Anterior thalamic complex is intimately interconnected with the presubiculum
[pg. 73]
Projection to Presubiculum:
There are topopgraphical differences in the thalamic connections of the ventral and dorsal portions of the presubiculum The ventral portion receives most of its input from the anterodorsal and anteroventral nuclei, whereas the dorsal part receives projections mainly from the laterodorsal and anterodorsal nuclei. The thalamic projections mainly terminate in layers I, III, and IV. The nucleus reuniens also projects to layer I of the presubiculum, but this is much lighter.
[pg. 82]

Nucleus Reuniens

Projection to CA1:
Fibers travel via the internal capsule and cingulum bundle rather than through fornix and fimbria; reach all septotemporal (though with a preference for mid) levels of CA1 in stratum lacunosum-moleculare; overlapping with entorhinal fibers.
They terminate with asymmetrical synapses on spines and thin dendritic shats in the stratum lacunosum-moleculare on both principal neurons and GABAergic interneurons

Midline (non-specific) Nuclei

Paraventricular nuclei

Parataenial nuclei

ventrolateral

to primary motor cortex: PMID 14653187

to secondary(supplemantery) motor cortex: PMID 3085570

nucleus reuniens

nucleus centralis medialis

rhomboid nucleus

Paraventricular Nucleus

neurons located in rostral part of intralaminar nuclear complex
excitatory
projects to spiny projection neurons of Neostriatum
makes contact with dendritic spines

Striatal projections to patch (Herkenham and Pert, 1981; Gerfen et al., 1982; Berendse et al., 1988)

To Patch MSN

Parafasicular/Centromedian Nuclei

neurons located in parafisicular/centromedian nuclei in intralaminar nuclear complex
excitatory
projects to spiny projection neurons of Neostriatum
makes contact with dendritic shafts

Striatal projections to matrix (Herkenham and Pert, 1981; Gerfen et al., 1982; Berendse et al., 1988)

To Direct Matrix MSN

To Indirect Matrix MSN

parataenial nuclei

ventral anterior nucleus

mediodorsal nucleus

to dorsolateral prefrontal cortex: PMID 3085570

Interanteromedial nucleui

laterodorsal nuclei

Anterodorsal nuclei

Anteroventral nuclei

mediodorsal

to mPFC prelimbic/infralimbic (layer 3) : PMID 16082676

Medial Septal Nuclei

30% to 50% of the cells in the medial septal nucleus that project to the hippocampal formation are cholinergic.
Cells located medially in the medial septal nucleus tend to be GABAergic
Cells located laterally in the medial septal nucleus tend to be cholinergic
Septal projections to the hippocampal formation is topographically organized; cells located medially tend to project preferentially to septal or dorsal regions of the hippocampal formation while cells located laterally tend to project to temporal levels [pg. 60]
Projection to the Dentate Gyrus:
Septal fibers highly innervate cells of the polymorphic layer, particularly in a narrow region just subjacent to the granule cell layer. The large mossy cells are innervated by cholinergic fibers, lightly distributed throughout the molecular layer.
The Septal projection to the dentate gyrus is heterogeneous, with GABAergic projections terminating preferentially on other GABAergic nonpyramidal cells (such as basket pyramidal cells) and form symmetrical, inhibitory contacts; most heavily terminating on interneurons located in the polymorphic layer.

Cholinergic septal projections terminate preferentially on granule cells, making asymmetrical, excitatory contacts on dendritic spines, chiefly the inner 1/3 of the molecular layer (only 5% to 10% are on interneurons)
[pg. 60]

(Medial)

(Lateral)

Lateral Septal Nuclei

Reciprocal Projections to CA3:
The projections travels via the fimbria and precommussural fornix; it is bilateral; and some CA3 fibers cross the ventral hippcampal commissure to innervate the homolgous region of he contralateral lateral septal nucleus.
It is topographically organized such that septal portions of the CA3 project dorsally in the lateral septal nucleus, and progressively more temporal portions of CA3 cells terminate more laterally.
[pg. 73]

(Medial)

(Lateral)

Dorsomedial

Ventral

Ventral Striatum

Nucleus Accombens

Olfactory Tubercle

Cells from a variety of hypothalamic nuclei collectively form a sizable input to the hippocampal formation; but however are so diffuse and lacking a distinct biochemical marker, such that it is difficult to study their patterns of termination in the hippocampal formation
[pg. 61]

Supramammillary nuclei

Population of large cells which caps and partially surrounds the medial mammillary nuclei.
[pg. 61]
Projection to the Dentate Gyrus:
Terminates heavily in a narrow zone of the molecular layer located just superficial to the granule cell layer and lightly in the polymorphic layer or the rest of the molecular layer.
Most terminate on he proximal dendrites of granule cells.
Although there is substantial evidence that the projection is excitatory and using glutamate, there is still conflict over the kind of neurotransmitter used.
Most of these cells colocalize calretinin some colocalize substance P
In addition to the supramammillary cells, there are cells scattered in several hypothalamc nuclei (many of which are in a perifornical position or in the lateral hypothalamic area) which project to the dentate gyrus.

