Neuroanatomy of the Zebrafish Brain
A Topological Atlas

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1 Introduction: neuroanatomy for a neurogenetic model system

"Zebrafish hit the big time": This title of a recent commentary in Science (Kahn, 1994) reflects the growing importance of a new model organism for developmental research, the zebrafish *Danio rerio* (Fig. 1). Pioneering work using this model began in the laboratories of George Streisinger and Charles Kimmel in the early 1970s, and to date studies of zebrafish have contributed notably to understanding early nervous system development and its genetic regulation in at least three areas:

1. Differentiation of first neurons and their associated tracts and commissures in the embryonic zebrafish brain
2. Neuromeres and expression of regulatory genes in embryonic zebrafish
3. Generation of zebrafish mutants via saturation mutagenesis

In this introduction, we will discuss briefly the relevance of a zebrafish brain atlas to these areas of research. However, rather than review each of these areas in detail, we will focus on how the neuroanatomy of the adult zebrafish brain might be helpful for future research in this model system.

**Differentiation of first neurons and their associated tracts and commissures in the embryonic zebrafish brain**

The first embryonic neurons in the zebrafish central nervous system (CNS) can be visualized immediately prior to final mitosis during neuromere formation and are found in a serially repeated sequence in the spinal cord (Hanneman and Westerfield, 1989; Bernhardt et al., 1990; Kuwada et al., 1990) and in the brain (Hanneman et al., 1988; Wilson et al., 1990). Soon thereafter, these neurons extend pioneering axons in a highly predictable, stereotyped fashion, and by 24 hours they form an early scaffold of tracts and commissures (Fig. 2; Metcalfe et al., 1986; 1990; Chitnis and Kuwada, 1990; Wilson et al., 1990; Wilson and Easter, 1991; Ross et al., 1992). This early axon scaffold includes eight tracts and four commissures (Fig. 2). At 48 hours, the number of fibers in these early tracts has increased by a hundredfold, and three more tracts and their commissures (intertectal and habenular commissures, commissure of the posterior tuberculum) have formed (Wilson et al., 1990), resulting in a total of eleven tracts and seven commissures. (Since many of the designations for early tracts

*Figure 1. Adult zebrafish*
and commissures only apply to the embryonic zebrafish brain, they are not listed in the index.)

The fact that many follower axons between 24 and 48 hours of development grow along the few axons constituting the early scaffold indicates that the first (pioneer) axons might provide cues to guide the follower axons (Wilson et al., 1990). However, the pioneer axons themselves and all axons approaching axonal intersections necessarily need additional guidance cues (Chitnis and Kuwada, 1991; Chitnis et al., 1992), indicating that multiple guidance cues may be required generally for orderly axonal outgrowth.

Many early regulatory genes have expression boundaries at positions where the neurons and tracts of the early scaffold are located, and this early morphological patterning can be changed systematically by experimentally altering gene expression (Wilson et al., 1993; Macdonald et al., 1994). This indicates that the early scaffold in the brain might reflect early regionalization processes. Thus, another hypothesis, namely, that the early scaffold is a transitory structure during embryogenesis, must also be considered. Documentation of the postembryonic transformation of embryonic CNS structures into their adult configuration in the zebrafish is needed in order to decide whether the early scaffold develops directly into adult nuclei and tracts or, alternatively, represents a transitory embryonic structure.

A striking similarity in the organization of the embryonic and adult zebrafish brain is that each of the seven commissures present at 48 hours corresponds topologically to adult commissures. They bear the same names in both life stages, except for the embryonic ventral tegmental commissure, which is called the anulate commissure in adult teleosts. However, since we observe 13 adult commissures, the development of 6 commissures remains undocumented at present. The good topological correspondence between embryonic and at least some adult tracts and commissures does seem to suggest that they develop into each other by addition of fibers, though the alternative hypothesis that all embryonic tracts may be transitory must be kept in mind. The fact that all embryonic tracts are in a subpial position, i.e. they are located at the periphery of the CNS, in contrast to most adult tracts, which lie deep in the CNS, lends support to the latter hypothesis.

Another way of comparing embryonic and adult zebrafish brains is to look at neuronal connections in both life-history stages. The embryonic neuronal connections constituting the early axon scaffold are shown in Figure 3, and the adult connections are discussed in chapter 6. In the embryonic and the adult zebrafish brain, the medial longitudinal fascicle (MLF) carries descending axons of neurons in the nucleus of the medial longitudinal fascicle (NMLF). Similarly, the embryonic dorsal longitudinal tract (DLT) carries descending primary sensory fibers of trigeminal ganglion cells, as does the adult descending trigeminal root (DT). Such cases support the hypothesis that parts of the early scaffold develop directly into adult structures. Other

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**Figure 2.**
At day 1 postfertilization, a simple scaffold of eight tracts can be visualized in the zebrafish immunohistochemically (see text). Four tracts are associated with commissures (tract of the anterior commissure (TAC), tract of the postoptic commissure (TPOC), tract of the posterior commissure (TPC), tract of the ventral tegmental commissure (TVTC). The four additional tracts are the supraoptic tract (SOT), the dorsoventral diencephalic tract (DVDT), the medial longitudinal fascicle (MLF), and the dorsal longitudinal tract (DLT). Also present in the telencephalon at day 1 (but not shown) are fibers of the olfactory nerve. Compiled from Metcalfe et al. 1986 & 1990, Chitnis & Kuwada 1990, Wilson et al. 1990, and Ross et al. 1992.
embryonic connections clearly are transitory, such as the ascending axons of the spinal Rohon-Beard cells in the DLT (Metcalfe et al., 1990) or the tegmental neurons, whose axons ascend in the tract of the postoptic commissure to cross in that commissure (Wilson et al., 1990); both connections are absent in the adult brain.

It is evident that a large gap of knowledge exists between the detailed documentation of neural development in the embryonic zebrafish and its adult neuroanatomy. Thus, the postembryonic development of the zebrafish brain must be studied before we can understand by which mechanisms the developmental transformation from the relatively simple embryonic condition to the complex adult brain occurs. As exemplified above, the atlas of the adult zebrafish brain is a necessary tool for doing so.

**Neuromeres and expression of regulatory genes in the embryonic zebrafish**

Recently, theories on the neuromeric organization of the vertebrate brain have enjoyed a renaissance. Although classical observations of repeated constrictions along the rostrocaudal axis of the vertebrate hindbrain were long disqualified as artifactual, today, the reality of neuromeres in the vertebrate hindbrain (rhombomeres) is substantiated by various approaches, such as the investigation of primary neurons, early axonal pathfinding processes, glial boundaries, proliferation zones, and, most important, differential gene expression coinciding with neuromere boundaries (Holland and Hogan, 1988; Keynes and Stern, 1988; Lumsden and Keynes, 1989; Murphy et al., 1989; Wilkinson et al., 1989a; 1989b; Lumsden, 1990; Wilkinson and Krumlauf, 1990; Clarke and Lumsden, 1993).

In terms of gene expression, rhombomeres are best characterized by different expression boundaries of homeobox genes of the _hox_-cluster and by the zinc-finger gene _Krox-20_ (Holland and Hogan, 1988; Murphy et al., 1989; Wilkinson et al., 1989a; 1989b; Wilkinson and Krumlauf, 1990). In tetrapods, eight rhombomeres are recognized while only seven have been described for the zebrafish (Kimmel, 1993). Since rhombomeres 3 and 5 express the zinc-finger gene _Krox-20_ in tetrapods (Wilkinson et al., 1989a; 1989b) as well as in the zebrafish (Oxtoby and Jowett, 1993), one must conclude that zebrafish lack the most caudal rhombomere. Also similar to tetrapods, the gene expression boundaries at the spinal cord-brain stem junction of two zebrafish _hox_ genes (_hox-2.1_ and _hox-2.2_) correspond well with those of their mouse orthologs (_Hox-2.1_ and _Hox-2.2_), although in zebrafish they clearly extend into the most posterior hindbrain (Njølstad and Fjose, 1993).
Another homeobox gene, the zebrafish \textit{hix-1} gene, is expressed in the hindbrain, where it reveals various rhombomeric and subrhombomeric boundaries in a temporal sequence in the zebrafish (Fjose et al., 1994).

Several genes of the homeobox-containing \textit{engrailed (Eng)} gene family (Njølstad and Fjose, 1988; Hatta et al., 1991; Fjose et al., 1992; Ekker et al., 1992), one paired box-containing gene, \textit{pax/b} (Krauss et al., 1991a; 1991b; 1992b; Mikkola et al., 1992; Püschel et al., 1992b), and two genes of the \textit{wnt-family} (\textit{wnt-1} and \textit{wnt/dl}; Molven et al., 1991; Krauss et al., 1992a) are expressed at and probably involved in forming the midbrain-hindbrain boundary in zebrafish. Moreover, the \textit{wnt-1} (Molven et al., 1991), \textit{wnt[al]} (Krauss et al., 1992a) and \textit{pax[al]} (Krauss et al., 1991b; Püschel et al., 1992a) genes are involved in specifying the dorsal hindbrain and spinal cord in zebrafish.

The existence of neuromeres in the prospective midbrain and forebrain (diencephalon and telencephalon) of vertebrates is still somewhat controversial. However, evidence for mesomeres (prospective midbrain) and prosomeres (prospective forebrain) has recently been presented (Bulfone et al., 1993; Figdor and Stern, 1993; Puelles and Rubenstein, 1993). Puelles and Rubenstein (1993) present a predictive and testable overall model of vertebrate forebrain segmentation that includes data on descriptive (histology, morphology) and experimental (histrochemistry, grafting) embryology as well as on gene expression data. This neuromeric model suggests that in addition to eight hindbrain neuromeres and one neuromere for the mesencephalon (mesomere), the forebrain consists of six more neuromeres (prosomeres). What is traditionally considered the diencephalic vesicle displays two segments, one for the pretectum (synencephalon, P1) and one that includes the adult epithalamus and dorsal thalamus (P2). Rostral to these two segments are four more prosomeres (P3–P6) constituting the secondary prosencephalon. Several points are important to note with respect to this neuromeric model:

1. As in the rhombencephalon, different gene-expression boundaries in the prosencephalon are co-localized with prosomere boundaries in the rostrocaudal axis. In addition, some prosencephalic gene-expression patterns coincide with boundaries in the dorsoventral plane of the brain.

2. Several expression patterns of early regulatory genes rostral to the rhombomeres in the zebrafish correspond well with the neuromeric model of Puelles and Rubenstein (1993). One of the \textit{pax} genes (\textit{pax[al]}) is expressed in alar plate regions of the future diencephalon and telencephalon (Püschel et al., 1992a), as is its mouse ortholog, the \textit{pax-6} gene. Furthermore, the forebrain expression patterns of one homeobox gene of the \textit{distal-less} family, \textit{dlx2} (Akimenko et al., 1994), as well as of the \textit{wnt[al]} gene (Krauss et al., 1992a) in the zebrafish are similar to the expression patterns of their mouse orthologs, the \textit{Dlx2} and the \textit{Wnt-3} genes.

3. The diencephalon is not the derivative of a single prosomere. All of prosomere 2 contributes to the diencephalon, a portion of prosomere 3 contributes the ventral thalamus, and the (diencephalic) posterior tuberculum derives from the ventral portions of prosomeres 1 to 3.

4. Only the dorsal portions of prosomeres 4 to 6 will become the adult telencephalon, while the ventral portions will develop into the hypothalamus.

The zebrafish thus provides an excellent test system for a neuromeric model of brain organization. A case in point is the posterior tuberculum, which is rather small in tetrapods (e.g. the inconspicuous mammalian subthalamic nucleus), but very large in teleosts (see chapter 6). Its large size makes it easier to study in zebrafish, and combined gene expression and grafting experiments are likely to reveal its embryonic origin, especially now that the neuroanatomy has been established.

There is a long way to go before the complex cascade of interactions of genes and their products in early vertebrate development is understood. The fact that various
2 Taxonomic background

gene-expression patterns in the zebrafish correspond well with the neuromeric model of Puelles and Rubenstein (1993) is very encouraging for further research in this model system, which holds the promise of revealing fundamental neurogenetic patterns and mechanisms in vertebrates.

**Generation of zebrafish mutants via saturation mutagenesis**

The goal of saturation mutagenesis is to identify most – if not all – genes affecting early animal development and to understand their hierarchical, regulative role during development (for reviews, see: Mullins and Nüsslein-Volhard, 1992; Solnica-Krezel et al., 1994). This approach has recently been applied to the zebrafish system, and the results are impressive. Roughly 1300 zebrafish mutants have been described phenotypically by the Nüsslein-Volhard laboratory, and a further 600 were identified by the Dräger laboratory (Kahn, 1994). The identification and cloning of mutant genes is now feasible: an initial genome map of the zebrafish has been constructed, and some of the loci identified by mutation have already been mapped out (Postlethwait et al., 1994). These advances in zebrafish research will greatly facilitate the investigation of the hierarchical interactions of regulatory genes during early ontogeny and, ultimately, may lead to an understanding of pattern formation relevant to vertebrate development in general.

