Neural markers guide
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The markers shown in the guide are suggestions based on commonly used markers in published literature. There is often overlap in markers between different cell types, therefore we advise combining multiple markers and observing ultrastructural features where possible.
Neuroepithelial (NE) cells are symmetrically dividing cells that form the neural plate and neural tube during embryonic development. They exhibit typical epithelial features such as tight junctions and are highly polarized along their apical-basal axis.

Nestin
An intermediate filament protein expressed in NE cells. Its expression persists in radial glia until astrocyte development.

Neural progenitor cells derived from human iPSCs stained with anti-nestin (red) (ab105389).

SOX2
A transcription factor and the earliest marker of the neural plate. It is expressed in proliferating cells and those that acquire glial fates, but downregulated in post-mitotic neurons.

E13 mouse spinal cord sections stained with anti-SOX2 (ab97959).

Notch1
A transmembrane receptor that regulates the formation, migration, and differentiation of neural crest cells.

Mouse embryo tissue sections stained with anti-notch1 (green) (ab65297).

HES1 and HES3
Transcription factors that maintain the symmetrical cell division of NE cells. When NE cells become radial glia, HES3 is downregulated and HES5 is upregulated.

Mouse NIH3T3 cells stained with anti-HES1 (green) (ab71559).

E-cadherin and occludin
Cell-cell junction proteins that are lost after neural tube closure, prior to neurogenesis.

Human pluripotent stem cells stained with anti-E-cadherin (ab40772).

SOX10
A transcription factor present in migrating neural crest cells.

A375 cells stained with anti-SOX10 (ab155279)
Radial glia

During neurogenesis, neuroepithelial (NE) cells transform into radial glia. Epithelial features such as tight junctions are downregulated in favor of adherens junctions. Glial hallmarks begin to emerge, including astrocyte markers and morphological features such as glycogen granules.

**Vimentin and nestin**
Intermediate filament proteins whose expression persists until astrocyte development. Nestin is also found in NE cells, whilst vimentin occurs during the epithelial-to-mesenchymal transition (EMT) of NE cells to radial glia.

*Rhesus monkey brain tissue sections stained with anti-vimentin (ab92547).*

**PAX6**
A transcription factor that promotes neurogenesis.

*Mouse embryonic (E12.5) brain sections stained with anti-PAX6 (ab5790).*

**HES1 and HES5**
Transcription factors that regulate the maintenance of radial glia.

*Mouse brain tissue sections stained with anti-HES5 (red) (ab25374).*

**Astrocytic markers: GFAP, GLAST, and BLBP**
These astrocytic markers emerge as neuroepithelial cells become radial glia.

*Rat embryonic (E16) spinal cord sections stained with anti-BLBP (ab32423).*

**Adhesion and extracellular matrix molecules: TN-C and N-cadherin**
Upregulation of adhesion and extracellular matrix proteins accompanies the transformation of NE cells into radial glia.

*Mouse embryonic coronal cortical section stained with anti-N-cadherin (red) (ab76011).*

**SOX2**
A transcription factor and the earliest marker of the neural plate. It is expressed in proliferating cells and those that acquire glial fates, but downregulated in post-mitotic neurons.

*Chicken embryonic (E7) brain tissue sections stained with anti-SOX2 (ab97959).*
Immature neurons and intermediate progenitors

Radial glia divide asymmetrically to produce one radial glia cell and one intermediate progenitor cell (IPC). IPCs differentiate into post-mitotic immature neurons, which migrate to their final destination in the nervous system and integrate into the neuronal network.

Intermediate progenitors

**TBR2**
A transcription factor whose expression marks the transition from radial glia to intermediate progenitors.

*Embryonic (E15) mouse cortical sections stained with anti-TBR2 (red) (ab23345).*

**MASH1 (Ascl1)**
A transcription factor essential for neural differentiation. It can also label active neural stem cells.