[pg. 61]
The supramammillary region projects wealky, if at all, to CA3 and CA1
[pg. 73]

Medial mammillary nuclei

Lateral mammillary nuclei

Tuberomammillary nuclei

ventromedial nucleus

Premammillary nuclei

ɑ-melanocyte-stimulating hormone-positive cells

The hippocampus, like the dentate gyrus, recieves mostly noradrenergic and serotonergic inputs from brain stem nuclei (very few, if any, are dopaminaergic)
[pg. 73]

Pontine Nucleus Locus Coeruleus

Noradrenergic fibers terminate mainly in the polymorphic layer of the dentate gyrus and extend into the stratum lacidum of CA3, in the zones occupied by the mossy fibers
[pg. 61]
Projection to the Dentate Gyrus:
The dentate gyrus recieves a minor, diffusely distributed dopaminergic projection that arises mainly from cells located in the ventral tegmental area, terminating mainly in the polymorphic layer
[pg. 61]
A number of GABAergic interneurons appear to be preferentially innervated by the serotonergic fibers. The targets are often the pyramidal basket cells.
Fusiform neurons in the region, particularly those that stain for the calcium-binding protein calbindin, are also heavily innervated.
[pg. 61-62]
Projection to CA3:
Noradrenergic fibers and terminals arising form the locus coeruleus are most densely distributed in the stratum lucidum and the most superficial portion of the stratum lacunosum-moleculare. A much thinner plexus of axons is distributed throughout the other layers of CA3.
[pg. 73]

Raphe Nuclei

Projection to the Dentate Gyrus:
The serotonergic projection that originates from the median and dorsal divisions of the raphe nuclei also terminates most heavily in the polymorphic layer in an immediately subgranular portion of the layer.
[pg. 61]
As with the cholinergic projection from the septum, many of the cells in the raphe nuclei that project the the hippocampal formation appear to be nonserotonergic, but their transmitter is not known.
[pg. 62]

Projection to CA3:
Serotonergic fibers are distributed diffusely and sparesely in CA3 than noradrenergic fibers
There are two calibers of axon, thick and thin, innervating the hippocampus. Most of the serotonergic varicosities which are located on the thin fibers, do not appear to have standard synaptic junctions and may release transmitter into the extracellular space.The varicosities on the thicker fibers, in contrast, form standard asymmetrical synapses that preferentially terminate on GABAergic inhibitory nuerons, specificially those that project to the dendrites of hippocampal neurons
[pg. 73]
Projection to Presubiculum:
A particularly dense innervation arises from the dorsal and central raphe nuclei; at least a component of this projection is serotonergic and innervates layer I. The noradrenergic locus coeruleus innervated the plexiform layer.
[pg. 85]

septum

hypothalamus

supramammillary nucleus

tuberomammillary nucleus

lateral area

To NS Parvalbumin+

Paraventricular Nucleus

neurons located in rostral part of intralaminar nuclear complex
excitatory
projects to spiny projection neurons of Neostriatum
makes contact with dendritic spines

Striatal projections to patch (Herkenham and Pert, 1981; Gerfen et al., 1982; Berendse et al., 1988)

To Patch MSN

Parafasicular/Centromedian Nuclei

neurons located in parafisicular/centromedian nuclei in intralaminar nuclear complex
excitatory
projects to spiny projection neurons of Neostriatum
makes contact with dendritic shafts

Striatal projections to matrix (Herkenham and Pert, 1981; Gerfen et al., 1982; Berendse et al., 1988)

To Direct Matrix MSN

To Indirect Matrix MSN

Medial Geniculate Nucleus

To Caudal GPe

http://www.ncbi.nlm.nih.gov/pubmed/1381984

To Caudal Striatum

http://www.ncbi.nlm.nih.gov/pubmed/1381984

Acessory Basal and Cortical Nuclei

Basal Nuclei

Parvicellular Portion

Posterior Cortical Nuclei

Amygdalohippocampal Area

lateral nucleus

basal nucleus

cortical nuclei

periamygdaloid complex

Caudal

To Nucleus Accumbens

http://www.ncbi.nlm.nih.gov/pubmed/7530817

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

Layer 6

to putamen:PMID 3085570

to subthalamic nucleus:PMID 3085570

Layer 1

Layer 2

pyramidal cells

Layer 3

pyramidal cells

to motor/layer5/pyramidal+basket: PMID 9579775

Layer 4

Layer 5

pyramidal cells

basket cell

to motor/layer5/pyramidal: PMID 9579775

Layer 6

to putamen: PMID 3085570

Layer 1

Layer 2

Layer 3

Layer 4

to primary motor cortex: PMID 19672624

Layer 5

Layer 6

Layer 1

Layer 2

pyramidal cells

to somatosensory/layer5/pyramidal: PMID 10234015

Layer 3

pyramidal cells

to somatosensory/layer5/pyramidal: PMID 10234015, 9579775

to somatosensory/layer5/basket: PMID 9579775

Layer 4

PMID 19672624

spiny stellate cells

to somatosensory (layers 2/3 pyramidal): PMID 11826166

pyramidal cells

to primary motor cortex (layers 2/3/5) : PMID 10215140

Layer 5

pyramidal cells

basket cells

to somatosensory/layer5/pyramidal: PMID 9579775

Layer 6

Layer 6a

pyramidal cells

PMID: 9236245

short pyramidal cells

to somatosensory cortex: PMID 9236245

inverted pyramidal cells

to somatosensory cortex: PMID9236245

spiny bipolar cells

to somatosensory cortex: PMID 9236245

Layer 6b

to entorhinal cortex: PMID 15099698

Projection to the presubiculum:

Terminates mainly in layers I, III, and V

[pg. 83]

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

to motor cortex: PMID15099698

Layer 6

extrinsic connections:

PMID:

3085570

to caudate: PMID 3085570

PMID:

2592611

Layer 1

NADPH diaphorase +

PMID: 9007187

Dendritic arbors extend horizontally within layer 1 and descend into layers 2 and 3.