Zebrafish mutants include not only abnormal phenotypes in very early development during the formation of germ layers and those showing massive body plan aberrations but also minor defects that become phenotypically only visible in later development. At the level of a detailed screening of CNS mutants, the present atlas may turn out to be useful, since many phenotypic defects in mutants are likely to differ from wild-type organization at the neuroanatomical level. In order to assess such defects, an atlas of the adult zebrafish CNS appears to be indispensable.

The zebrafish belongs to the teleostean family of cyprinids (minnows), which includes other neurobiologically well investigated species such as goldfish (*Carassius auratus*) and carp (e.g. *Cyprinus carpio*). In a recent taxonomic revision (Barman, 1991), all species of the genus *Brachydanio* were reassigned to the genus *Danio*. Thus, the current species designation of the zebrafish is *Danio* (formerly *Brachydanio*) rerio (Hamilton-Buchanan, 1822). As a cyprinid, the zebrafish belongs to the large group of ostariophysan teleosts (6000 species, Lauder and Liem, 1983). Most ostariophysans are characterized by a sophisticated apparatus – the Weberian ossicles – to transmit sound from the swim bladder to the inner ear. The ostariophysans belong to the most derived group of teleosts, the euteleosts (17 000 species), which have three more basic teleostean outgroups, the osteoglossomorphs, elopomorphs, and clupeomorphs (1000–2000 species).

Zebrafish live in large schools and are communal breeders. Their natural habitats are the freshwaters of South and East Asia, i.e. India, Pakistan, Bangladesh, Burma, Sri Lanka, and Nepal (Barman, 1991).
3 Technical details

Histology

Fifty adult specimens of Danio rerio were processed in the course of this study. The animals were deeply anesthetized in methane sulfonate salt (Sigma, Deisenhofen, Germany) before being transcardially perfused with cold 0.1 M phosphate buffer (Sörensen; pH 7.4) followed by cold AFA (90 ml: 80% ethanol, 5 ml: 37% formalin, 5 ml: glacial acetic acid). The fish were then decapitated, and the skulls were opened dorsally to expose the brains. After one day in fixative, the brains were removed from the skulls and again postfixed for at least another month prior to further processing. The brains were then dehydrated, embedded in paraffin, and cut at 12 μm into either transverse, sagittal, or horizontal series of sections. To determine gross anatomy, some brains were fixed as described, removed from the skulls, and investigated under a stereomicroscope.

One specimen of Danio rerio was processed similarly, but the whole head was fixed for 15 days after perfusion and then decalcified in Titrplex III (Merck, Darmstadt, Germany) for 19 days. Subsequently, the head was put in Na₂SO₄ overnight and then rinsed in tap water, again overnight, before dehydration and embedding in paraffin. This specimen was cut at 10 μm into a transverse whole head series.

All sectioned brains were stained according to the procedure of Bodian, which reveals neurofilaments (see: Romeis, 1989), and counterstained with the Nissl-stain cresyl violet.

Preparation of figures

One series each of the transverse, sagittal, and horizontal histological sections was chosen for photographic documentation. While the numbers given in the atlas figures depicting the transverse plane represent the actual section numbers, the most lateral and dorsal sections shown in the sagittal and horizontal planes start arbitrarily with section number 1. However, the differences between figure numbers in the sagittal and horizontal series also represent the actual distances between sections.

The whole head transverse series served as a reference for structures that are almost always torn apart by removing the brain from the skull. The pituitary shown in transverse sections was photographed in this series and added to the photographed transverse sections with the aid of computer reconstruction. This was not done for the epiphysis, since it is well demonstrated in its full extent in some of the sagittal sections. Atlas photographs and corresponding ink drawings were computerized for further processing. Using computer techniques, artifacts and other undesired structures such as meninges or ventricular contents were removed, and graphics were added (e.g. background shading and lettering).
The following account outlines the major CNS divisions in the zebrafish and the organization of these divisions into nuclei or laminae, including a description of major tracts and commissures. CNS divisions will be dealt with according to the classical anatomical sequence: telencephalon, diencephalon, mesencephalon, metencephalon (including cerebellum), myelencephalon, and medulla spinalis. Since many tracts and commissures caudal to the diencephalon extend into several brain parts and even into the spinal cord, they are treated in a final separate section. When appropriate, discrepancies between the neuromeric model of Puellus and Rubenstein (1993) outlined above (see: Introduction) and classical brain divisions will be discussed.

The principal terminology applied to nuclei and larger CNS divisions is indicated at the beginning of each major section. For general review articles on fish neuroanatomy, the reader is referred to Nieuwenhuys (1963), Northcutt and Braford (1980), Northcutt and Davis (1983), Nieuwenhuys and Pouwels (1983), and Nieuwenhuys and Meek (1990).

Tract designations often imply a specific origin and target of their axons. The present text includes only nomenclature on tracts that have been confirmed with experimental neuronal tracing. However, this does not imply that the interconnection indicated in the tract designation as the dominant one is the only one running in a specific tract. Unless unambiguous connectional information already exists in the zebrafish or other teleosts, we remained conservative in using tract designations that imply a specific connection, to allow future terminology to develop meaningfully as refinements of connectivity in the zebrafish brain emerge.

The relative proportions of the major brain divisions of the zebrafish (Fig. 4) reveal some features typical of cyrinids, i.e. relatively large vagal and facial lobes, although these are not as pronounced as in other cyrinid species (such as goldfish or carp). Further comments pertaining directly to specific brain variability in teleosts are given in the appropriate paragraphs of the present chapter, which describes the zebrafish brain. A more general discussion of the functional anatomy of the teleostean brain follows in chapter 6.

**Telencephalon**

The terminology of Nieuwenhuys (1963) as modified by Northcutt and Davis (1983) is applied except where noted. In teleosts, the topology of the telencephalon (Tel) is highly distorted (Nieuwenhuys and Meek, 1990). In all other vertebrate groups, the telencephalic hemispheres develop by paired evagination and thickening of the most rostral embryonic neural tube, and each hemisphere contains a lateral diverticulum of the ventricle centrally. In ray-finned fish, and most pronounced in teleosts (including the zebrafish), the roof plate of the embryonic telencephalon extends laterally with the effect that the paired alar plates forming the hemispheric walls roll out lateroventrally, a process called eversion. Thus, it is very difficult to infer from the adult topology of teleostean telencephalic cell masses alone their homologous structures in other vertebrates, though some advances have been made recently (see chapter 6).

The most rostral telencephalic divisions are the paired olfactory bulbs. The primary olfactory fibers (nervus olfactorius, I) entering the olfactory bulbs are the axons of the olfactory receptors, which are of placodal origin and, by definition, not part of the CNS. The rest of the telencephalon comprises two subdivisions, area dorsalis and area ventralis telencephali.

**Olfactory bulbs**

The olfactory bulbs (OB) form paired rostroventral protrusions adjacent to the remaining telencephalon and are interconnected with the latter by two tracts carrying secondary olfactory fibers: the lateral and the medial olfactory tracts. The lateral olfactory tract (LOT) enters the dorsal area of the telencephalon more rostrally compared with the more caudal entrance of the medial olfactory...
tract (MOT) into the ventral area of the telencephalon. Each olfactory bulb consists of four laminae that are roughly concentrically arranged throughout most of the bulb's extent, starting peripherally with a primary olfactory fiber layer (POF, present only in the rostroventral olfactory bulbs), followed by a glomerular layer (GL), an external cellular layer (ECL, including the efferent large mitral cells whose axons form most of the lateral and medial olfactory tracts), and an internal cellular layer (ICL). A distinct secondary olfactory fiber layer present in many other tetrapods rostral to the formation of the lateral and medial olfactory tracts between the internal and external cellular layers is not apparent in the zebrafish.

**Area ventralis telencephali**
The ventral telencephalic area (V) is divided into periventricularly located nuclei which are in contact with the median ependymal lining of the ventricle, i.e. dorsal, ventral, supracommissural, and postcommissural nuclei (Vd/Vv/Vs/Vp), and nuclei which have migrated away from the ependyma to various degrees, i.e. central and lateral nuclei, dorsal and ventral entopeduncular nuclei (Vc/Vl/ENd/ENv). Periventricularly, a dorsal (Vd) and a ventral (Vv) nucleus lie rostral to the anterior commissure. The dorsal nucleus (Vd) is contiguous caudally with the supracommissural nucleus (Vs), which in turn is contiguous with the postcommissural nucleus (Vp). A periventricular nucleus called Vn (another nucleus of Nieuwenhuys, 1963) in some other tetrapods is not present in the area ventralis telencephali of the zebrafish.

In the rostral, precommissural telencephalon, the migrated nuclei of the area ventralis include the central (= commissural) nucleus (Vc) and the lateral nucleus (Vl). While the central nucleus is located immediately lateral to the dorsal nucleus (Vd), the lateral nucleus has migrated to the very periphery of the brain. A cell-sparse neuropilar region is present between Vl and Vd/Vv. A distinct intermediate nucleus of area ventralis, described in some other tetrapods as a lateral extension of the postcommissural nucleus, is absent in the zebrafish.

At caudal telencephalic levels, the lateral nucleus of area ventralis is replaced by the entopeduncular cell clusters. These form separate ventral (ENv) and dorsal (ENd) bands of tightly packed cells starting at the level of the anterior commissure. While the dorsal band of entopeduncular cells disappears more rostrally, the ventral band located around the lateral forebrain bundle extends into the telencephalo-diencephalic boundary (= preoptic) region. The dorsal entopeduncular nucleus may be homologous to the intermediate nucleus of the area ventralis of other species, although no close morphological association with the postcommissural nucleus, which is characteristic for other teleosts, is seen in the zebrafish.

**Area dorsalis telencephali**
Dorsal to the area ventralis telencephali lie the large cell masses of the area dorsalis telencephali (D). Since most of area dorsalis is developmentally everted, the ependymal lining of the unpaired median ventricle (TelV) continues dorsal to Vd into the medial zone of the dorsal telencephalic area (Dm) and becomes located at the apparent periphery of the telencephalon. A thin tela chorioida covering most of D encloses the paired telencephalic ventricles. However, this tela has been removed in all our preparations.

Through most of the rostrocaudal extent of area dorsalis, four distinct cell masses, the medial (Dm), dorsal (Dd), lateral (Dl), and posterior (Dp) zones, surround a central zone (Dc). The sulcus ypsiloniformis (SY; Nieuwenhuys, 1959) separates Dd from Dm. Nucleus taeniae (NT) is located immediately ventral to Dp. In the most rostral as well as in the most caudal parts of the zebrafish telencephalon, medial and lateral zones of area dorsalis merge without an apparent boundary.

Although medial, central, and lateral zones of area dorsalis in the zebrafish are large cell aggregates extending over most of the telencephalon, we chose to await first connectional and immunohistochemical data in this species before further subdividing these areas, as has been done for *Salmo* and *Lepomis* (Northcutt and Davis, 1983). These
species are only distantly related to the zebrafish, and their telencephalic organization is sufficiently different to make a direct comparison of detailed subdivisions difficult at present.

**Telencephalic tracts and commissures**
The anterior commissure is divided into a dorsal part (Cantd) lying immediately ventral to the supracommissural nucleus of area ventralis telencephali, and a ventral part (Cnttv) which abuts the preoptic region dorsally. In the precommissural telencephalon, several fascicules converge rostrocaudally and eventually fuse to form the lateral forebrain bundle (LFB). This is a compact tract located lateral to the medial forebrain bundle (MFB) and both tracts extend into the diencephalon.
The medial olfactory tract (MOT) enters the area ventralis telencephali ventrally and courses caudally, lateral to the ventral nucleus, to the level of the anterior commissure. The lateral olfactory tract (LOT) enters the area dorsalis telencephali more rostrally and courses laterally to the ventral border of the posterior zone of area dorsalis telencephali.

**Diencephalon (including synencephalon and pretectum)**
The terminology of Braford and Northcutt (1983), Northcutt and Wullimann (1988), and Wullimann and Meyer (1990) is applied except where noted.
The diencephalon proper has five major divisions which, in the adult brain, appear in a dorsoventral arrangement. They are the epithalamus, dorsal thalamus, ventral thalamus, posterior tuberculum and hypothalamus. The area praeoptica, although often considered part of the hypothalamus, is treated here in its own right because it constitutes an intermediate region between telencephalon and diencephalon. The synencephalon (the intermediate region between the dorsal diencephalon and mesencephalon) and the pretectum will also be treated in this section because these regions are intricately intermingled with diencephalic cell groups. The different meaning of synencephalon in the neuromeric model of Puelles and Rubenstein (1993) is discussed below.