*Mouse subventricular zone tissue sections stained with anti-MASH1 (ab74065).*

Immature neurons

**Doublecortin and beta III tubulin**
Doublecortin is a microtubule-associated phosphoprotein that promotes neurite extension and cell migration, whilst beta III tubulin is a class of neuron-specific tubulin.

*Mouse adult dentate gyrus sections stained with anti-doublecortin (red) (ab18723).*

**NeuroD1**
A transcription factor that promotes neuronal development.

*Mouse brain tissue stained with anti-neuroD1 (ab60704).*

**TBR1**
A transcription factor whose expression marks the transition from intermediate progenitors to post-mitotic neurons.

*Mouse brain sections stained with anti-TBR1 (red) (ab31940).*

**Stathmin 1**
A cytoplasmic phosphoprotein involved in cytoskeletal regulation.

*Mouse brain tissue sections stained with anti-stathmin 1 (ab109986).*
Oligodendrocytes and oligodendrocyte precursor cells

Oligodendrocytes are responsible for the production of myelin, which insulates the axons of neurons within the central nervous system. Their function is equivalent to that of Schwann cells in the peripheral nervous system.

Oligodendrocyte precursor cells

- **PDGF receptor alpha**
  - A cell surface tyrosine kinase receptor and a marker of oligodendrocyte precursor cells.
  - *Human brain cerebellum tissue stained with anti-PDGF receptor alpha (ab124392).*

- **NG2**
  - A membrane chondroitin sulfate proteoglycan (aka CSPG4) expressed by oligodendrocyte precursor cells.
  - *Rat brain tissue sections stained with anti-NG2 (green) (ab50009).*

Oligodendrocytes

- **Olig 1, 2, and 3**
  - Transcription factors necessary for oligodendrocyte development.
  - *Rat brain tissue sections stained with anti-olig2 (green) (ab109186).*

- **Oligodendrocyte specific protein (OSP) and myelin oligodendrocyte glycoprotein (MOG)**
  - Proteins found on the surface of oligodendrocytes.
  - *Rat oligodendrocytes stained with anti-myelin oligodendrocyte binding protein (ab115597).*

- **Myelin basic protein (MBP)**
  - A structural component of myelin, expressed exclusively by myelinating glia.
  - *Mouse brain tissue sections stained with anti-myelin basic protein (green) (ab40390).*

- **SOX10**
  - Transcription factor that directs neural stem cells towards the glial lineage. Used in combination with other markers to identify oligodendrocytes.
  - *Chick embryo (E4) sections stained with anti-SOX10 (ab27655).*
Schwann cells are the myelin-producing cells of the peripheral nervous system where they form the myelin sheath around axons. Their function is equivalent to that of oligodendrocytes in the central nervous system.

### Schwann cell markers throughout development

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<td>SOX10, GAP43, S100, NCAM, P75NTR</td>
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**Myelin protein zero (MPZ)**
A structural component of the myelin sheath.

*Rat Schwann cells stained with anti-myelin protein zero (ab31851).*

**NCAM**
A glycoprotein involved in cell adhesion, expressed by non-myelinating Schwann cells.

*Zebrfish embryo stained with anti-NCAM (green) (ab9272).*

**GAP43**
A cytoplasmic protein expressed by non-myelinating glia.

*Rat spinal cord (ventral horn) stained with GAP43 (ab16053).*

**S100**
Homodimeric protein that is often found in cells derived from the neural crest.

*Rat Schwann cells stained with anti-S100 (ab4066).*
Astrocytes

Astrocytes are the star-shaped glial cells and serve a wide variety of functions in the central nervous system, which are vital for brain development, physiology and pathology.

