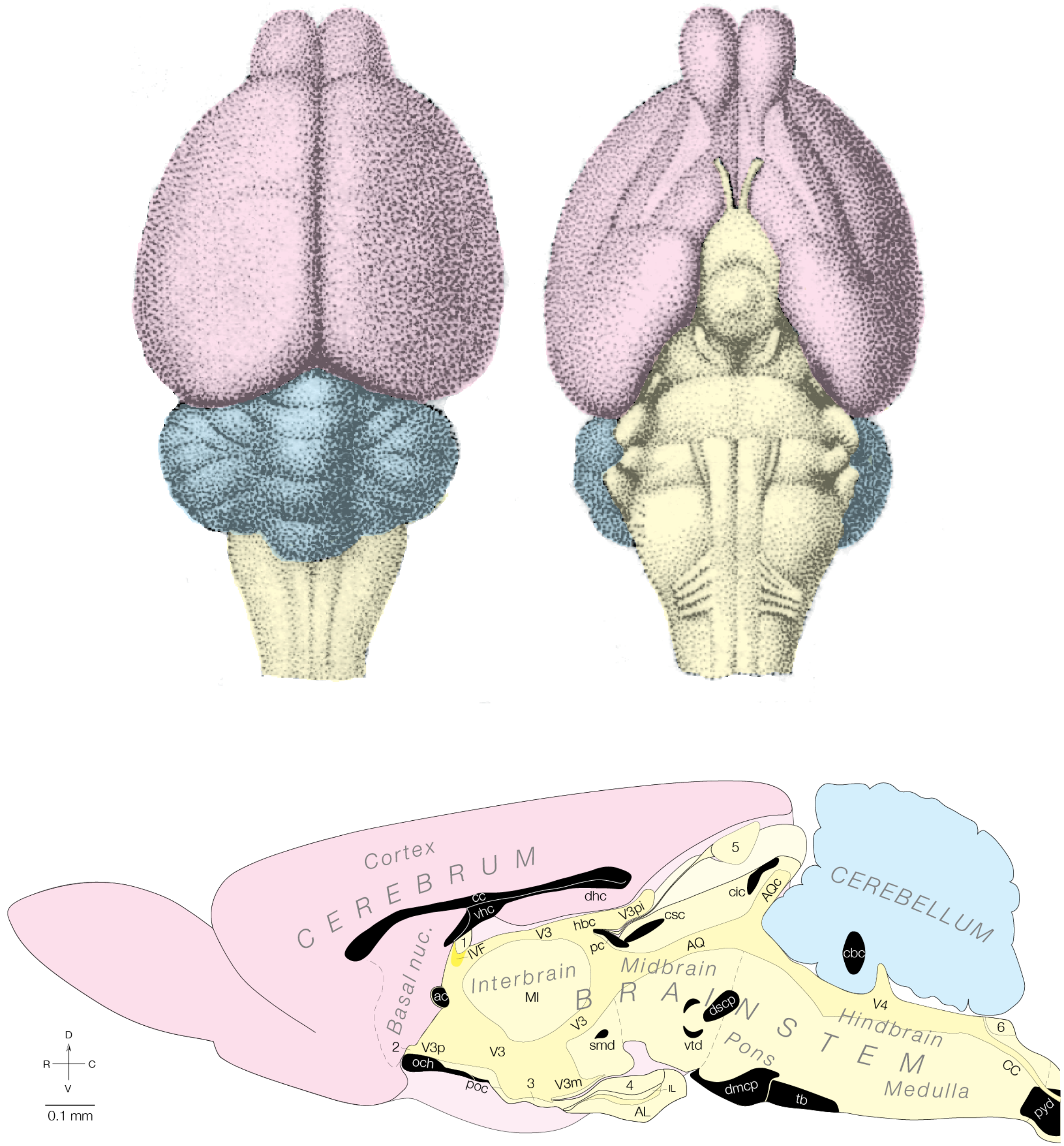

Fig. 1. Top. Dorsal (left) and ventral (right) views of the adult rat brain, with the cerebral hemispheres (cerebrum) in red, the cerebellum in blue and the brainstem in yellow (from Leuret and Gratiolet 1857). Bottom. A midsagittal view of the right half of the adult rat brain, reconstructed from the atlas series and color coded as in the top drawings. Major fiber systems crossing the midline are shown in black. Major circumventricular organs include: 1, subfornical organ; 2; vascular organ of the lamina terminalis; 3, median eminence; 4, posterior (neural lobe) pituitary; 5, pineal gland; and 6, area postrema. For abbreviations, see list at the end of the book.