**Area praeoptica**
The preoptic area encloses the most rostral diencephalic ventricle (DiV) and can be divided into a ventral series of parvo cellular preoptic nuclei and a dorsal series of magnocellular preoptic nuclei. The anterior parvo cellular preoptic nucleus (PPa) extends rostrally to become located ventral to the telencephalon. It is replaced in the diencephalon by the posterior parvo cellular preoptic nucleus (PPp). The suprachiasmatic nucleus (SC) is found ventrolateral to the latter.
Dorsal to the posterior parvo cellular preoptic nucleus a magnocellular preoptic nucleus (PM) emerges, which is followed more caudally by the gigantocellular part of magnocellular preoptic cells (PMg). A parvo cellular part of the magnocellular preoptic nucleus, as described in the goldfish (Braford and Northcutt, 1983), is not evident morphologically in the zebrafish.

**Epithalamus**
The epithalamus consists of the dorsal (Had) and ventral (Hav) nuclei of the habenula, and two dorsal outgrowths, the epiphysis (E = pineal organ) and the saccus dorsalis (SD). The latter is a chorioidal tela, whereas the former is an endocrine and light-sensitive organ.

**Dorsal thalamus**
The dorsal thalamus (DT) emerges below the caudal portion of the ventral habenular nucleus and consists of an anterior nucleus (A) and two more caudally situated nuclei, the dorsal posterior thalamic (DP) and central posterior thalamic (CP) nuclei.

**Ventral thalamus**
The rostral part of the ventral thalamus (VT) is located directly below the rostral part of the ventral habenular nucleus since it reaches far more rostrally than the dorsal thalamus does. The ventral thalamus is located ventral to
the dorsal thalamus only in its caudal extent. The ventral thalamus consists of an intermediate nucleus (I) as well as ventromedial (VM) and ventrolateral (VL) nuclei. The rostral lateral nucleus (R) of Butler and Saidel (1991) is also present in the zebrafish. It lies somewhat lateral to the ventral thalamic nuclei just described and is likely to belong to these nuclei. However, Anken and Rahmann (1995) recognize it as part of the entopeduncular complex.

Posterior tuberculum
As in other teleosts, the posterior tuberculum is much larger than both the dorsal and the ventral thalamus in the zebrafish. Its periventricular part consists of two nuclei, the periventricular nucleus of the posterior tuberculum (TPp) and the posterior tuberal nucleus (PTN), both of which are located between ventral thalamus and hypothalamus, as well as of the paraventricular organ (PVO). The migrated nuclei of the posterior tuberculum include primarily the pregglomerular nuclei, which are – in rostromedial to caudal sequence – the anterior, lateral, medial, and caudal pregglomerular nuclei (PGA/PGL/PGM/PGe). The (pregglomerular) tertiary gustatory nucleus (TGN), which has been misinterpreted as the visual nucleus glomerulosus of other teleosts (see chapter 6), is located ventral to the medial pregglomerular nucleus. Ventrolateral to the caudal pregglomerular nucleus lies the so-called corpus mamillare (CM), which is also included in the posterior tuberculum here. Additional nuclei which are likely to be part of the posterior tuberculum are the posterior thalamic nucleus (P), the nucleus subglomerulosus (SG), and the torus lateralis (TLa).

Hypothalamus
As in other teleosts, the hypothalamus of the zebrafish is by far the largest diencephalic area and includes ventral, dorsal, and caudal zones. While the ventral and caudal zones form most of the median tuberal portion of the hypothalamus (TH), the dorsal zone is additionally expanded laterally and includes the paired inferior (or lateral) lobes (IL) of the hypothalamus. These are separated from the tuberal hypothalamus by a deep ventral sulcus. All three hypothalamic zones display primarily periventricular cell masses which are flanked laterally by separate migrated nuclei.

The ventral hypothalamic zone with the periventricular nucleus (Hv) extends farthest rostrally. The anterior tuberal nucleus (ATN) and the lateral hypothalamic nucleus (LH) lie lateral to it. More caudally, the dorsal hypothalamic zone emerges and forms paired lateroventricular recesses (LR) surrounded by periventricular cell masses (Hd). Presumably migrated from these periventricular cell masses are the small-celled diffuse nucleus (DIL) and the larger-celled central nucleus (CIL) of the inferior lobe. The caudal protrusion of the inferior lobe lies ventral to the tegmentum and includes in its dorso-medial aspect the mammillary body (CM), which more likely belongs to the posterior tuberculum. The caudal hypothalamic zone starts out rostrally as a thick periventricular nucleus (Hv), which lies ventral to the posterior tuberal nucleus of the posterior tuberculum. More caudally, the caudal hypothalamus consists of paired posterior or ventricular recesses (PR) surrounded by periventricular nuclei (Hc). The pituitary (Pit) is ventrally attached to the ventral and caudal hypothalamic zones. A saccus vasculosus seen in many other teleosts caudal to the pituitary is absent in the zebrafish.

Synencephalon
According to Braford and Northcutt (1983), the synencephalon designates a series of structures which are intermediate between the dorsal diencephalon and mesencephalon. These structures are located in the vicinity of the posterior commissure and include the nucleus of the medial longitudinal fascicle (NMLF), the periventricular pretectum (PPd/PPv), the paracommissural nucleus (PCN), and the subcommissural organ (SCO). Note, however, that in the neuromeric model of Puelles and Rubenstein (1993), the synencephalon is the most caudal prosomere (P1) and gives rise to all pretectal nuclei.
Pretectum
The pretectum is one of the most variable brain regions in teleosts (Northcutt and Wullimann, 1988; Wullimann and Meyer, 1990; Butler et al., 1991; Wullimann et al., 1991b). Following Braford and Northcutt (1983), we recognize a periventricular pretectum (see this chapter: Synencephalon), a central, and a superficial pretectum. The number and morphology of superficial and central pretectal nuclei in the zebrafish clearly represent the reduced pattern of pretectal organization in teleosts, in which nucleus corticalis as well as nucleus glomerulosus are absent (see chapter 6). The superficial pretectum is embedded in the optic tract and includes a parvocellular (PSp) and a magnocellular (PSm) nucleus. The PSm is caudally contiguous with the posterior pretectal nucleus (PO), whose cells appear to be slightly less large and less orderly arranged around a central neuropil compared with the magnocellular superficial pretectal nucleus. The central pretectal nucleus (CPN) is found dorsal to PSm and PO. The accessory pretectal nucleus (APN) lies dorsolateral to the posterior pretectal nucleus. Two additional nuclei are sometimes considered part of the pretectum: the dorsal accessory optic nucleus (DAO), which is ventrally adjacent to PSm and PO, and the ventral accessory optic nucleus (VAO), which lies more ventromedially. The VAO is very large in zebrafish compared with other cyprinids.

As mentioned already, all pretectal nuclei discussed here may derive from prosomere 1 and form the larger synencephalon of Puelles and Rubenstein (1993). Another hypothesis of interest here is that the superficial pretectal nuclei (PSp/PSm) may be homologous to the griseum tectale of birds (Marin and Puelles, 1994), in which case the superficial pretectal nuclei would be a derivative of the mesencephalic vesicle (mesomere) and not of prosomere 1 (L. Puelles, personal communication).

Diencephalic tracts and commissures
Starting in the telencephalon, both lateral and medial forebrain bundles (LFB/MFB) extend as distinct tracts into the diencephalon, the lateral one dorsal to the preglomerular area and the medial one approaching the posterior tuberal nucleus.

Ventral to the anterior preoptic region, the optic nerves (nervus opticus, ON, II) interdigitate in the optic chiasm (CO) and reach the contralateral side of the brain. Beyond the chiasm, the optic fibers are conventionally called the optic tract (OT), which is composed of a dorsomedial (DOT) and a ventrolateral (VOT) optic tract. The DOT runs dorsally along the lateral surface of the posterior preoptic and thalamic regions towards the optic tectum, while the VOT courses caudally along the ventral boundary of the optic tectum.

The pretecto-mammillary tract (TPM) originates in the magnocellular superficial pretectal nucleus and runs through the posterior pretectal nucleus to terminate in the mammillary body. The habenular nuclei project via the fasciculus retroflexus (FR; = tractus habenulo-interpeduncularis) to the interpeduncular nucleus (NI; Villani et al., 1994).

The habenular commissure (Chab) runs between the two dorsal habenular nuclei. Immediately caudal to the optic chiasm lies the large postoptic commissure (Cpop; = suprapontic commissure). The minor and transverse commissures are included here in the postoptic commissure, since they were not as clearly separable as in other species. Ventral to the postoptic commissure, the horizontal commissure (Chor) crosses the midline within the ventral hypothalamic zone. The tracts forming the horizontal commissure run caudally on each brain side, ventral to the preglomerular area, beyond which they turn first dorsally and then rostrally again towards the anterior tip of the optic tectum. All along their course, these tracts are also referred to as the horizontal commissure. A third diencephalic commissure lies caudal to the posterior tuberal nucleus. This is the commissure of the posterior tuberculum (Ctub; Herrick, 1948).

The posterior commissure (Cpost) is located in the region treated earlier as synencephalon.
Mesencephalon

The terminology of Nieuwenhuys and Pouwels (1983) is applied except where noted. The mesencephalon includes, dorsally, the (multisensory) optic tectum and, ventrally, the torus semicircularis and the tegmentum.

Tectum opticum
The optic tectum (TeO) is the most complex layered structure in the zebrafish brain. It consists of four zones (periventricular grey zone, deep white zone, central zone, and superficial grey and white zone), which can be further subdivided into 15 layers (Northcutt, 1983). Different from all other vertebrates, the most superficial tectal layer in teleosts does not consist of retinal fibers (see chapter 6: Vision). This marginal layer consists of axons whose perikarya are in the torus longitudinalis (TL). The latter is a paired, longitudinal eminence of granular cells attached to the tectum. It is located in the medial tectal ventricle (TeV) and only occurs in ray-finned fish (for a review, see: Wullimann, 1994). The intertectal commissure (Ctcc) runs between the tectal hemispheres.

Torus semicircularis
The sensory torus semicircularis (TS) is the mesencephalic target of ascending octavolateralis systems and lies on top of the lateral tegmentum from where it bulges out into the tectal ventricle. In cyprinids, the central nucleus (TSc) is related to audition and the ventrolateral nucleus (TSvl) is related to mechanoreception (Echteder, 1984; McCormick and Hernandez, 1996).

Tegmentum
The term tegmentum is used ambiguously in the literature. In mammals, the roof of the mesencephalon consists of the superior colliculus (tectum opticum of other vertebrates, which is part of the visual system) and the inferior colliculus (torus semicircularis of other vertebrates, which is part of the auditory system). The ventral mesencephalon is separated from this roof by the ventricle and forms the tegmentum, which has a dominant role in motor functions. The tegmentum arises embryonically from the basal plate, in contrast to the alar plate-derived, sensory-related tegmentum opticum and torus semicircularis. The tegmentum includes many motor structures, such as the oculomotor (NIII) and trochlear (NIV) nerve nuclei, the parasympathetic Edinger-Westphal nucleus (EW), the nucleus ruber (NR), and the most rostral portion of the superior reticular formation (SRF). It also harbors the dorsal and rostral tegmental nuclei (DTN/RT), the perilemniscal nucleus (PL), the nucleus of the lateral Lemniscus (NLL), and the interpeduncular nucleus (IN). The rostral tegmental nucleus as defined by Grover and Sharma (1981) is homologous to the lateral thalamic nucleus defined by Braford and Northcutt (1983). However, we prefer Grover and Sharma's term here since they were the first to show that in cyprinids a projection to the optic tectum originates in the rostral tegmental nucleus. The nucleus of the lateral Lemniscus is defined according to Prasada Rao et al. (1987), who showed that this nucleus projects to the spinal cord in goldfish. Recently, Becker et al. (1995) have confirmed this for zebrafish.

Whereas the axons of the oculomotor nerve (nervus oculomotorius, III) exit the brain ventrally between tegmentum and inferior lobe, the trochlear motor nucleus sends its axons dorsally, where they decussate (DIV) in the valvula cerebelli, turn caudolaterally, and exit the brain as the trochlear nerve (nervus trochlearis, IV) between torus semicircularis and rhombencephalon.