Calretinin +

horizontal bipolar/bitufted

radial bipolar

multipolar neurons

Calbindin+

Layer 2

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

PMID: 9007187

Long dendrites that ramified throughout layers 2-5.

Most common CR+ neurons in rat mPFC.

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bipolar neurons

bitufted neurons

Layer 3

Layer 3 (caudal)

to entorhinal cortex: PMID 2592611

to perirhinal cortex: PMID 2592611

to insular cortex: PMID 2592611

to anterior cingulate: PMID 2592611

NADPH diaphorase +

bipolar neurons

PMID: 9007187

Long processes that extend up into layer 1 or descend into layer 6.

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bipolar neurons

bitufted neurons

pyramidal neurons

CA1/Subiculum-Innervated Interneurons

PMID: 15233760

Aspiny Stellate Cells

Spiny Stellate Cells

Layer 4 (caudal)

to entorhinal cortex: PMID 2592611

to perirhinal cortex: PMID 2592611

to insular cortex: PMID 2592611

to anterior cingulate: PMID 2592611

Layer 5

Layer 5 (rostral-ventral)

to piriform cortex (layer 2/3): PMID 2592611

Layer 5 (rostral-dorsal)

to entorhinal cortex: PMID 2592611

to perirhinal cortex: PMID 2592611

to insular cortex: PMID 2592611

to anterior cingulate: PMID 2592611

Layer 5 (caudal)

to entorhinal cortex: PMID 2592611

to perirhinal cortex: PMID 2592611

to insular cortex: PMID 2592611

to anterior cingulate: PMID 2592611

NADPH diaphorase +

bipolar neurons

PMID: 9007187

Long processes that extend up into layer 1 or descend into layer 6.

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bitufted neurons

large multipolar neurons

spiny large multipolar neurons

small/medium multipolar neurons

CA1/Subiculum-Innervated Interneurons

PMID: 15233760

Aspiny Stellate Cells

Bitufted Cells

Layer 6

Layer 6 (rostral-ventral)

to piriform cortex (layer 2/3): PMID 2592611

Layer 6 (rostral-dorsal)

to entorhinal cortex: PMID 2592611

to perirhinal cortex: PMID 2592611

to insular cortex: PMID 2592611

to anterior cingulate: PMID 2592611

Layer 6 (caudal)

to entorhinal cortex: PMID 2592611

to perirhinal cortex: PMID 2592611

to insular cortex: PMID 2592611

to anterior cingulate: PMID 2592611

Layer 6a

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bitufted neurons

large multipolar neurons

small/medium multipolar neurons

Layer 6b

NADPH diaphorase +

"pyramidal-like" neurons

horizontal neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

bipolar neuron

Calbindin+

bitufted neurons

small/medium multipolar neurons

CA1/Subiculum-Innervated Interneurons

PMID: 15233760

Aspiny Stellate Cells

Spiny Stellate Cells

Layer 1

NADPH diaphorase +

PMID: 9007187

Dendritic arbors extend horizontally within layer 1 and descend into layers 2 and 3.

Calretinin +

horizontal bipolar/bitufted

radial bipolar

multipolar neurons

Calbindin+

Layer 2

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bipolar neurons

bitufted neurons

Layer 3

NADPH diaphorase +

bipolar neurons

PMID: 9007187

Long processes that extend up into layer 1 or descend into layer 6.

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bipolar neurons

bitufted neurons

pyramidal neurons

Layer 5

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bitufted neurons

large multipolar neurons

Layer 6a

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bitufted neurons

large multipolar neurons

small/medium multipolar neurons

Layer 6b

NADPH diaphorase +

"pyramidal-like" neurons

horizontal neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

bipolar neuron

Calbindin+

bitufted neurons

small/medium multipolar neurons

Layer 1

NADPH diaphorase +

PMID: 9007187

Dendritic arbors extend horizontally within layer 1 and descend into layers 2 and 3.

Calretinin +

horizontal bipolar/bitufted

radial bipolar

multipolar neurons

Calbindin+

Layer 2

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bipolar neurons

bitufted neurons

Layer 3

NADPH diaphorase +

bipolar neurons

PMID: 9007187

Long processes that extend up into layer 1 or descend into layer 6.

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bipolar neurons

bitufted neurons

Layer 5

NADPH diaphorase +

bipolar neurons

PMID: 9007187

Long processes that extend up into layer 1 or descend into layer 6.

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bitufted neurons

large multipolar neurons

spiny large multipolar neurons

small/medium multipolar neurons

Layer 6a

NADPH diaphorase +

bitufted neurons

multipolar neurons

"pyramidal-like" neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

Calbindin+

bitufted neurons

large multipolar neurons

small/medium multipolar neurons

Layer 6b

NADPH diaphorase +

"pyramidal-like" neurons

horizontal neurons

Calretinin +

radial bipolar

bitufted neurons

multipolar neurons

Parvalbumin+

multipolar neuron

bitufted neurons

bipolar neuron

Calbindin+

bitufted neurons

small/medium multipolar neurons

to nucleus accumbens, agranular insular, anterior cingulate, ectorhinal, entorhinal, infralimbic, motor, perirhinal, piriform, prelimbic, retrosplenial, somatosensory, caudate-putamen:

PMID 21800317

to nucleus accumbens, agranular insular, anterior cingulate, ectorhinal, entorhinal, infralimbic, motor, perirhinal, piriform, prelimbic, retrosplenial, somatosensory, caudate-putamen:

PMID 21800317

to entorhinal cortex: Andersen, Per. The hippocampus book. Oxford University Press, USA, 2007. Print.