successively of the *interbrain* (diencephalon), *midbrain* (mesencephalon), and *hindbrain* (rhombencephalon), which in turn is somewhat arbitrarily divided into *pons* (metencephalon) and *medulla* (myelencephalon).

The brainstem and spinal cord contain virtually all motoneurons (except for a few neuroendocrine gonadotropin-releasing hormone motoneurons in the septal region of the basal nuclei), with neuroendocrine motoneuron pools concentrated in the ventral interbrain (hypothalamus), and preganglionic autonomic and somatic motoneuron pools found along most of the length of the midbrain, hindbrain, and spinal cord. The brainstem is probably responsible for mediating all unconditioned reflexes and changes in behavioral state, such as the sleep-wake cycle. In contrast, it seems likely that the cerebral and cerebellar hemispheres are essential for voluntary control of the motor systems and for long lasting associative learning.

A midline view of the brain also demonstrates two other sets of features that serve as useful landmarks. One set includes the so-called *circumventricular organs*, which lack a traditional blood-brain barrier to lipophobic substances, and certain *glands*. The subfornical organ is the most rostrodorsal circumventricular organ, and embryologically it lies at the dorsal junction between the cerebral hemispheres and interbrain; the tiny vascular organ of the lamina terminalis lies at the tip of the preoptic recess of the third ventricle; the median eminence lies along the floor of the third ventricle, just rostral to the infundibulum—which extends as the neural lobe of the pituitary gland and also lacks a blood-brain barrier; and the area postrema, which lies at the dorsal border between brainstem and spinal cord, just dorsal to the rostral end of the central canal. Figure 1 also shows the rest of the pituitary gland (the intermediate and anterior lobes, which are derived from Rathke's pouch), and the pineal gland, an evagination of the caudal interbrain roof plate between the habenular and posterior commissures (see Swanson 1992a; Alvarez-Bolado and Swanson 1996).

The second set of midline features includes the *major fiber systems that cross to the other side of the brain*. In the cerebral hemispheres they include the corpus callosum (great cerebral commissure) and its embryologically caudal continuation, the dorsal and ventral hippocampal commissures. In the interbrain they include the anterior, postoptic (supraoptic) and habenular commissures; and the optic chiasm. The midbrain contains the posterior commissure, the commissures of the superior and inferior colliculi, the dorsal and ventral tegmental commissures, and the decussation of the superior cerebellar peduncle. The hindbrain contains the decussation of the middle cerebellar peduncle and caudally adjacent trapezoid body, and the decussation of the pyramidal (corticospinal) tract. And finally, the cerebellum contains the rather small cerebellar commissure.

While our primary concern in this book is with the disposition of the major cell groups and fiber systems in the rat brain, certain other features should be mentioned for the sake of completeness. To begin with, the central nervous system of a 315 gram adult male rat (the size and sex of the rat used for our atlas) weighs on the order of 2.7 grams, with the brain contributing about 2.0 grams and the spinal cord about 0.7 grams (Donaldson 1924). Furthermore, the central nervous system is completely surrounded by connective tissue sheaths (*the meninges*), contains a fluid-filled central cavity (*the ventricular system*), and has a rich *blood supply*.

The general principles of *cerebrospinal fluid* (CSF) production by the *choroid plexuses*, and its flow through the ventricular system and *subarachnoid space*, as well as the flow of blood through the central nervous system, are similar in all mammals, and are reviewed in most textbooks of human neuroanatomy (for good accounts see Carpenter and Sutin 1983, and Williams 1995). The central nervous system does not, of course, have a true *lymphatic system*;

instead, the function of this system is generally thought to be subserved by the cerebrospinal fluid.