The tegmentum is bordered rostrally by the synencephalon, the dorsal thalamus, and the posterior thalamus; ventrally by the hypothalamus; and dorsolaterally by the torus semicircularis. Caudally, the tegmentum is contiguous with the medulla oblongata without a clearcut morphological boundary. The interpeduncular nucleus and the trochlear nucleus are often considered to be the most caudal tegmental nuclei. However, the rhombencephalic griseum centrale as well as the superior reticular formation extend rostrally up to this level. A final deci-
sion on tegmental boundaries may result from homeotic gene expression data and grafting experiments. Recently, Marin and Puelles (1994) have demonstrated an embryonic polarizing gradient from the (rhombencephalic) isthmus region acting on the differentiation of mesencephalic structures in the avian brain. Their experiments indicate a mesencephalic-rhombencephalic boundary lying somewhat more rostral, i.e. between the oculomotor and trochlear motor nuclei and rostral to the interpeduncular nucleus.

**Rhombencephalon (metencephalon and myelencephalon)**

The terminology of Nieuwenhuys and Pouwels (1983) is applied except where noted. The rhombencephalon (hindbrain) is often divided into a rostral metencephalon and a caudal myelencephalon. With the exception of the cerebellum, the ventral (medullary) remainder of the metencephalon can be separated only arbitrarily from the more caudal myelencephalic portion of the medulla oblongata. Thus, we treat cerebellum and medulla oblongata as entities here. Medulla oblongata and tegmentum are collectively referred to as brain stem.

The terms metencephalon and myelencephalon are only meaningful in mammals and birds. In those derived vertebrates, the metencephalon appears to be clearly separable from the myelencephalon as it exhibits a large dorsal cerebellum and ventral pons, which consists of relay neurons for cortical fibers to the cerebellum.

**Cerebellum**

As in all teleosts, the cerebellum (Ce) of the zebrafish has three parts: the vestibulolateralis lobe (including the medial caudal lobe, LCa, and the paired lateral eminentiae granulares, EG), the corpus cerebelli (CCe), and the valvula cerebelli, which has medial and lateral subdivisions (Vam/Val). The cerebellar commissure (Ccer) is located within the ventral boundary zone between valvula and corpus cerebelli. Although the valvula extends into the tectal ventricle, its histology (presence of a granular and a molecular layer, plus aggregations of large Purkinje- and eurydendroid cells) and its caudal attachment to the rostral medulla oblongata leave no doubt about it being part of the cerebellum. While both the vestibulolateralis lobe and the corpus cerebelli have homologues in other vertebrates, the valvula cerebelli is uniquely present in ray-finned fishes (Nieuwenhuys, 1967; Wullimann and Northcutt, 1988; 1989).

**Medulla oblongata**

Primary sensory and motor nuclei

The medulla oblongata (MO) contains the sensory and motor nuclei of the trigeminal (nervus trigeminus, V), abducens (nervus abducens, VI), facial (nervus facialis, VII), octaval (nervus octavus, VIII), glossopharyngeal (nervus glossopharyngeus, IX), and vagal (nervus vagus, X) nerves. The anterior and posterior lateral line nerves (ALLN/PLL) are separate from the other cranial nerves. In terms of the number of ganglia and peripheral innervation of neuromasts, both the anterior and posterior lateral line nerve roots include more than one nerve (Northcutt, 1989). However, these nerves are included here in the anterior and posterior lateral line nerve roots shown for the zebrafish (Fig. 4).

There are two separate trigeminal motor nuclei, one located dorsally to the lateral longitudinal fascicle (NFLd), and one situated at the ventrolateral edge of this fascicle (NFLv). Both motor nuclei extend more caudally where the lateral longitudinal fascicle runs more medially. Four trigeminal sensory nuclei (Puzdrowski, 1988) are described here. The most rostral, the isthmic primary sensory trigeminal nucleus (NIs), lies immediately caudal to the secondary gustatory nucleus. More caudally, at the medio-dorsal edge of the descending trigeminal root (Df), lies the less clearly delineated (sensory) nucleus of the descending trigeminal root (NDf). It can best be recognized at the
level of the caudal octavalateralis region. A third trigeminal sensory nucleus, the medial funicular nucleus (MFN), emerges at the very end of the medulla oblongata. The large pyriform neurons of the mesencephalic nucleus of the trigeminal nerve (MNv, located at the tectal ventricle near the synencephalon and optic tectum) have sensory fibers running peripherally in the trigeminal nerve (see chapter 6: Motor nuclei of cranial nerves).

The abducens nerve has two separate populations of motor neurons. The rostral motor nucleus and its root (V1r) are located at the level of the superior reticular formation, and the caudal motor nucleus (V1c) and its root (V1c) are at the level of the intermediate reticular formation. Once outside the brain stem, the roots fuse and course rostrally.

The sensory root of the facial nerve (VIIr) enters the brainstem together with the anterior lateral line nerves. The sensory facial root first courses towards the midline of the brain stem, where it turns caudally and finally terminates in the facial lobe (LVII). Ventral to the facial sensory root and dorsal to the ventral rhombencephalic commissure and intermediate reticular formation lies the facial motor nucleus (VIIIm).

The octaval nerve (VIII) enters the zebrafish brain in an extended rostro-caudal region. Five primary sensory nuclei receive its projections: the anterior, magnocellular, descending, and posterior octaval nuclei, plus the tangential nucleus. It is difficult to subdivide the octaval area in teleosts. Subdivisions of this area in the zebrafish were carried out in close comparison with a detailed connectational study in the goldfish (McCormick and Hernandez, 1996).

The large neurons of the tangential nucleus (T) are located at the periphery of the brain stem, immediately ventral to the entrance of the anterior portion of the octaval nerve. These darkly staining neurons have a very distinctive large nucleus and nucleolus, and are distributed over a distance of only about 100μm. The slightly smaller neurons located more caudally are part of the descending octaval nucleus (DON), which is by far the largest octaval system. It not only extends ventrally and dorsally around the octaval root but also reaches far medially. Its most caudal part at the level of the vagal root is referred to as the posterior octaval nucleus (PON). The magnocellular octaval nucleus (MaON) is located between the tangential nucleus and the transversely coursing portion of the sensory facial root. Rosstral to the magnocellular octaval nucleus, the anterior octaval nucleus (AON) arches dorsally around the descending trigeminal root. Dorsal to the inner arcuate fibers, another octaval-related nucleus (although not a primary sensory nucleus) is present, referred to as the secondary octaval population (SO).

The root of the glossopharyngeal nerve (IX) which is peripherally related to the first gill arch, enters the brain ventral to the secondary gustatory tract. While its sensory nucleus forms a cell aggregation (LIx) located intermediate between facial and vagal lobes, its motor neurons do not form a separate nucleus. Rather, they are contained in the visceromotor column together with the motor neurons of the vagal nerve (NIx). The vagal nerve innervates the remaining gill arches and is, therefore, of much larger diameter. It carries gustatory information which is processed in the vagal lobe (LX), a large, paired brain stem structure flanking the unpaired facial lobe laterally. While some degree of histological segregation is apparent within the vagal lobe, a clear lamination, as seen in goldfish or carp, is absent. Also, from histology alone it cannot be decided whether motor neurons are included in the vagal lobe or not. The viscerosensory commissural nucleus of Cajal (NC) lies caudal to the vagal lobe.

There are two sensory nuclei related to the lateral line nerves in the zebrafish: the medial and caudal octavalateralis nuclei. The extensive medial octavalateralis nucleus (MON) is located in the most dorsal brain stem above the octaval nuclei; it is covered by a molecular layer called the cerebellar crest (CC). The latter is conventionally considered part of the medulla oblongata and not of the cerebellum, although the granular eminence cells extend parallel fibers into the cerebellar crest. The caudal
octavolateralis nucleus (CON) is smaller and lies lateral to the facial and vagal lobes.

Reticular formation
The rhombencephalic reticular formation can be divided into midline, medial, and lateral columns (Nieuwenhuys and Pouwels, 1983). Immediately caudal to the interpeduncular nucleus, the midline column includes the superior raphe nucleus (SR). Its large neuronal perikarya are surrounded by a distinct neuropil. This is not the case for the more irregularly spaced neurons of the inferior raphe nucleus (IR), which lie in the ventral midline of the brain stem at the level of the facial and vagal lobes. The medial column of the reticular formation includes the superior, intermediate, and inferior nuclei of the reticular formation, called here for convenience superior, intermediate, and inferior reticular formation (SRF/IMRF/IRF). The superior reticular formation extends rostrally into the mesencephalon. The lateral column of the reticular formation includes the cerebellar-projecting lateral reticular nucleus (LRN).

Additional medullary nuclei
The griseum centrale (GC) is a longitudinally oriented nucleus situated along the ventral lining of the rhombencephalic ventricle. It extends partially into the mesencephalon.

The locus coerulus (LC) consists of a few conspicuously shaped, large neurons dorsal to the superior reticular formation. Their widespread noradrenergic projections have recently been documented in the zebrafish (Ma, 1994a; 1994b).

The nucleus lateralis valvulae (NLV) is a large collection of granular cells at the ventral border of the cerebellum and brain stem. The dorsal tegmental nucleus (DTN) is sometimes considered part of the NLV. However, its cells are more densely packed than are those of the NLV and extend rostrally into the mesencephalon.

Two higher-order sensory nuclei are clearly delineable in the rostral brain stem. The visually related nucleus isthmi (NI) and the secondary gustatory nucleus (SGN). The large Mauthner cell (MAC) lies in the rostral octavolateralis region, between the anterior octaval nucleus and the ventral rhombencephalic commissure. It has two large dendrites, a lateral one extending towards the anterior/magnocellular octaval nuclei and a ventral one extending into the intermediate reticular formation. The Mauthner axon (MA) crosses the midline within the dorsal part of the medial longitudinal fascicle (MLF), and this heavily myelinated axon then descends in the MLF into the spinal cord.

The inferior olive (IO) is a large nucleus at the ventral periphery of the caudal brain stem. It is the source of climbing fibers reaching the cerebellum in teleosts (Finger, 1983; Wullimann and Northcutt, 1988; 1989).

Medulla spinalis
The terminology of Nieuwenhuys and Pouwels (1983) is applied except where noted. Only the rostral spinal cord at the level of the entrance of the second dorsal root (DR) is characterized here. The second dorsal root is treated here, because the first dorsal root is minute. (Note, however, that the corresponding first ventral root is huge and likely innervates hypaxial (somatic) musculature in the lower jaw.) First dorsal and ventral spinal roots are located approximately 100–150 μm caudal to the commissura infima of Haller. The second dorsal root, shown in this atlas, lies about 500–800 μm caudal to that commissure.

At the level of the second dorsal root, dorsal and ventral horns (DH/VH) of the grey matter are clearly visible surrounding the central canal (C). The longitudinally running tracts have been rearranged dramatically compared to their position and composition in the brain stem. They lie in the peripherally located white matter. The white matter of the spinal cord can be subdivided here into dorsal, lateral (which consists of a dorsal and a ventral part),
and ventral funiculi (Fd/Fld/Flv/Fv), as in mammalian neuroanatomy (Nieuwenhuys et al., 1988).

**Brain stem/spinal tracts and commissures**

The terminology is according to Nieuwenhuys and Pouwels (1983) unless otherwise indicated. Approximately at midtectal levels, the descending fibers of the optic tectum form the massive tecto-bulbar tract (TTB) running ventromedially along the surface of the torus semicircularis and the tegmentum. Many fibers in the tecto-bulbar tract cross the midline in the ansulate commissure (Cans), which is located immediately rostral to the interpeduncular nucleus. Lateral to this nucleus, the crossed tecto-bulbar tract (TTBc) then continues its caudal course into the ventromedial brain stem. A portion of the uncrossed tecto-bulbar tract (= tractus tectobulbaris rectus, TTBbr) detaches very rostrally from the main tecto-bulbar fiber masses and runs caudally, separate from the more laterally located main portion of the uncrossed tecto-bulbar tract. At the level of the inferior reticular formation, both TTBc and TTBbr are no longer visible. Because of its large size, the medial longitudinal fascicle (MLF) is often considered to be the major descending fiber system in the brain of anamniotes. It begins within the nucleus of the MLF and runs – immediately ventral to the rhombencephalic ventricle (RV) – towards the caudal end of the medulla oblongata. Whereas the dorsal part of the MLF (including the Mauthner axon) continues to course into the spinal cord, the ventral portion of the MLF associates with other fiber systems in the funiculus ventralis prior to reaching the spinal cord. Throughout most of its rhombencephalic extent, the MLF is intersected by the ventral rhombencephalic commissure (Cven). A smaller commissure, the octavolateralis-related inner arcuate fibers (IAF), also crosses via the MLF.