Layer 1

Layer 2

to layer 5: PMID 2913064

receives most inhibition through horizontal connections: PMID 10862703

pyramidal neuron

fast-spiking basket cells

adapting small/nest basket cells

Layer 3

to layer 5: PMID 2913064

receives most inhibition through horizontal connections: PMID 10862703

pyramidal neuron

fast-spiking basket cells

adapting small/nest basket cells

Layer 4

to layers 1/2: PMID 2913064

pyramidal neuron

to layers 2/3 (pyramidal/fast-spiking basket): PMID 10862703

Layer 5

to layer 3: PMID 2913064

to layers 2/3 (adapting small/nest basket cells): PMID 10862703

Layer 5a

Layer 5b

Layer 6

PMID:

2913064

to entorhinal cortex: Andersen, Per. The hippocampus book. Oxford University Press, USA, 2007. Print.

to entorhinal cortex: Andersen, Per. The hippocampus book. Oxford University Press, USA, 2007. Print.

to entorhinal cortex: Andersen, Per. The hippocampus book. Oxford University Press, USA, 2007. Print.

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

Layer 6

to entorhinal cortex: Andersen, Per. The hippocampus book. Oxford University Press, USA, 2007. Print.

Projection to Presubiculum:
Distributes to dorsal 1/2 of presubiculum and terminates in layers I and III

Layer II more pronounced
Layers IV-VI less clearly defined

Layer I

Cell poor; rich in transversely oriented fibers
[pg. 85]

Interneurons

GABAergic
Exist in all layers, though most abundant in superficial layers (where they are most distinguishable by colocalization with peptides or expression of various calcium-binding proteins: often parvalbumin (less calbindin-D28-positive)
Some GABAergic neurons in layers II and III project to dentate gyrus

Stellate Cells

Layer II

Quite clear
Contains mainly medium-sized to large stellate cells and small pyramidal cells groups in clusters (cell islands)
[pg. 85]

Pyramidal Cells

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

Interrneurons

Axo-Axonic Cell

Stellate Cells

Layer III

Predominantly occupied by pyramidal cells
[pg. 85]

Pyramidal Cells

Axons collateralize mainly in layer I and III
Apical dendrites ascend, branch in layer II, and form a terminal tuft in layer I
[pg. 87]

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

TO Proximal CA1

Stellate Cells

Interneurons

Multipolar Cell

Fusiform Cell

Horizontal Cell

Bipolar Cell

Layer IV

Lamina Dissecans
cell-free layer, but does contain scattered fusiform or pyramidal cells with apical dendrites extending to layer I and an axon permeating into white matter, characteristic of projection neurons
Some cells stain positively with antibodies against GABA, NPY, calrtinin , calbindin, or somatostatin
[pg. 87]

Fusiform Pyramidal Cell

Layer V

Layer Va

Forms a band of large, darkly stained pyramidal neurons
Most conspicuous region in entorhinal cortex
[pg. 85]

Pyramidal Cells

Have large apical dendrites that ascend toward the superficial portion of layer II and into layer I; axons run deep into white matter and the angular bundle, additional collaterals innervating the superficial layers of the entorhinal cortex.
Collaterals form column-like plexus close to cell body location and span the thickness of the entorhinal cortex, distributing mainly to layers V and VI, but occasionally reaching layer II
[pg. 87]

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Distal)

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Interneurons

Horizontal Cell

Multipolar Cell

Layer Vb

Less densely packed pyramidal cells; smaller cells from deeper levels intermingling
[pg. 85]
Contains three types of cells, pyramidal, multipolar, and horizontal- all of which are projection neurons, sending axons into white matter- or local circuit neurons, connecting deep to superficial layers
[pg. 88]

Pyramidal Cells

Large and small

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

Multipolar Cell

An atypical form with long, wavy dendrites; some of which meander from the entorhinal cortex, through angular bundle, and into the subiculum. Some of these cells thus contribute to the projection from the dentate gyrus and hippocampus
[pg. 87-88]

Horizontal Cell

Dendrites confined to layer V

Interneurons

Layer VI

Contains a highly heterogeneous population of cell sizes and shapes; cell blend gradually into subjacent subcortical white matter and the overlying layer V
[pg. 85]
Three cell types:
Cells that mainly influence other cells in layer VI or Vb;
Cells that by means of their highly collateralized axons can influence a vertical column of cells in layers I to IIII; and
Cells whose axons are directed towards deep white matter and are therefore likely to be projection neurons--some of which project to dentate gyrus and hippocampus

Pyramidal Cells

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

Layer II less pronounced
Layers IV-VI more clearly defined

Layer I

Interrneurons

Stellate Cells

Layer II

Less clear; larger cells and less defined cell islands
Border between II and III is less clear

Pyramidal Cells

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

Interrneurons

Axo-Axonic Cell

Stellate Cells

Layer III

Pyramidal Cells

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

TO Distal CA1

Interneurons

Multipolar Cell

Stellate Cell

Fusiform Cell

Horizontal Cell

Bipolar Cell

Layer IV

Lamina Dissecans

Fusiform Pyramidal Cell

Layer V

Layer Va

Horizontal Stellate Cell

Pyramidal Cells

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Distal)