**GFAP**
An intermediate filament and major component of the astrocyte cytoskeleton.

*Mouse brain tissue sections stained with anti-GFAP (ab7260).*

**EAAT1 (GLAST)**
An astrocyte-specific glutamate transporter.

*Zebrafish retina tissue sections stained with anti-EAAT1 (green) (ab416).*

**EAAT2 (GLT-1)**
An astrocyte-specific glutamate transporter.

*Mouse brain tissue sections stained with anti-EAAT2 (green) (ab41621).*

**Glutamine synthetase**
An enzyme involved in the metabolism of nitrogen. In the brain it is primarily found in astrocytes.

*Rat brain tissue sections stained with anti-glutamine synthetase (ab73993).*

**S100 beta**
A calcium binding protein, also found in oligodendrocyte precursor cells (OPCs) Double labeling with NG2 will distinguish the OPCs from the astrocytes.

*Mouse brain tissue sections stained with anti-S100 beta (ab52642).*

**ALDH1L1**
An enzyme that catalyzes the conversion of 10-formyltetrahydrofolate, NADP+ and water to tetrahydrofolate, NADPH and CO2.

*Mouse brain tissue sections stained with anti-ALDH1L1 (red) (ab87117).*
Microglia

Microglia are the macrophages of the brain and spinal cord and act as an immune defense in the central nervous system. Due to the shared lineage of microglia and macrophages, many markers are common to both cell types, therefore combinations of markers are usually used to identify them.

**CD11b and CD45**
A combination of CD11b and CD45 labeling can distinguish microglia from macrophages: Resting microglia are CD11b+, CD45low, whereas macrophages are CD11b+, CD45high.

*Rat brain tissue sections stained with anti-CD11b/c (red) (ab1211).*

**Iba1**
A useful microglia marker for IHC and ICC, upregulated after cerebral ischemia.

*Human brain tissue sections stained with anti-Iba1 (ab107159).*

**F4/80**
A 160 KDa glycoprotein found on murine resting microglia.

*Mouse brain stained with anti-F4/80 (red) (ab16911).*

**CD68**
A lysosomal protein expressed in high levels by macrophages and activated microglia and in low levels by resting microglia.

*Mouse ischemic brain sections stained with anti-CD68 (green) (ab53444).*

**CD40**
Expressed by activated microglia, necessary for antigen presentation.

*Human tonsil sections stained with anti-CD40 (ab13545).*
Mature neurons are terminally differentiated and are no longer able to divide. Their purpose is to receive, process, and transfer information in the central and peripheral nervous systems.

**NeuN**
An RNA binding protein that is highly specific for post-mitotic neurons.

*Mouse cerebrum sections stained with anti-NeuN (green) (ab177487).*

**MAP2**
A neuron-specific protein that promotes assembly and stability of the microtubule network.

*Mouse primary neurons stained with anti-MAP2 (green) (ab5392).*

**160 kDa Neurofilament medium**
Major intermediate filament found in neurons.

*Rat cerebellum sections stained using anti-160 kDa neurofilament medium (ab64300).*

**200 kDa Neurofilament heavy**
Major intermediate filament found in neurons.

*Rat brain sections stained using anti-200 kDa neurofilament heavy (red) (ab8135).*

**Synaptophysin**
Synaptic vesicle protein that regulates vesicle endocytosis in neurons.

*Human iPS cell-derived neurons stained with anti-synaptophysin (green) (ab32127).*

**PSD95**
Synaptic protein that associates with receptors and the cytoskeleton.

*Rat cerebellum sections stained with anti-PSD95 (ab18258).*
Glutamatergic neurons

Glutamatergic neurons produce glutamate, which is one of the most common excitatory neurotransmitters in the central nervous system.