The ascending lateral longitudinal fascicle (LLF) is the homologue of the mammalian lateral lemniscus. The LLF contains fibers of the auditory and mechanosensory systems which originate in the primary sensory brainstem nuclei and terminate in the torus semicircularis. Caudally, the LLF lies dorsal to the superior reticular formation, adjacent to the ventral rhombencephalic commissure. It becomes displaced more laterally as it approaches the torus semicircularis.

The anterior mesencephalo-cerebellar tract (TMCa) carries mostly cerebellar afferents from the pretectum (Wullimann and Northcutt, 1988; 1989). The TMCa runs medial to the lateral longitudinal fascicle for some distance before turning dorsally to traverse the nucleus lateralis valvulae. Upon entering the cerebellum, part of the TMCa fuses with the posterior mesencephalo-cerebellar tract (TMCp), which contains the axons of the dorsal tegmental nucleus and nucleus lateralis valvulae. The TMCa and TMCp together form the anterior cerebellar tract (AC). A posterior cerebellar tract (PC) carrying cerebellar afferents from many brain stem nuclei (Wullimann and Northcutt, 1988; 1989) enters the cerebellar corpus at the level of the granular eminence. Many efferent cerebellar fibers decussate in the brachium conjunctivum and terminate, for example, in the nucleus ruber (Wullimann and Northcutt, 1988). In the zebrafish we could not identify the brachium conjunctivum neuroanatomically.

On entering the brain stem, the sensory root of the trigeminal nerve (Ts) bifurcates. Besides giving off fibers to the isthmic primary sensory trigeminal nucleus (Ns; Puzdrowski, 1988), the sensory trigeminal root turns caudally and becomes the descending trigeminal root (Df). Located ventral to the octavolateralis area, the Df descends towards the caudal tip of the medulla oblongata. Here, the Df is located lateral to the medial funicular nucleus, which receives a considerable trigeminal input. Those fibers which eventually project further caudally into the spinal cord become located within the dorsal part of the lateral funiculus. Throughout most of its course, the descending trigeminal root is accompanied ventromedially by the ascending secondary gustatory tract (SGT), which runs from the primary gustatory centers to the secondary gustatory nucleus.
The bulbo-spinal tract (TBS) emerges medial to the caudal intermediate reticular formation and runs caudally, constantly growing in size, along the medial edge of the inferior reticular formation. Immediately prior to reaching the spinal cord, the bulbo-spinal tract is displaced laterally and associates with other tracts in the dorsal part of the funiculus lateralis.

The vestibulo-spinal tract (TVS) forms at the rostral level of the inferior reticular formation where it lies dorsal to the inferior olive. It associates more caudally with other tracts in the ventral part of the funiculus lateralis. Both the TVS and the TBS carry descending spinal projections. Two additional commissures are present in the medulla oblongata. The commissure of the secondary gustatory nuclei (Cgus; Herrick, 1905) runs between these large, paired sensory nuclei. The commissura infima of Haller (Cinf) is located dorsal to the commissural nucleus of Cajal.
Figure 4.
Lateral (a) and dorsal (b) views of the adult zebrafish brain. The telencephalon comprises a dorsal and a ventral telencephalic area as well as an olfactory bulb, which is entered rostrally by the olfactory nerve. The diencephalon is located rostroventrally to the midbrain and is largely covered by the optic tectum. Externally visible portions of the diencephalon include the optic nerve, the preglomerular area, the torus lateralis, the habenula, and the hypothalamus. The hypothalamus can be separated into a rostromedial tuberal hypothalamus and paired lateral lobes. Saccus dorsalis and epiphysis were removed during preparation and are not shown. The brainstem, which harbors most cranial nerve roots except for the optic and olfactory nerves, is covered rostrally by the cerebellum (i.e. the corpus cerebelli and the granular eminence), and includes more caudally the crista cerebellaris, the prominent paired vagal lobes, and the unpaired facial lobe. Finally, the medulla oblongata grades into the spinal cord (medulla spinalis).

CC  crista cerebellaris
CCE corpus cerebelli
Ctcc commissura tecti
EG  eminentia granularis
Ha  habenula
IL  inferior lobe of hypothalamus
LL  lateral line nerves
LVII facial lobe
LX  vagal lobe
MO  medulla oblongata
MS  medulla spinalis
OB  olfactory bulb
PG  preglomerular area
Pit  pituitary
PSp  parvocellular superficial pretectal nucleus
Tel  telencephalon
TeO  tectum opticum
TH  tuberal hypothalamus
TL  torus lateralis
I  olfactory nerve
II  optic nerve
IV trochlear nerve
V  trigeminal nerve
VII facial nerve
VIII octaval nerve
X  vagal nerve
Figure 5.
Lateral view of the adult zebrafish brain indicating the position of levels illustrated in the following series of cross sections. This series gives a detailed overview of the neuroanatomy of the adult zebrafish brain. Individual sections were not taken at equal intervals but were chosen according to the appearance of novel anatomical structures, beginning from the rostralmost extension of the olfactory bulb and proceeding through the entire brain up to the rostral spinal cord. The section plane of this series is bent slightly rostroventrally rather than corresponding to the ideal vertical axis.
Cross Section 23

ECL: external cellular layer of olfactory bulb including mitral cells
GL: glomerular layer of olfactory bulb
POF: primary olfactory fiber layer

Cross Section 31

ECL: external cellular layer of olfactory bulb including mitral cells
GL: glomerular layer of olfactory bulb
ICL: internal cellular layer of olfactory bulb

200 µm

23

31
Cross Section 50

D  dorsal telencephalic area
ECL  external cellular layer of olfactory bulb including mitral cells
GL  glomerular layer of olfactory bulb
ICL  internal cellular layer of olfactory bulb
LOT  lateral olfactory tract
MOT  medial olfactory tract
TelV  telencephalic ventricle
V  ventral telencephalic area
Vd  dorsal nucleus of V

200 μm
D  dorsal telencephalic area
LOT  lateral olfactory tract
MOT  medial olfactory tract
TeV  telencephalic ventricle
V  ventral telencephalic area
Vc  central nucleus of V
Vd  dorsal nucleus of V
VI  lateral nucleus of V
Vv  ventral nucleus of V
Cantd  commissura anterior, pars dorsalis
D   dorsal telencephalic area
Dc  central zone of D
Dd  dorsal zone of D
Dl  lateral zone of D
Dm  medial zone of D
Dp  posterior zone of D
ENd  entopeduncular nucleus, dorsal part
LOT  lateral olfactory tract
MOT  medial olfactory tract
SY  sulcus ypsiloniformis
TelV  telencephalic ventricle
V   ventral telencephalic area
Vd  dorsal nucleus of V
Vv  ventral nucleus of V
Cross Section 92

Cantd  commissura anterior, pars dorsalis
CanTv  commissura anterior, pars ventralis
D      dorsal telencephalic area
Dc     central zone of D
Dd     dorsal zone of D
DIV    diencephalic ventricle
DI     lateral zone of D
Dm     medial zone of D
Dp     posterior zone of D
ENd    entopeduncular nucleus, dorsal part
ENV    entopeduncular nucleus, ventral part
LFB    lateral forebrain bundle
LOT    lateral olfactory tract
MOT    medial olfactory tract
PPa    paraventricular preoptic nucleus, anterior part
SY     sulcus ypsiloniformis
V      ventral telencephalic area
Vs     supracommissural nucleus of V
D  dorsal telencephalic area
Dc  central zone of D
Dd  dorsal zone of D
DIV  diencephalic ventricle
DI  lateral zone of D
Dm  medial zone of D
Dp  posterior zone of D
ENd  entopeduncular nucleus, dorsal part
ENV  entopeduncular nucleus, ventral part
LFB  lateral forebrain bundle
LOT  lateral olfactory tract
MFB  medial forebrain bundle
NT  nucleus taeniae
PPa  parvocellular preoptic nucleus, anterior part
SY  sulcus ypsiloniformis
TelV  telencephalic ventricle
V  ventral telencephalic area
Vp  postcommissural nucleus of V
Cross Section 107

CO  chiasma opticum
D  dorsal telencephalic area
Dc  central zone of D
Div  diencephalic ventricle
Di  lateral zone of D
Dm  medial zone of D
Dp  posterior zone of D
Env  entopeduncular nucleus, ventral part
LFB  lateral forebrain bundle
MFB  medial forebrain bundle
NT  nucleus taeniae
ON  optic nerve
OT  optic tract
PPa  parvocellular preoptic nucleus, anterior part
TelV  telencephalic ventricle
V  ventral telencephalic area
Vp  postcommissural nucleus of V

200 µm
Cross Section 114

CO  chiasma opticum
D  dorsal telencephalic area
DIV  diencephalic ventricle
DI  lateral zone of D
Dm  medial zone of D
Dp  posterior zone of D
ENv  entopeduncular nucleus, ventral part
LFB  lateral forebrain bundle
MFB  medial forebrain bundle
NT  nucleus taeniae
OT  optic tract
PM  magnocellular preoptic nucleus
PPp  parvocellular preoptic nucleus, posterior part
SC  suprachiasmatic nucleus
TeV  telencephalic ventricle
VM  ventromedial thalamic nucleus
Cross Section 121

Chor  commissura horizontalis  
Cpop  commissura postoptica  
D    dorsal telencephalic area  
DIV  diencephalic ventricle  
Hav  ventral habenular nucleus  
LFB  lateral forebrain bundle  
MFB  medial forebrain bundle  
OT   optic tract  
PMg  gigantocellular part of magnocellular preoptic nucleus  
PPp  parvocellular preoptic nucleus, posterior part  
PSp  parvocellular superficial pretectal nucleus  
SC   suprachiasmatic nucleus  
SD   saccus dorsalis  
VL   ventrolateral thalamic nucleus  
VM   ventromedial thalamic nucleus
Cross Section 125

- Chor: commissura horizontalis
- Cpop: commissura postoptica
- D: dorsal telencephalic area
- DIV: diencephalic ventricle
- DOT: dorosmedial optic tract
- Hav: ventral habenular nucleus
- LFB: lateral forebrain bundle
- MFB: medial forebrain bundle
- PPp: parvocellular preoptic nucleus, posterior part
- PSp: parvocellular superficial pretectal nucleus
- R: rostrolateral nucleus (of Butler & Saidel 91)
- SC: suprachiasmatic nucleus
- SD: saccus dorsalis
- VL: ventrolateral thalamic nucleus
- VM: ventromedial thalamic nucleus
- VOT: ventrolateral optic tract
Cross Section 127

Chor commissura horizontalis
CPN central pretectal nucleus
Cpop commissura postoptica
DAO dorsal accessory optic nucleus
DIV diencephalic ventricle
DOT dorsomedial optic tract
FR fasciculus retroflexus
Hav ventral habenular nucleus
Hv ventral zone of periventricular hypothalamus
I intermediate thalamic nucleus
LFB lateral forebrain bundle
MFB medial forebrain bundle
PPp parvocellular preoptic nucleus, posterior part
PSm magnocellular superficial pretectal nucleus
PSp parvocellular superficial pretectal nucleus
SC suprachiasmatic nucleus
SD saccus dorsalis
TeO tectum opticum
VL ventrolateral thalamic nucleus
VM ventromedial thalamic nucleus
VOT ventrolateral optic tract
A    anterior thalamic nucleus
Chor    commissura horizontalis
CPN    central pretectal nucleus
DAO    dorsal accessory optic nucleus
DIV    diencephalic ventricle
DOT    dorsomedial optic tract
FR    fasciculus retroflexus
Had    dorsal habenular nucleus
Hav    ventral habenular nucleus
Hv    ventral zone of periventricular hypothalamus
LFB    lateral forebrain bundle
MFB    medial forebrain bundle
PPp    parvocellular preoptic nucleus, posterior part
PSm    magnocellular superficial pretectal nucleus
PPSp    parvocellular superficial pretectal nucleus
SD    saccus dorsalis
TeO    tectum opticum
VL    ventrolateral thalamic nucleus
VM    ventromedial thalamic nucleus
VOT    ventrolateral optic tract
Cross Section 136