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Interneurons

Multipolar Cell

Interneurons

Layer Vb

Pyramidal Cells

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

Multipolar Cell

Horizontal Cell

Interneurons

Layer VI

Pyramidal Cells

Pyramidal Cell (Medial)

Pyramidal Cell (Intermediate)

Pyramidal Cell (Lateral)

To NS Parvalbumin+

To NS ACh Inter

Pyramidals

Layer 1

Layer 2

Layer 3

Layer 4

Layer 5

PT (Deeper Layer 5)

pyramidal neuron
projects mainly to brainstem
uses glutamate as neurotransmitter

PT projects ipsilaterally indirect pathway (Lei et al., 2004)
Deeper layer 5 targets patch (Gerfen, 1989)
Synapses located on striatal dendritic spines

To Patch MSN

IT (Superficial Layer 5)

located mostly in layer 5 of cortex (some 3)
dense in agranular cortical regions
many corticocortical & corticostriatal connections
glutamate as neurotransmitter
striatal arborizations
excitatory

IT targets direct pathway (Lei et al., 2004)
Superficial layer 5 targets matrix (Gerfen, 1989)
Synapses located on striatal dendritic spines

To Direct Matrix MSN

To Indirect Matrix MSN

PT (Superficial Layer 5)

http://www.ncbi.nlm.nih.gov/pubmed/15385612

To Indirect Matrix MSN

To Direct Matrix MSN

Layer 6

Source (unless otherwise specified): Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Molecular Layer

Interneurons

Molecular Layer-Perforant Path Associated (MOPP) Cell

Multipolar or triangular cell body located deep in molecular layer

Axon produces terminal plexus largely limited to the outer two-thirds of the molecular layer

Aspiny dendrites remain mainly within the molecular layer

[pg 57]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Interneuron Specific (IS) Cell

Demonstrated using immunohistochemisty for vasoactive intestinal peptide (VIP) [pg. 58]
Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Chandelier (axo-axonic) Cell

Cell bodies located immediately adjacent to or sometimes within granule cell layer

Dendrites confined to molecular layer

Axon descends from molecular layer, collateralizes profusely, and terminates exclusively on the initial axon segments of granule cells

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Each axo-axonic cell may innvervate as many as 1000 granule cells

Input currently unknown, but may be perforant path associated

[pg. 58]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Granule Cell Layer

Granule Cells

Oval cell bodies of 10 x 18μm

Dendritic tree forms characteristic cone shape, extending as far as hippocampal fissure or ventricular surface

[pg. 55]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Axonal projections from granule cells to CA3 pyramidal cells are called mossy fibers

Mossy fiber expansions, mossy fiber en passant presynaptic terminals, range from 3 to 5μm and form irregular, complex, interdigitated attachments with thorny excrescences on CA3 pyramidal cell dendrites. They occur every 135μm along parent axon, each axon forming about 15 of these complex boutons; thus, each granule cell makes 15 contacts with each CA3 pyramidal cell, but each pyramidal cell recieves input from about 72 granule cells

A single mossy fiber expansion can make up to 37 synaptic contacts with a singl
e CA3 pyramidal cell dendrite

[pg. 64-65]

Granule Cell
(Infrapyramidal Blade)

Small cell bodies, shorter dendritic trees, 1.3 spines/ μm
[pg. 55]
Ratio of basket cells to granule cells
1:180 septal
1:300 temporal
[pg. 56]
Mossy fibers enter infrapyramidal bundle (innervating basal CA3 pyramidal cell dendrites) and continue deep to stratum lucidum
[pg. 64]

Granule Cell
(Crest)

Mossy fibers enter infrapyramidal bundle (innervating basal and proximal CA3 pyramidal cell dendrites), cross to suprapyramidal bundle, and continue through stratum lucidum
[pg. 64]

Granule Cell
(Suprapyramidal Blade)

Large cell bodies, longer dendritic trees, 1.6 spines/ μm
[pg. 55]
Ratio of basket cells to granule cells
1:100 septal
1:150 temporal
[pg. 56]
Mossy fibers enter stratum lucidum (innervating proximal CA3 pyramidal cell dendrites) and continue to very superficial portion of this layer
[pg. 64]

Granule Cell (Septal 1/2)

Granule Celll (Septal 3/4)

Granulel Cell (Temporal 1/4)

Interneurons

Pyramidal Basket Cell

Cell bodies of 25 to 35µmwedged slightly in deep surface of granule cell layer

"basket" consists of a pericellylar plexuses that surround and form synapses wit h granule cell bodies

Single, aspiny, apical dendrite extends into the molecular layer while several prin ciple basal dendrites ramify and extend into polymorphic cell layer.

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hipp ocampus book. New York, NY: Oxford University Press, Inc.

[pg. 56]

Randoms

Several cell types with different somal shapes, axonal and dendritic configuratio ns. Most have axons that contribute to the basket plexus in the granule cell layer , forming symmetrical synaptic contacts with cell bodies, proximal dendrites, and initial segments of granule cells

All are immunoreactive for GABA, but not neurochemically homogeneous

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hipp ocampus book. New York, NY: Oxford University Press, Inc.