**vGluT1**
A glutamate transporter that transports cytoplasmic glutamate into vesicles.

*Zebrfish retina sections stained with anti-vGluT1 (green) (ab77822).*

**vGluT2**
A glutamate transporter that transports cytoplasmic glutamate into vesicles.

*Mouse brain tissue sections stained with anti-VGluT2 (ab79157).*

**NMDAR1**
An essential subunit of all NMDA receptors.

*Rat cortex stained with anti-NMDAR1 (ab17345).*

**NMDAR2B**
Another NMDA receptor subunit. This subunit forms the glutamate binding site on the NMDA receptors.

*Mouse cerebral cortex sections stained with anti-NMDAR2B (ab65783).*

**Glutaminase**
An enzyme catalyzing the deamination of glutamine into glutamate.

*Human cerebral cortex tissue labeled with anti-glutaminase (ab156876).*

**Glutamine synthetase**
An enzyme catalyzing the ATP-dependent amidation of glutamate to form glutamine. It is primarily expressed in astrocytes but expression levels rise in neurons in neurodegenerative diseases. When staining for glutamine synthetase, we recommend parallel use of NeuN.

*Zebrfish retina sections stained with anti-glutamine synthetase (purple) (ab93439).*
GABAergic neurons

GABAergic neurons generate gamma aminobutyric acid (GABA), one of the two inhibitory neurotransmitters in the central nervous system.

**GABA transporter 1 (GAT1)**
A transporter on the cell membrane that moves GABA into the cell.

*Mouse brain tissue sections stained with anti-GABA transporter 1 (ab64645).*

**GABA\(_\beta\) receptor 1 and 2**
GABA\(_\beta\) receptors are metabotropic transmembrane receptors for GABA that are linked via G-proteins to potassium channels. GABA\(_\beta\) receptor 1 and GABA\(_\beta\) receptor 2 assemble as heterodimers in neuronal membranes.

*Rat brain (hippocampus) stained with anti-GABA\(_\beta\) receptor 1 (red) (ab55051).*

**GAD65**
The 65 kDa isomorph of glutamate decarboxylase that catalyzes the formation of GABA from glutamate.

*Rat cerebellar cortex labeled with anti-GAD65 (ab26113).*

**GAD67**
The 67 kDa isomorph of glutamate decarboxylase. Unlike GAD65, which is also expressed in the pancreas, GAD67 is CNS-specific.

*Mouse cerebellum sections stained with anti-GAD67 (ab26116).*
**Dopaminergic neurons**

Dopaminergic neurons produce dopamine, a neurotransmitter with roles in neurological functions such as mood and reward. Progressive loss of dopaminergic neurons is the cause of many of the motor symptoms associated with Parkinson’s disease.

**Tyrosine hydroxylase (TH)**
An enzyme that converts L-tyrosine to L-3,4-dihydroxyphenylalanine (L-DOPA), which is a dopamine precursor.

*Rat brain sections stained with anti-tyrosine hydroxylase (ab75875).*

**Dopamine transporter (DAT)**
A transmembrane transporter that controls the re-uptake of extracellular dopamine into presynaptic neurons.

*Mouse substantia nigra sections stained with anti-dopamine transporter (ab128848).*

**FOXA2**
A transcriptional activator that regulates specification and differentiation of dopaminergic neurons.

*Mouse substantia nigra sections stained with anti-FOXA2 (ab108422).*

**GIRK2**
A G-protein regulated potassium channel expressed within certain dopaminergic neurons of the substantia nigra.

*Mouse substantia nigra tissue sections stained with anti-GIRK2 (ab65096).*

**Nurr1**
A transcription factor that induces TH expression and subsequently dopaminergic neuron differentiation.

*Rat cerebral nerve cells stained with anti-nurr1 (ab41917).*

**LMX1B**
A transcription factor involved in a number of processes during dopaminergic neuron development.

*Human brain tissue stained with anti-LMX1B (ab139736).*
Serotonergic neurons

Serotonergic neurons synthesize the neurotransmitter serotonin (5-HT), which is found in the gastrointestinal tract, blood platelets, and the central nervous system.

**Tryptophan hydroxylase (TPH)**
An enzyme involved in serotonin synthesis. There are two isoforms of tryptophan hydroxylase, TPH1 and TPH2. TPH2 is the isoform predominantly found in the brain.