A  anterior thalamic nucleus
APN accessory prefrontal nucleus (of Wullimann & Meyer 90)
ATN anterior tuberal nucleus
Chab commissura habenularum
Chor commissura horizontalis
CPN central prefrontal nucleus
DAO dorsal accessory optic nucleus
DIV diencaphalic ventricle
DOT dorsomedial optic tract
E  epiphysis
FR fasciculus retroflexus
Had dorsal habenular nucleus
Hav ventral habenular nucleus
Hv ventral zone of periventricular hypothalamus
LFB lateral forebrain bundle
MFB medial forebrain bundle
PGa anterior pregglomerular nucleus
PGi lateral pregglomerular nucleus
PGZ periventricular gray zone of optic tectum
PO posterior prefrontal nucleus (of Wullimann & Meyer 90)
TeO tectum opticum
TPM tractus pretectomamillaris
TPp periventricular nucleus of posterior tuberculum
VAO ventral accessory optic nucleus
VL ventrolateral thalamic nucleus
VM ventromedial thalamic nucleus
VOT ventrolateral optic tract
ZL zona limitans
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<th>Abbreviation</th>
<th>Description</th>
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<td>anterior tuberal nucleus</td>
</tr>
<tr>
<td>Chor</td>
<td>commissura horizontalis</td>
</tr>
<tr>
<td>CP</td>
<td>central posterior thalamic nucleus</td>
</tr>
<tr>
<td>Cpost</td>
<td>commissura posterior</td>
</tr>
<tr>
<td>Ctec</td>
<td>commissura tecti</td>
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<tr>
<td>DIL</td>
<td>diffuse nucleus of the inferior lobe</td>
</tr>
<tr>
<td>DIV</td>
<td>diencephalic ventricle</td>
</tr>
<tr>
<td>DP</td>
<td>dorsal posterior thalamic nucleus</td>
</tr>
<tr>
<td>FR</td>
<td>fasciculus retroflexus</td>
</tr>
<tr>
<td>Hd</td>
<td>dorsal zone of periventricular hypothalamus</td>
</tr>
<tr>
<td>Hv</td>
<td>ventral zone of periventricular hypothalamus</td>
</tr>
<tr>
<td>LFB</td>
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</tr>
<tr>
<td>LH</td>
<td>lateral hypothalamic nucleus</td>
</tr>
<tr>
<td>LR</td>
<td>lateral recess of diencephalic ventricle</td>
</tr>
<tr>
<td>MFB</td>
<td>medial forebrain bundle</td>
</tr>
<tr>
<td>PCN</td>
<td>paracommissural nucleus</td>
</tr>
<tr>
<td>PGI</td>
<td>lateral pregglomerular nucleus</td>
</tr>
<tr>
<td>PGm</td>
<td>medial pregglomerular nucleus</td>
</tr>
<tr>
<td>PGZ</td>
<td>periventricular gray zone of optic tectum</td>
</tr>
<tr>
<td>PPd</td>
<td>periventricular pretectal nucleus, dorsal part</td>
</tr>
<tr>
<td>PPv</td>
<td>periventricular pretectal nucleus, ventral part</td>
</tr>
<tr>
<td>PTN</td>
<td>posterior tuberal nucleus</td>
</tr>
<tr>
<td>SCO</td>
<td>subcommissural organ</td>
</tr>
<tr>
<td>TeO</td>
<td>tectum opticum</td>
</tr>
<tr>
<td>TL</td>
<td>torus longitudinals</td>
</tr>
<tr>
<td>TLa</td>
<td>torus laterals</td>
</tr>
<tr>
<td>TPM</td>
<td>tractus pretectomamillaris</td>
</tr>
<tr>
<td>TPP</td>
<td>periventricular nucleus of posterior tuberculum</td>
</tr>
<tr>
<td>VOT</td>
<td>ventrolateral optic tract</td>
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</table>
Cross Section 162

Chor  commissura horizontalis
Cpost  commissura posterior
Ctecc  commissura tecti
DIL  diffuse nucleus of the inferior lobe
DIV  diencephalic ventricle
FR  fasciculus retroflexus
Hc  caudal zone of periventricular hypothalamus
Hd  dorsal zone of periventricular hypothalamus
LR  lateral recess of diencephalic ventricle
P  posterior thalamic nucleus
PGm  medial preglomerular nucleus
PGZ  periventricular gray zone of optic tectum
Pit  pituitary
PTN  posterior tuberal nucleus
RT  rostral tegmental nucleus (of Grover & Sharma 81)
TeO  tectum opticum
TeV  tectal ventricle
TGN  tertiary gustatory nucleus (of Wullimann 88)
TL  torus longitudinalis
TLa  torus lateralis
TPM  tractus pretectomammillaris
TPp  periventricular nucleus of posterior tuberculum
TS  torus semicircularis
VOT  ventrolateral optic tract
CIL  central nucleus of the inferior lobe
CM   corpus mammillare
Ctec  commissura tecti
Ctub  commissure of the posterior tuberculum
DIL  diffuse nucleus of the inferior lobe
DTN  dorsal tegmental nucleus
EW   Edinger-Westphal nucleus
FR   fasciculus retroflexus
Hc   caudal zone of periventricular hypothalamus
Hd   dorsal zone of periventricular hypothalamus
LLF  lateral longitudinal fascicle
LR   lateral recess of diencephalic ventricle
MLF  medial longitudinal fascicle
NMLF nucleus of MLF
PGc  caudal preglomerular nucleus
PGZ  periventricular gray zone of optic tectum
Pit  pituitary
PR   posterior recess of diencephalic ventricle
TeO  tectum opticum
TeV  tectal ventricle
TL   torus longitudinalis
TLa  torus lateralis
TPM  tractus pretectomamillaris
TSc  central nucleus of torus semicircularis
TSvl ventrolateral nucleus of torus semicircularis
TTB  tractus tectobulbaris
Val  lateral division of valvula cerebelli
Vas  vascular lacuna of area postrema
CIL  central nucleus of the inferior lobe
CM  corpus mamillare
Ctec  commissura tecti
DIL  diffuse nucleus of the inferior lobe
DTN  dorsal tegmental nucleus
Hd  dorsal zone of periventricular hypothalamus
LLF  lateral longitudinal fascicle
LR  lateral recess of diencephalic ventricle
MLF  medial longitudinal fascicle
Nin  nucleus interpuduncularis
NLL  nucleus of the lateral lemniscus (of Prasada Rao et al. 87)
NLV  nucleus lateralis valvulae
NIII  oculomotor nucleus

POZ  periventricular gray zone of optic tectum
PL  perilemmiscal nucleus
TeO  tectum opticum
TeV  tectal ventricle
TL  torus longitudinallis
TLa  torus lateralis
TMCa  tractus mesencephalocerebellaris anterior
TSc  central nucleus of torus semicircularis
TSvl  ventrolateral nucleus of torus semicircularis
TTB  tractus tectobulbaris
TTBc  tractus tectobulbaris cruciatus
Val  lateral division of valvula cerebelli
Vam  medial division of valvula cerebelli
Cross Section 201

AC  anterior cerebellar tract
CteC  commissura tecti
Cven  commissura ventralis rhombencephali
DIL  diffuse nucleus of the inferior lobe
GC  griseum centrale
LLF  lateral longitudinal fascicle
MLF  medial longitudinal fascicle
NLV  nucleus lateralis valvulae
PGZ  periventricular gray zone of optic tectum
RV  rhombencephalic ventricle
SR  superior raphe
SRF  superior reticular formation
TeO  tectum opticum
TL  torus longitudinalis
TSc  central nucleus of torus semicircularis
TSvl  ventrolateral nucleus of torus semicircularis
TTB  tractus tectobulbaris
TTBc  tractus tectobulbaris cruciatus
TTBr  tractus tectobulbaris rectus
Val  lateral division of valvula cerebelli
Vam  medial division of valvula cerebelli
IV  trochlear nerve
Cross Section 208

AC    anterior cerebellar tract
CCe   corpus cerebelli
Cven  commissura ventris rhombencephali
GC    griseum centrale
LLF   lateral longitudinal fascicule
MLF   medial longitudinal fascicule
NI    nucleus isthmi
NLV   nucleus lateralis valvulae
Nfmd  trigeminal motor nucleus, dorsal part
PGZ   periventricular gray zone of optic tectum
RV    rhombencephalic ventricle
SR    superior raphe
SRF   superior reticular formation
TeO   tectum opticum
TSc   central nucleus of torus semicircularis
TSvl  ventrolateral nucleus of torus semicircularis
TTB   tractus tectobulbaris
TTBc  tractus tectobulbaris cruciatus
TTBr  tractus tectobulbaris rectus
Varm  medial division of valvula cerebelli
IF    trochlear nerve
Cross Section 219

ALLN  anterior lateral line nerves
CCe   corpus cerebelli
Ccer  commissura cerebelli
Cven  commissura ventralis rhombencephali
EG    eminencia granularis
GC    griseum centrale
LLF   lateral longitudinal fascicle
MLF   medial longitudinal fascicle
NTmd  trigeminal motor nucleus, dorsal part
NTmv  trigeminal motor nucleus, ventral part
Nfs   primary sensory trigeminal nucleus

PC    posterior cerebellar tract
PGZ   periventricular gray zone of optic tectum
RV    rhombencephalic ventricle
SGT   secondary gustatory tract
SRF   superior reticular formation
TeO   tectum opticum
TTBc  tractus tectobulbaris cruciatus
TTBr  tractus tectobulbaris rectus
Vmd   dorsal motor root of the trigeminal nerve
Vs    sensory root of the trigeminal nerve
VII   facial nerve
Cross Section 223

ALLN  anterior lateral line nerves
AON  anterior octaval nucleus
CCe  corpus cerebelli
Cven  commissura ventralis rhombencephali
DF  descending trigeminal root
EG  eminentia granularis
GC  griseum centrale
LLF  lateral longitudinal fascicle
MLF  medial longitudinal fascicle
NTmv  trigeminal motor nucleus, ventral part
PC  posterior cerebellar tract
PGZ  periventricular gray zone of optic tectum
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
SRF  superior reticular formation
TeO  tectum opticum
TTBc  tractus tectobulbaris cruciatus
TTBr  tractus tectobulbaris rectus
Trm  ventral motor root of the trigeminal nerve
Tr  rostral root of the abducens nerve
VII  facial nerve
Cross Section 230

ALLN  anterior lateral line nerves
AON  anterior octaval nucleus
CCe  corpus cerebelli
Cven  commissura ventralis rhombencephali
DT  descending trigeminal root
EG  eminentia granularis
IMRF  intermediate reticular formation
LCa  lobus caudalis cerebelli
MAC  Mauthner cell
MLF  medial longitudinal fascicle
MON  medial octavolateralis nucleus
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
TeO  tectum opticum
TTBc  tractus tectobulbaris cruciatus
TTBr  tractus tectobulbaris rectus
VIIIs  sensory root of the facial nerve
VIII  octaval nerve
Cross Section 239

ALLN  anterior lateral line nerves
CC  crista cerebellaris
CCe  corpus cerebelli
Cven  commissura ventralis
rhombencephali
DON  descending octaval nucleus
DV  descending trigeminal root
EG  eminentia granularis
IAF  inner arcuate fibers
IMRF  intermediate reticular formation
LCa  lobus caudalis cerebelli
MA  Mauthner axon
MaON  magnocellular octaval nucleus
MLF  medial longitudinal fascicle
MON  medial octavolateralis nucleus
NDV  nucleus of the descending trigeminal root
NVc  abducens nucleus, caudal part
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
SO  secondary octaval population (of McCormick & Hernandez 95)
T  tangential nucleus
VIIis  sensory root of the facial nerve
VIII  octaval nerve
CC  crista cerebellaris
CCe  corpus cerebelli
Cven  commissura ventralis rhombencephali
DON  descending octaval nucleus
DV  descending trigeminal root
IMRF  intermediate reticular formation
LCa  lobus caudalis cerebelli
MA  Mauthner axon
MLF  medial longitudinal fascicle
MON  medial octavolateralis nucleus
NDV  nucleus of the descending trigeminal root
NTIIIm  facial motor nucleus
PLLN  posterior lateral line nerve
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
VIIIs  sensory root of the facial nerve
VIII  octaval nerve
Cross Section 260

CC  crista cerebellaris
DON  descending octaval nucleus
DV  descending trigeminal root
IMRF  intermediate reticular formation
LCa  lobus caudalis cerebelli
LVII  lobus facialis
MA  Mauthner axon
MLF  medial longitudinal fascicle
MON  medial octavolateralis nucleus
NDF  nucleus of the descending trigeminal root
PLLN  posterior lateral line nerve
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
TBS  tractus bulbospinalis
VIIa  sensory root of the facial nerve
VIII  octaval nerve
Crista cerebellaris
Caudal octavolateralis nucleus
Commissura ventralis rhombencephali
Descending octaval nucleus
Descending trigeminal root
Olive inferior
Interior raphe
Interior reticular formation
Lobus facialis
Lobus glossofaryngeus
Mauthner axon
Medial longitudinal fascicle
Posterior lateral line nerve
Rhombencephalic ventricle
Secondary gustatory tract
Tractus bulbo-spinalis
Tractus vestibulospinalis
Octaval nerve
Glossopharyngeal nerve
Cross Section 279