Some multipolar with several aspiny dendrites entering the molecular and polym
orphic layers

Some fusiform-shaped with similar dendritic distribution

[pg. 57]

Polymorphic Cell Layer

Interneurons

Hilar-Commissural Associational Pathway-Related (HICAP) Cell

Multipolar or triangular cell bodies

Thin, aspiny dendrites extend in molecular layer and hilus

Axons perforate granule cell layer and branch in inner third of molecular layer

[pg. 59]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hipp

ocampus book. New York, NY: Oxford University Press, Inc.

Hilar-Perforant Path Associated (HIPP) Cell

Long-spined multipolar cell
Two or three principle dendrites run parallel to granule cell layer, extending for entire transverse length of one blade
Axonal plexus can extend 3.5mm along septotemporal axis, generating as many as 10,000 synaptic terminals
[pg. 58-9]
Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Mossy (stellate) Cells

Large (25-35 μm) triangular or multipolar-shaped cell bodies
Three or more thick dendrites extend for long distances in polymorphic cell layer (though some pierce through to molecular layer), bigurcating once or twice with a few side branches
Proximal dendrites densely covered by thorny excrescences (large, complex spines)
Distal dendrites have more sparse predunculate spines
Axons project to inner third of molecular layer of ipisilateral and contralateral dentate gyrus (major excitatory associational/commissural projection to Dentate Gyrus)
[pg. 58]
Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Mossy Cell

Mossy Cell

Mossy Cell

Stratum Lacunosum Moleculare

Interneurons

[applies to all hippocampal interneurons]

All are immunoreactive for GABA- but in other cortical regions colocalize a numb er of neuroactive substances; thus, many can be visualized with anibodies to pe ptides such as somatostatin, VIP, cholecystokinin, neuropeptide Y (NPY), and ca lcium-binding protiens such as parvalbumin, calbindin, and calretinin: useful mar kers for establishing subcatagories of a large population of GABAergic interneur ons

[pg. 71]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hipp ocampus book. New York, NY: Oxford University Press, Inc.

Stratum Lacunosum-Moleculare (LM) Cell

[applies to all of hippocampal LM cells]

Dendrites oriented horizontally with occasional branches that extend into the pyr amidal cell layer

Axon also mostly horizonally oriented and ramifies in the stratum lacunosum-moleculare or superficial stratum radiatum, forming symmetrical synapses on the distal dendrites of pyramidal cells

[pg. 70]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hipp ocampus book. New York, NY: Oxford University Press, Inc.

Interneuron Specific (IS) Cell

Stratum Radiatum

Interneurons

Oriens-Lacunosum Moleculare Associated (O-LM) Cell

Stellate Shaped Basket Cells

Interneuron Specific (IS) Cell

Stellate-Like Interneurons

[applies to all of hippocampal stellate-like interneurons]

Stellate or multipolar dendritic plexus is confined to layer

Axons tend to ramify locally in stratum radiatum and terminate on dendrites of pyramidal cells

[pg. 70]

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Andersen, P, Morris, R, Amaral, D, Bliss, T, & O'Keefe, J. (Ed.). (2007). The hippocampus book. New York, NY: Oxford University Press, Inc.

Stratum Lucidum

Pyramidal Cell Layer

CA3 Pyramidal Cells

Very heterogeneous
Schaffer Collaterals: Strongest projection (thickest axon) is Proximal CA3 to Distal CA1
CA3 cell axons distribute to as much as two-thirds of the septotemporal exent of the ipsilateral and contralateral CA1 fields
A single CA3 neuronal plexus comprises as much as 150 to 300 mm of total axonal length, on which 30,000 to 60,000 synaptic varicosities are formed.
Connection restricted at temporal levels, here neurons may give rise to axonal plexuses that innervate only the temporal third of the CA1 field.
[pg. 75]
Associational Connections:
Much less prevalent in rat and almost absent in humans
Projections to Lateral Septal Nucleus of Basal Forebrain:
Virtually all of CA3 cells give rise to projections to both CA1 and the lateral septal nucleus
[pg. 73]

Pyramidal Cel (Proximal)

Ratio of granule to pyramidal cells 12:1
[pg. 56]
300 µm^2 s toma size
8 to 10 mm dendritic length
few dendrites extend into stratum lacunosum-moleculare (little input from entorhinal cortex)
many mossy fiber terminals on apical and basal dendrites (much input from dentate gyrus)
[pg. 68]

Pyramidal Cell (Septal)

thorny excresences on basal and proximal dendrites
[pg. 64]

Pyramidal Cell (Medial)

thorny excresences on proximal dendrites only (that transverse the stratum lucidum)
[pg. 64]

Pyramidal Cell (Temporal)

thorny excresences on proximal dendrites only (that transverse the stratum lucidum)
[pg. 64]

Pyramidal Cell (Mid)

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

Pyramidal Cell (Distal)

Ratio of granule to pyramidal cells 2:3
[pg. 56]
700 μm^2 s toma size
16 to 18 mm dendritic length
many dendrites extend into stratum lacunosum-moleculare (much input from entorhinal cortex)
mossy fiber terminals only on apical dendrites (little input from dentate gyrus)
[pg. 68]

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

Dorsal Pyramidal Cells

Projection to VTA

PMID: 21764750

(A) The GABA agonists baclofen and muscimol (B-M) were infused into dorsal CA3 bilaterally, or LS in one hemisphere and VTA in the opposite hemisphere, just before reexposure to the original cocaine-paired context.