*Mouse dorsal raphe coronal brain slices stained with anti-TPH2 (ab111828).*

**Serotonin transporter**
A transmembrane protein responsible for the re-uptake of 5-HT from the synaptic cleft into the presynaptic neuron.

*Human cerebral cortex stained with anti-serotonin transporter (ab174770).*

**Pet1**
A transcription factor that drives the transcription of genes essential for the metabolism as well as re-uptake of serotonin.

*Human fetal brain lysate stained using anti-pet1 (ab182111).*
Cholinergic neurons use the neurotransmitter acetylcholine. Their progressive loss is one of the hallmarks of neurodegenerative diseases with cognitive deficits such as Alzheimer’s disease.

**Choline acetyltransferase (ChAT)**
An enzyme that catalyzes the synthesis of acetylcholine.

*Mouse cerebral cortex sections stained with anti-choline acetyltransferase (ab178850).*

**Vesicular acetylcholine transporter (VACHT)**
A transporter that uses a proton gradient established by the vacuolar ATPase to transport acetylcholine into secretory vesicles.

*Guinea pig ileum stained with anti-vesicular acetylcholine transporter (ab31544).*

**Acetylcholinesterase**
An enzyme that catalyzes the breakdown of acetylcholine into acetate and choline.

*Mouse striatum stained with anti-acetylcholinesterase (ab97051).*
References and further reading

**Neuroepithelial cells**


**Radial glia**


**Immature neurons and intermediate progenitors**


**Oligodendrocytes and oligodendrocyte precursor cells**


**Schwann cells and Schwann cell precursors**


Astrocytes


Microglia


Mature neurons


Glutamatergic neurons


**GABAergic neurons**


**Dopaminergic neurons**


Nakatani, T., Kumai, M., Mizuhara, E., Minaki, Y. & Ono, Y. Lmx1a and Lmx1b cooperate with Foxa2 to coordinate the specification of dopaminergic neurons and control of floor plate cell differentiation in the developing mesencephalon. *Dev. Biol.* **339**, 101–113 (2010).


**Serotonergic neurons**


**Cholinergic neurons**
Neural lineage markers at a glance

Neuroepithelial cells
- Nestin
- SOX2
- Pax6
- Hes1
- Hes3
- Occludin
- E-cadherin
- SOX10

Schwann cell precursor
- SOX10
- GAP43
- BLBP
- MPZ
- Dhh
- P75NTR

Myelinating Schwann cell
- SOX10
- S100
- EGFR
- MP2
- Dhh
- P75NTR

Non myelinating Schwann cell
- SOX10
- S100
- GAP43
- NCAM
- P75NTR

Radial glia
- Vimentin
- GFAP
- EAAT1/GLAST
- BLBP
- TN-C
- N-cadherin
- Nestin
- SOX2

Intermediate progenitors
- TR2
- MASH1

Oligodendrocyte precursor cell
- PDGFRα
- NG2

Oligodendrocytes
- Olig1
- Olig2
- Olig3
- Olig4
- MP2
- MOG
- SOX10

Astrocytes
- GFAP
- EAAT1/GLAST
- EAAT2/GLT-1
- Glutamine synthetase
- S100 beta
- ALDH1L1

Microglia
- CD11b
- CD45
- Iba1
- F4/80
- CD68

Glutamatergic neurons
- vGlut1
- vGlut2
- EAAT2
- GLAST
- Glutamate
- Glutamine
- Synaptophysin
- NADPH

GABAergic neurons
- GAT1
- GABA receptor 1
- GABA receptor 2
- GAD67
- GAD65

Dopaminergic neurons
- TH
- DAT
- GAT1
- GABA
- NCAM
- Beta III tubulin

Serotonergic neurons
- TPH
- Serotonin transporter
- PET1

Cholinergic neurons
- ChAT
- VAChT
- Acetylcholinesterase

Intermediate progenitors
- TBR2
- MASH1

To find out more, please visit abcam.com/neuralmarkers