CC  crista cerebellaris
CON  caudal octavolateralis nucleus
DT  descending trigeminal root
IAF  inner arcuate fibers
IO  oliva inferior
IR  inferior raphe
IRF  inferior reticular formation
LRN  lateral reticular nucleus
LXII  lobus facialis
LX  lobus vagus
MA  Mauthner axon
MLF  medial longitudinal fascicle
NXm  vagal motor nucleus
PON  posterior octavolateral nucleus
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
TBS  tractus bulbo spinalis
TVS  tractus vestibulospinalis
X  vagal nerve
Cross Section 290

DV descending trigeminal root
IO inferior olive
IR inferior raphe
IRF inferior reticular formation
LX lobeus vagus
MA Mauthner axon
MLF medial longitudinal fascicle
NMv vagal motor nucleus
RV rhombencephalic ventricle
SGT secondary gustatory tract
TBS tractus bulbospinalis
TVS tractus vestibulospinalis

X vagal nerve
Cross Section 303

DV  descending trigeminal root
FV  funiculus lateralis pars ventralis
Fv  funiculus ventralis
IRF inferior reticular formation
LX  lobe vagus
MA  Mauthner axon
MFN  medial funicular nucleus
MLF  medial longitudinal fascicle
Nxm  vagal motor nucleus
RV  rhombencephalic ventricle
SGT  secondary gustatory tract
TBS  tractus bulbospinalis
Figure 6.
Dorsal view of the adult zebrafish brain illustrating the position of levels shown in the series of sagittal sections. The series of sagittal sections shown on the following pages proceeds at irregular intervals from lateral to medial, giving an overview of the topological organization of the left half of the adult zebrafish brain. However, as the section plane does not correspond to the ideal longitudinal axis but deviates to the right side at rostral levels and to the left at caudal levels, neither section 46 nor section 53 represents a perfect midsagittal section.
Sagittal Section 1

ALLN  anterior lateral line nerves
D   dorsal telencephalic area
DI  lateral zone of D
Dp  posterior zone of D
EG  eminencia granularis
PGZ periventricular gray zone of optic tectum
TeO  tectum opticum
TeV  tectal ventricle
TLa  torus lateralis
TSvi ventrolateral nucleus of torus semicircularis
TTB  tractus tectobulbaris
VOT  ventrolateral optic tract

III  oculomotor nerve
IV  trochlear nerve
V  trigeminal nerve
VII facial nerve
### Sagittal Section 9

<table>
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<th>Abbreviation</th>
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<tr>
<td>ALLN</td>
<td>anterior lateral line nerves</td>
</tr>
<tr>
<td>CCe</td>
<td>corpus cerebelli</td>
</tr>
<tr>
<td>Ccer</td>
<td>commissura cerebelli</td>
</tr>
<tr>
<td>CPN</td>
<td>central pretectal nucleus</td>
</tr>
<tr>
<td>D</td>
<td>dorsal telencephalic area</td>
</tr>
<tr>
<td>DIL</td>
<td>diffuse nucleus of the inferior lobe</td>
</tr>
<tr>
<td>DI</td>
<td>lateral zone of D</td>
</tr>
<tr>
<td>Dp</td>
<td>posterior zone of D</td>
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<td>EG</td>
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<td>lateral olfactory tract</td>
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<td>NI</td>
<td>nucleus isthmi</td>
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<tr>
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<td>nucleus lateralis valvulae</td>
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<tr>
<td>NT</td>
<td>nucleus taeniae</td>
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<td>PGI</td>
<td>lateral preglomerular nucleus</td>
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<tr>
<td>PGZ</td>
<td>periventricular gray zone of optic tectum</td>
</tr>
<tr>
<td>PL</td>
<td>perilemniscal nucleus</td>
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<tr>
<td>PSm</td>
<td>magnocellular superficial pretectal nucleus</td>
</tr>
<tr>
<td>PSp</td>
<td>parvocellular superficial pretectal nucleus</td>
</tr>
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<td>tectum opticum</td>
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<td>TLa</td>
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<td>TSc</td>
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<tr>
<td>TSvl</td>
<td>ventrolateral nucleus of torus semicircularis</td>
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<td>TTB</td>
<td>tractus tectobulbaris</td>
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<tr>
<td>VOT</td>
<td>ventrolateral optic tract</td>
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<tr>
<td>III</td>
<td>oculomotor nerve</td>
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<tr>
<td>IT</td>
<td>trochlear nerve</td>
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<tr>
<td>Ts</td>
<td>sensory root of the trigeminal nerve</td>
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<tr>
<td>VII s</td>
<td>sensory root of the facial nerve</td>
</tr>
<tr>
<td>VIII</td>
<td>octaval nerve</td>
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</table>
Sagittal Section 15

ALLN  anterior lateral line nerves
AON  anterior octaval nucleus
CC  crista cerebellaris
CCe  corpus cerebelli
Ccer  commissura cerebelli
Chor  commissura horizontalis
CIL  central nucleus of the inferior lobe
CPN  central pretectal nucleus
D  dorsal telencephalic area
DAO  dorsal accessory optic nucleus
Dc  central zone of D
DIL  diffuse nucleus of the inferior lobe
DI  lateral zone of D
Dp  posterior zone of D
DTN  dorsal tegmental nucleus
EG  eminencia granularis
GL  glomerular layer of olfactory bulb

LFB  lateral forebrain bundle
LLF  lateral longitudinal fascicle
LOT  lateral olfactory tract
MaON  magnocellular octaval nucleus
MON  medial octavalateralis nucleus
NI  nucleus isthmi
NLV  nucleus lateralis valvulae
NT  nucleus taeniae

ON  optic nerve
PGa  anterior pregglomerular nucleus
PGl  lateral pregglomerular nucleus
PGm  medial pregglomerular nucleus
PGZ  periventricular gray zone of optic tectum
PLLN  posterior lateral line nerve
POF  primary olfactory fiber layer
PSm  magnocellular superficial pretectal nucleus

PSp  parvocellular superficial pretectal nucleus
TeO  tectum opticum
TeV  tectal ventricle
TLa  torus lateralis
TS  torus semicircularis
TTB  tractus tectobulbaris
TTBr  tractus tectobulbaris rectus
V  ventral telencephalic area
Val  lateral division of valvula cerebelli
VI  lateral nucleus of V
VOT  ventrolateral optic tract

III  oculomotor nerve
IV  trochlear nerve
Vs  sensory root of the trigeminal nerve
VIIIs  sensory root of the facial nerve
VIII  octaval nerve
| AC | anterior cerebellar tract  |
| APN | accessory pretectal nucleus  |
| (of Wullimann & Meyer 90) |  |
| CC | crista cerebellaris  |
| CCe | corpus cerebelli  |
| Cce | commissura cerebelli  |
| Chor | commissura horizontalis  |
| CIL | central nucleus of the inferior lobe  |
| CON | caudal octavolateralis nucleus  |
| Cpost | commissura posterior  |
| D | dorsal telencephalic area  |
| DAO | dorsal accessory optic nucleus  |
| Dc | central zone of D  |
| Dd | dorsal zone of D  |
| DIL | diffuse nucleus of the inferior lobe  |
| DI | lateral zone of D  |
| DON | descending octaval nucleus  |
| DOT | dorsomedial optic tract  |
| Dp | posterior zone of D  |
| DTN | dorsal tegmental nucleus  |
| DF | descending trigeminal root  |
| ECL | external cellular layer of olfactory bulb including mitral cells  |
| ENd | entopeduncular nucleus, dorsal part  |
| ENv | entopeduncular nucleus, ventral part  |
| GL | glomerular layer of olfactory bulb  |
| Hd | dorsal zone of periventricular hypothalamus  |
| ICL | internal cellular layer of olfactory bulb  |
| LCa | lobus caudalis cerebelli  |
| LFB | lateral forebrain bundle  |
| LLF | lateral longitudinal fascicle  |
| LR | lateral recess of diencephalic ventricle  |
| LX | vagal lobe  |
| MaON | magnocellular octaval nucleus  |
| MON | medial octavolateralis nucleus  |
| NLV | nucleus lateralis valvulae  |
| NFMd | trigeminal motor nucleus, dorsal part  |
| NFMv | trigeminal motor nucleus, ventral part  |
| ON | optic nerve  |
| PC | posterior cerebellar tract  |
| PGA | anterior preglomerular nucleus  |
| PGI | lateral preglomerular nucleus  |
| PGm | medial preglomerular nucleus  |
| PGZ | periventricular grey zone of optic tectum  |
| PO | posterior pretectal nucleus (of Wullimann & Meyer 90)  |
| POF | primary olfactory fiber layer  |
| RT | rostral tegmental nucleus (of Grover & Sharma 81)  |
| SG | subglomerular nucleus  |
| SGN | secondary gustatory nucleus  |
| SGT | secondary gustatory tract  |
| TBS | tractus bulbospinalis  |
| TeO | tectum opticum  |
| TeV | tectal ventricle  |
| TMCA | tractus mesencephalocerebellaris anterior  |
| TMCP | tractus mesencephalocerebellaris posterior  |
| TPM | tractus pretectomamillaris  |
| TTB | tractus tectobulbairis  |
| V | ventral telencephalic area  |
| Val | lateral division of valvula cerebelli  |
| VI | lateral nucleus of V  |
| VOT | ventrolateral optic tract  |
| III | oculomotor nerve  |
| IV | trochlear nerve  |
| VII | sensory root of the facial nerve  |
Sagittal Section 34

A  anterior thalamic nucleus
ATN  anterior tuberal nucleus
Cans  commissura ansulata
Cantd  commissura anterior, pars dorsalis
Cantv  commissura anterior, pars ventralis
CC  crista cerebellaris
CCE  corpus cerebelli
Ccer  commissura cerebelli
Cgus  commissure of the secondary gustatory nuclei
Chor  commissura horizontalis
CM  corpus mamillare
CP  central posterior thalamic nucleus
Cpop  commissura postoptica
Cpost  commissura posterior
Ctec  commissura tecti
Cven  commissura ventralis rhombencephali
D  dorsal telencephalic area
Dc  central zone of D
DIL  diffuse nucleus of the inferior lobe
Dm  medial zone of D
Dp  posterior zone of D
DP  dorsal posterior thalamic nucleus
DIW  trocheal decussation
Dv  descending trigeminal root
ECL  external cellular layer of olfactory bulb including mitral cells
FR  fasciculus retroflexus
GC  griseum centrale
GL  glomeral layer of olfactory bulb
Ha  habenula
Hc  caudal zone of periventricular hypothalamus
Hd  dorsal zone of periventricular hypothalamus
ICL  internal cellular layer of olfactory bulb
IMRF  intermediate reticular formation
IO  oliva inferior
IRF  inferior reticular formation
LCA  lobus caudalis cerebelli
LFB  lateral forebrain bundle
LH  lateral hypothalamic nucleus
LLF  lateral longitudinal fascicle
LR  lateral recess of diencephalic ventricle
LX  vagal lobe
MFB  medial forebrain bundle
MFN  medial funicular nucleus
MON  medial octavolateralis nucleus
MOT  medial olfactory tract
NLV  nucleus lateralis valvulae
ON  optic nerve
OT  optic tract
PGZ  periventricular gray zone of optic tectum
POF  primary olfactory fiber layer
PPa  parvocellular preoptic nucleus, anterior part
PPv  periventricular pretectal nucleus, ventral part
PR  posterior recess of diencephalic ventricle
PTN  posterior tuberal nucleus
SO  secondary octaval population (of McCormick & Hernandez 95)
SRF  superior reticular formation
TBS  tractus bulbo spinalis
TeO  tectum opticum
TeV  tectal ventricle
TL  torus longitudinalis
TPp  periventricular nucleus of posterior tuberculum
TVS  tractus vestibulospinalis
V  ventral telencephalic area
Val  lateral division of valvula cerebelli
Vam  medial division of valvula cerebelli
Vd  dorsal nucleus of V
Vp  postcommisural nucleus of V
Vs  supracommissural nucleus of V
VT  ventral thalamus
Vv  ventral nucleus of V
III  oculomotor nerve
VII  sensory root of the facial nerve
### Sagittal Section 46