Animals with aCSF reinstated cocaine-seeking Animals with B-M failed to reinstate

GABAergic cd-LS neurons (16) to VTA GABA (I-I)

GABA release from cd-LS neurons acts on GABAergic receptors to inhibit local VTA GABA neurons that project to VTA DA neurons.

DA (E-E) neurons show robust activation via disinhibition.

CA2 Pyramidal Cells

Pyramidal Cel (Proximal)

Ratio of granule to pyramidal cells 12:1
[pg. 56]
300 μm^2 s toma size
8 to 10 mm dendritic length
few dendrites extend into stratum lacunosum-moleculare (little input from entorhinal cortex)
many mossy fiber terminals on apical and basal dendrites (much input from dentate gyrus)
[pg. 68]

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Ratio of granule to pyramidal cells 2:3
[pg. 56]
700 μm^2 s toma size
16 to 18 mm dendritic length
many dendrites extend into stratum lacunosum-moleculare (much input from entorhinal cortex)
mossy fiber terminals only on apical dendrites (little input from dentate gyrus)
[pg. 68]

Interneurons

Pyramidal Basket Cell

[applies to all of hippocampal basket cells]
Beaded, aspiny dendrites that extend into stratum oriens, stratum radiatum, and stratum lacunosum moleculare; receive both asymmetrical and symmetrical synapses
at least 2000 excitatory inputs from hippocampal pyramidal cells (one for each, thus degree of convergence on a single basket cell is enormous)
the transverse extend of the basket cell axonal plexus is between 900 and 1300 μm, within which are as many as 10,000 synaptic varicosities, thus each basket cell innervates as many as 1000-plus pyramidal cells
[pg. 70]

Chandelier (axo-axonic) Cell

[applies to all of hippocampal axo-axonic cells]
Dendrites span all hippocampal strata
Axons have transverse extent is about 1 mm, traveling just superficial to pyramidal cell layer and periodically giving rise to collaterals tthat enter the pyramidal cell layer and terminate on the proximal axons of pyramidal neurons.
Each axo-axonic cell terminates on about 1200 pyramidal cell axon initial segments; each segment innervated by 4 to 10 axo-axonic cells
[pg. 70]

Interneuron Specific (IS) Cell

Bistratified Cell

[applies to all hippocampal bistratified cells]
Dendritic trees are multipolar but do not reach stratum lacunosum-moleculare
Dense terminal plexus is produced in deep portion of stratum radiatum, 80 mm long and generating up to 16,000 varicosities that terminate on both the dendritic shafts and dendritic spines of pyramidal cells
[pg. 70]

Oriens-Lacunosum Moleculare Associated (O-LM) Cell

[applies to all hippocampal O-LM cells]
Dense axonal arbor is confined to the stratum lacunosum-moleculare (terminating in conjunction with entorhinal afferents)
Cell bodies and dendritic tree vary in location, but always in zones occupied by recurrent pyramidal cell collaterals
Axons form symmetrical synapses with the distal apical dendrites of pyramidal neurons in a dysynaptic, feedback manner.
[pg. 70]

Stratum Oriens

Interneurons

Fusiform-Shaped Basket Cells

Oriens-Lacunosum Moleculare Associated (O-LM) Cell

Interneuron Specific (IS) Cell

Alveus

Attachment (and supporting information): Klausberger, T., & Somogyi, P. (2008). Neuronal diversity and temporal dynamics: the unity of hippocampal circuit operations. Science, 321(5885), 53-57

Three types of pyramidal cells (blue)

21 classes of interneuron

The main termination of five glutamatergic inputs are indicated on the left.

Dendrites of pyramidal cell innervation (orange)

Dendrites of other interneuron innervation (pink)

Axons (purple)

Main synaptic terminations (yellow).

PV, parvalbumin; VIP, vasoactive intestinal polypeptide; VGLUT, vesicular glutamate transporter; O-LM, oriens lacunosum moleculare.

Attachment and supporting information: Klausberger, T., & Somogyi, P. (2008). Neuronal diversity and temporal dynamics: the unity of hippocampal circuit operations. Science, 321(5885), 53-57.

Stratum Lacunosum Moleculare

Interneurons

Perforant Path- Associated

Basket CCK/VIP

Interneuron Specific II

Neurogliaform

Radiatum-retrohippocampal projection

Cholinergic

Stratum Radiatum

Interneurons

Schaffer collateral-associated

Apical dendritic innervating

Large Calbindin

Pyramidal Cell Layer

Attachment (and supporting information): Klausberger, T., & Somogyi, P. (2008). Neuronal diversity and temporal dynamics: the unity of hippocampal circuit operations. Science, 321(5885), 53-57.

Pyramidal Cells

More homogeneous

193 μm^2 s toma size
13.5 mm dendritic length
Cells have one (with slightly longer basal dendrite) or two (with slighlty longer apical dendrites) apical dendrites

CA1 Projection to the Subiculum:
Axons descend through stratum oriens and alveus to ramify in pyramidal cell layer and deep molecular layer
An individual axonal plexus can distribute to 1/3 of the transverse extend of the subicular pyramidal cell layer and for 1/3 of the septotemporal length

Essentially all CA1 pyramidal cells project to the lateral septal nucleus. However, the CA1 projection is strictly ipsilateral , and some of the fibers travel tot eh septal nuclei via the dorsal fornix rather than through the fimbria.
[pg. 73]

Pyramidal Cell (Proximal)

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (temporal)

Pyramidal Cell (Mid)