There are certain specializations or differences associated with these structures or systems in the rat itself. Nothing remarkable about *the meninges* in the rat has been reported; their general disposition is described by Zeman and Innes (1963), Greene (1968), and Hebel and Stromberg (1986). The shape of the *ventricular system* has been described in detail by McFarland et al. (1969), Westergaard (1969), and Jarvis and Andrew (1988). According to McFarland et al. (1969), it contains approximately 0.5 ml of cerebrospinal fluid in the adult, although the accuracy of this measurement is difficult to assess (fig. 2). The *vascular system* of the rat CNS

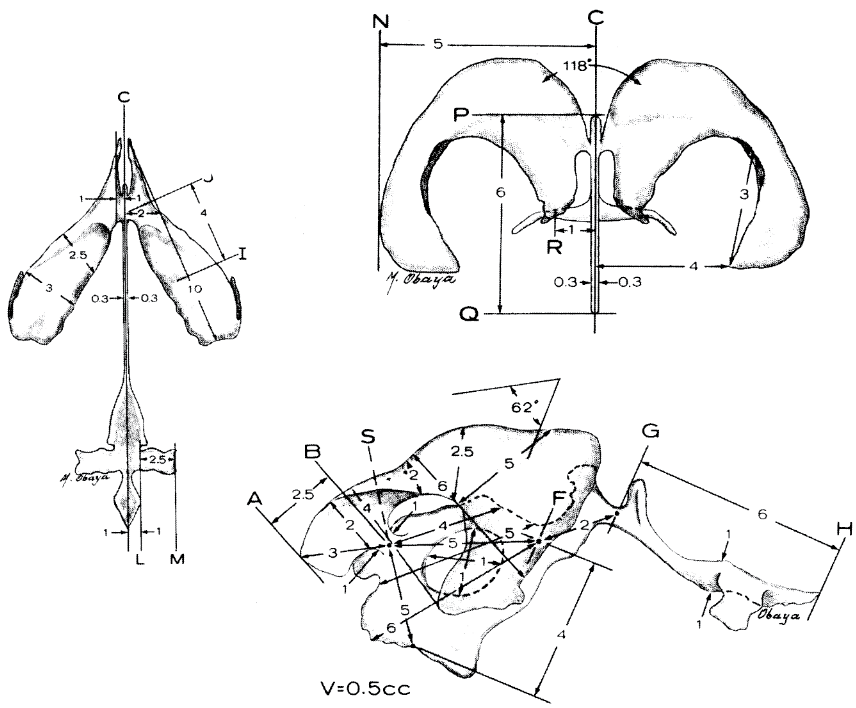

Fig. 2. The ventricular system of the adult rat brain as viewed from the top (left drawing), from the front (upper right drawing), and from the side (lower right drawing); measurements are in mm (from McFarland et al. 1969).

has not been the subject of detailed, systematic investigation. For general accounts of the major arteries and veins supplying the rat CNS, as well as the general distribution of capillaries, see Craigie (1920), Zeman and Innes (1963), Brown (1966), Greene (1968), Hebel and Stromberg (1986), and Scremin (1995). An introductory guide to more detailed accounts of particular regions would include the following: spinal cord (Tokioka 1973; Tveten 1976); brainstem and cerebellum (Craigie 1933; Moffat 1957); diencephalon and pituitary (Ambach and Palkovits 1979); septum (Ambach et al. 1975); amygdala (Merksz et al. 1978); and cerebral cortex (Craigie 1921, 1932; Eayrs 1954).

Finally, it is important to reemphasize that the maps presented here are from an adult male rat, and that the rat brain is sexually dimorphic. The best established sexual dimorphisms are associated with the so-called sexually dimorphic circuit, which begins in the vomeronasal organ and extends through the accessory olfactory bulb to parts of the amygdala, bed nuclei of the stria terminalis, and hypothalamus (see Segovia and Guillamón 1993; Simerly 1995). Therefore, caution must be used when employing the maps presented here to display neuroanatomical data from the female rat, and the maps need to be modified when known sexually dimorphic structures are involved.