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cans</td>
<td>commissura anulata</td>
</tr>
<tr>
<td>Cantd</td>
<td>commissura anterior, pars dorsalis</td>
</tr>
<tr>
<td>Cantv</td>
<td>commissura anterior, pars ventralis</td>
</tr>
<tr>
<td>CC</td>
<td>crista cerebellaris</td>
</tr>
<tr>
<td>CCe</td>
<td>corpus cerebelli</td>
</tr>
<tr>
<td>Ccer</td>
<td>commissura cerebelli</td>
</tr>
<tr>
<td>Cgus</td>
<td>commissure of the secondary gustatory nuclei</td>
</tr>
<tr>
<td>Chab</td>
<td>commissura habenularum</td>
</tr>
<tr>
<td>Chor</td>
<td>commissura horizontalis</td>
</tr>
<tr>
<td>Cinf</td>
<td>commissura infima of Haller</td>
</tr>
<tr>
<td>CM</td>
<td>corpus mamillare</td>
</tr>
<tr>
<td>Cpop</td>
<td>commissura postoptica</td>
</tr>
<tr>
<td>Cpost</td>
<td>commissura posterior</td>
</tr>
<tr>
<td>Ctec</td>
<td>commissura tecti</td>
</tr>
<tr>
<td>Ctub</td>
<td>commissure of the posterior tuberculum</td>
</tr>
<tr>
<td>Cven</td>
<td>commissura ventralis rhombencephali</td>
</tr>
<tr>
<td>D</td>
<td>dorsal telencephalic area</td>
</tr>
<tr>
<td>Dc</td>
<td>central zone of D</td>
</tr>
<tr>
<td>DIL</td>
<td>diffuse nucleus of the inferior lobe</td>
</tr>
<tr>
<td>DIV</td>
<td>diencephalic ventricle</td>
</tr>
<tr>
<td>Dm</td>
<td>medial zone of D</td>
</tr>
<tr>
<td>DON</td>
<td>descending octaval nucleus</td>
</tr>
<tr>
<td>Dp</td>
<td>posterior zone of D</td>
</tr>
<tr>
<td>DT</td>
<td>dorsal thalamus</td>
</tr>
<tr>
<td>DIV</td>
<td>trochlear decussation</td>
</tr>
<tr>
<td>DF</td>
<td>descending trigeminal root</td>
</tr>
<tr>
<td>E</td>
<td>ephiphysis</td>
</tr>
<tr>
<td>ECL</td>
<td>external cellular layer of olfactory bulb including mitral cells</td>
</tr>
<tr>
<td>GC</td>
<td>griseum centrale</td>
</tr>
<tr>
<td>GL</td>
<td>glomerular layer of olfactory bulb</td>
</tr>
<tr>
<td>Ha</td>
<td>habenula</td>
</tr>
<tr>
<td>Hc</td>
<td>caudal zone of periventricular hypothalamus</td>
</tr>
<tr>
<td>Hv</td>
<td>ventral zone of periventricular hypothalamus</td>
</tr>
<tr>
<td>ICL</td>
<td>internal cellular layer of olfactory bulb</td>
</tr>
<tr>
<td>IMRF</td>
<td>intermediate reticular formation</td>
</tr>
<tr>
<td>IRF</td>
<td>inferior reticular formation</td>
</tr>
<tr>
<td>LCa</td>
<td>lobus caudalis cerebelli</td>
</tr>
<tr>
<td>LII</td>
<td>facial lobe</td>
</tr>
<tr>
<td>LX</td>
<td>vagal lobe</td>
</tr>
<tr>
<td>MA</td>
<td>Mauthner axon</td>
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<tr>
<td>MLF</td>
<td>medial longitudinal fascicle</td>
</tr>
<tr>
<td>MOT</td>
<td>medial olfactory tract</td>
</tr>
<tr>
<td>NC</td>
<td>commissural nucleus of Cajal</td>
</tr>
<tr>
<td>NIp</td>
<td>nucleus interpeduncularis</td>
</tr>
<tr>
<td>NMLF</td>
<td>nucleus of the MLF</td>
</tr>
<tr>
<td>NIII</td>
<td>oculomotor nucleus</td>
</tr>
<tr>
<td>NIm</td>
<td>vagal motor nucleus</td>
</tr>
<tr>
<td>ON</td>
<td>optic nerve</td>
</tr>
<tr>
<td>PGZ</td>
<td>periventricular gray zone of optic tectum</td>
</tr>
<tr>
<td>PM</td>
<td>magnocellular preoptic nucleus</td>
</tr>
<tr>
<td>PMg</td>
<td>giganto cellular part of magnocellular preoptic nucleus</td>
</tr>
<tr>
<td>POF</td>
<td>primary olfactory fiber layer</td>
</tr>
<tr>
<td>PPa</td>
<td>parvo cellular preoptic nucleus, anterior part</td>
</tr>
<tr>
<td>PPp</td>
<td>parvo cellular preoptic nucleus, posterior part</td>
</tr>
<tr>
<td>PPv</td>
<td>periventricular pretectal nucleus, ventral part</td>
</tr>
<tr>
<td>PR</td>
<td>posterior recess of diencephalic ventricle</td>
</tr>
<tr>
<td>PTN</td>
<td>posterior tuberal nucleus</td>
</tr>
<tr>
<td>RV</td>
<td>rhombencephalic ventricle</td>
</tr>
<tr>
<td>SD</td>
<td>saccus dorsalis</td>
</tr>
<tr>
<td>SR</td>
<td>superior raphe</td>
</tr>
<tr>
<td>SRF</td>
<td>superior reticular formation</td>
</tr>
<tr>
<td>TBS</td>
<td>tractus bulbospinalis</td>
</tr>
<tr>
<td>TeO</td>
<td>tectum opticum</td>
</tr>
<tr>
<td>TeV</td>
<td>tectal ventricle</td>
</tr>
<tr>
<td>TL</td>
<td>torus longitudinalis</td>
</tr>
<tr>
<td>TPp</td>
<td>periventricular nucleus of posterior tuberculum</td>
</tr>
<tr>
<td>TTBc</td>
<td>tractus tectobulbaris cruciatus</td>
</tr>
<tr>
<td>V</td>
<td>ventral telencephalic area</td>
</tr>
<tr>
<td>Vam</td>
<td>medial division of valvula cerebelli</td>
</tr>
<tr>
<td>Vas</td>
<td>vascular lacuna of area postrema</td>
</tr>
<tr>
<td>Vd</td>
<td>dorsal nucleus of V</td>
</tr>
<tr>
<td>Vp</td>
<td>postcommisural nucleus of V</td>
</tr>
<tr>
<td>Vs</td>
<td>supracommissural nucleus of V</td>
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<tr>
<td>VT</td>
<td>ventral thalamus</td>
</tr>
<tr>
<td>Vv</td>
<td>ventral nucleus of V</td>
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<tr>
<td>ZL</td>
<td>zona limitans</td>
</tr>
<tr>
<td>III</td>
<td>oculomotor nerve</td>
</tr>
</tbody>
</table>
Sagittal Section 53

A  anterior thalamic nucleus
C  central canal
Cans  commissura ansalata
Cantd  commissura anterior, pars dorsalis
Cantv  commissura anterior, pars ventralis
CC  crista cerebellaris
CCE  corpus cerebelli
Ccer  commissura cerebelli
Cgus  commissure of the secondary gustatory nuclei
Chab  commissura habenularum
Chor  commissura horizontalis
Cinf  commissura infima of Haller
CM  corpus mamillare
CO  chiasma opticum
CP  central posterior thalamic nucleus
Cpop  commissura postoptica
Cpost  commissura posterior
Ctec  commissura tecti
Ctub  commissure of the posterior tuberculum
Cven  commissura ventralis rhombencephali
D  dorsal telencephalic area
Dc  central zone of D
Dd  dorsal zone of D
DH  dorsal horn
DIL  diffuse nucleus of the inferior lobe
DIV  diencephalic ventricle
DM  medial zone of D
DON  descending octaval nucleus
DP  posterior zone of D
DP  dorsal posterior thalamic nucleus
DIV  troclear decussation
E  epiphysis
ECL  external cellular layer of olfactory bulb including mitral cells
FR  fasciculus retroflexus
GC  griseum centrale
GL  glomerular layer of olfactory bulb
Ha  habenula
HC  caudal zone of periventricular hypothalamus
HV  ventral zone of periventricular hypothalamus
ICL  internal cellular layer of olfactory bulb
IMRF  intermediate reticular formation
LCa  lobus caudalis cerebelli
LTV  facial lobe
LT  vagal lobe
MFB  medial forebrain bundle
MLF  medial longitudinal fascicle
MOT  medial olfactory tract
NC  commissural nucleus of Cajal
NIP  nucleus interpeduncularis
NMLF  nucleus of the MLF
NIII  oculomotor nucleus
NIV  trochlear nucleus
NIVm  facial motor nucleus
NEm  vagal motor nucleus
ON  optic nerve
PGZ  periventricular gray zone of optic tectum
POF  primary olfactory fiber layer
PPa  parvo cellular preoptic nucleus, anterior part
PPp  parvo cellular preoptic nucleus, posterior part
PPv  periventricular pretectal nucleus, ventral part
PR  posterior recess of diencephalic ventricle
PTN  posterior tuberal nucleus
RV  rhombencephalic ventricle
SC  suprachiasmatic nucleus
SD  saccus dorsalis
SO  secondary octaval population
(T of McCormick & Hernandez 95)
SRF  superior reticular formation
TeO  tectum opticum
TeV  telencephalic ventricle
TL  torus longitudinalis
TPp  periventricular nucleus of posterior tuberculum
TTBc  tractus tectobulbaris cruciatus
V  ventral telencephalic area
Val  lateral division of valvula cerebelli
Vam  medial division of valvula cerebelli
Vc  central nucleus of V
VI  lateral nucleus of V
VS  supracommissural nucleus of V
VT  ventral thalamus
Vv  ventral nucleus of V
III  oculomotor nerve
VII  sensory root of the facial nerve
Figure 7.
Lateral view of the adult zebrafish brain demonstrating the position of levels shown in the series of horizontal sections. The selection of horizontal sections shown on the following pages does not include the most dorsal and ventral aspects of the brain. With regard to the spinal cord, the section plane of this series almost corresponds to the ideal horizontal axis.
APN  accessory pretectal nucleus (of Wullimann & Meyer 90)
CC  crista cerebellaris
CCe  corpus cerebelli
Cgus  commissure of the secondary gustatory nuclei
CP  central posterior thalamic nucleus
DIV  diencephalic ventricle
DOT  dorsomedial optic tract
DP  dorsal posterior thalamic nucleus
ECL  external cellular layer of olfactory bulb including mitral cells
EG  eminentia granularis
ENV  entopeduncular nucleus, ventral part
FR  fasciculus retroflexus
GC  griseum centrale
GL  glomerular layer of olfactory bulb
LCA  lobus caudalis cerebelli
LFB  lateral forebrain bundle
LLF  lateral longitudinal fascicle
LX  vagal lobe
MLF  medial longitudinal fascicle
NLV  nucleus lateralis valvulae
NMLF  nucleus of the medial longitudinal fascicle
NTV  trochlear nucleus
PC  posterior cerebellar tract
PGZ  periventricular gray zone of optic tectum
PM  magno cellular preoptic nucleus
PO  posterior pretectal nucleus (of Wullimann & Meyer 90)
POF  primary olfactory fiber layer
PPa  parvocellular preoptic nucleus, anterior part
PPv  periventricular pretectal nucleus, ventral part
PSm  magnocellular superficial pretectal nucleus
PSp  parvocellular superficial pretectal nucleus
RV  rhombencephalic ventricle
SGN  secondary gustatory nucleus
TelV  telencephalic ventricles
TeO  tectum opticum
TeV  tectal ventricle
TSVl  ventrolateral nucleus of torus semicircularis
V  ventral telencephalic area
Vam  medial division of valvula cerebelli
VI  lateral nucleus of V
VL  ventrolateral thalamic nucleus
VM  ventromedial thalamic nucleus
Vv  ventral nucleus of V
IV  trochlear nerve
ALLN  anterior lateral line nerves
AON  anterior octaval nucleus
Chor  commissura horizontalis
CON  caudal octavolateralis nucleus
Cven  commissura ventralis rhombencephali
DIV  diencephalic ventricle
DON  descending octaval nucleus
DOT  dorsomedial optic tract
FR  fasciculus retroflexus
GC  griseum centrale
LLF  lateral longitudinal fascicle
LVI  facial lobe
LX  vagal lobe
MFN  medial funicular nucleus
MLF  medial longitudinal fascicle
MON  medial octavolateralis nucleus
NC  commissural nucleus of Cajal
NIn  nucleus interpeduncularis
NTmd  trigeminal motor nucleus, dorsal part
PGZ  periventricular gray zone of optic tectum
PLLN  posterior lateral line nerve
PPa  parvoocular preoptic nucleus, anterior part
PPp  parvoocular preoptic nucleus, posterior part
RV  rhombencephalic ventricle
SC  suprachiasmatic nucleus
SO  secondary octaval population
(of McCormick & Hernandez 95)
SR  superior raphe
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TeO  tectum opticum
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TPp  periventricular nucleus of posterior tuberculum
TTB  tractus tectobulbaris
VOT  ventrolateral optic tract
III  oculomotor nerve
Vp  sensory root of the trigeminal nerve
VII  sensory root of the facial nerve
X  vagal nerve