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (temporal)

Pyramidal Cell (Distal)

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

TO PFC--- PMID: 1783682

Pyramidal Cell (temporal)

TO PFC--- PMID: 1783682

Interneurons

Axo-Axonic Cell

Basket PV

Basket CCK/VGLUT3

Bistratified

Ivy

Interneuron Specific I

Interneuron Specific III

Stratum Oriens

Interneurons

Oriens-Lacunosum Moleculare Associated (O-LM) Cell

Trilaminar

Back Projection

Oriens retro-hippocampal projection

Double projection

Alveus

One of the two primary output structures of the hippocampal formation
[pg. 77]

Molecular Layer (Superficial)

Molecular Layer (deep)

Pyramidal Cell Layer

Interneurons

Many small neurons intermingled with pyramidal cells
Subpopulations seems similar to CA1 interneurons; among them are GABAergic cells that stain for calcium-binding parvalbumin
[pg. 77]

Pyramidal Cells

Large cell bodies, relatively uniform in shape and size
Apical dendrites extend into molecular layer and basal dendrites into deep portions of pyramidal cell layer
Intrinsic connections always move ventrally
Two Types:
Regular Spiking Cells--
More numerous in superficial layers; preferential staining for NADPH-diaphorase/nitric synthetase
Columnal distribution of intrinsic synaptic contacts
Intrinsically Bursting Cells--
More numerous in deep pyramidal cell layer; preferencial staining for stomatostatin; project to entorhinal cortex
Transverse distribution of intrinsic synaptic contacts
[pg. 77]
Projection to the Basal Forebrain:
Subicular fibers terminate throughout the the nucleus accumbens, with the projection to its caudomedial part being most dense. As with other striatal structures, the subicular projection to the nucleus accumbens is unidirectional.
[pg. 80]
Projection to the Hypothalamus:
The subiculum probides the major input to the mammillary nuclei. The projection is heavy and districuted bilaterally in nearly equal density. The subiculomammillary fibers originate mainly from the septal 2/3 of the subiculum.
The temporal 1/3 makes a major connection with the ventromedial nucleus of the hypothalamus.
All of the medial nucleus is contacted by subicular fibers, but is topographically organized: less innervation occurs in lateral mammillary nucleus.
[pg. 80]

Intrinsically Bursting Cells

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Regular Spiking Cells

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Pyramidal Cell (Proximal)

TO PFC--- PMID: 1783682

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

The temporal 1/3 of the subiculym gives rise to return projections to the amygdaloid complex. THe major component of this projection terminates in the accessory basal nucleus, with more moderate projectionsreaching several other nuclei but not the lateral nucleus. The ventral subiculum also projects heavily to the bed nucleus of the stria terminalis and moderately to the ventral part of the clastrum or endopiriform nucleus.
[pg. 79]

Pyramidal Cell (Mid)

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

The temporal 1/3 of the subiculym gives rise to return projections to the amygdaloid complex. THe major component of this projection terminates in the accessory basal nucleus, with more moderate projectionsreaching several other nuclei but not the lateral nucleus. The ventral subiculum also projects heavily to the bed nucleus of the stria terminalis and moderately to the ventral part of the clastrum or endopiriform nucleus.
[pg. 79]

Pyramidal Cell (Distal)

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

The temporal 1/3 of the subiculym gives rise to return projections to the amygdaloid complex. THe major component of this projection terminates in the accessory basal nucleus, with more moderate projectionsreaching several other nuclei but not the lateral nucleus. The ventral subiculum also projects heavily to the bed nucleus of the stria terminalis and moderately to the ventral part of the clastrum or endopiriform nucleus.
[pg. 79]

Brodmann's area 27
Has a distinct, densely packed external cell layer that consists mainly of darkly stained, small pyramidal cells
Layer II cells are the most densely packed, whereas layer III cells have a looser arrangement
Dorsal presubiculum (post subiculum) has clearly distinguishable supericial and deep cell layers, whereas the ventral presubiculum has deep cell layers that are less distinguishable from deep layers of the entorhinal cortex or the principle cell layer of the subiculum
[pg. 84]

Molecular Layer (Layer I)

Layer II

Pyramidal Cells

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

Stellate Cells

Layer III

Pyramidal Cells

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Stellate Cells

Lamina Dissecans (Layer IV)

Layer V

Pyramidal Cells

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Temporal)

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Stellate Cells

Brodmann's area 49
lLayer II and III have large, densely packed, lightly stained pyramidal cells
No clear distinction between superficial and deep layers; deep layers are continuous with those of the entorhinal cortex.
[pg. 84]

Molecular Layer (Layer I)

Layer II

Pyramidal Cells

Layer V

Pyramidal Cells

Pyramidal Cell (Septal)

Pyramidal Cell (Medial)

Pyramidal Cell (Distal)

Pyramidal Cell (Proximal)

Pyramidal Cell (Mid)

Pyramidal Cell (Distal)

Stellate lCell

dashed line w/ arrow = excitatory
solid line w/ oval = inhibitory

color of line = color of region postsynaptic neuron is in

orange subtopic = inhibitory neuron
turquoise subtopic = excitatory neuron
purple subtopic = both excitatory and inhibitory

ACh Interneuron

contains acetylcholine
<2% of neurons in striatum
largest cells in striatum
axon can extend to 2mm
soma is large (up to 40 m)
long aspiny dendrites (can split into secondary and tertiary)
substance P receptor mRNA localizes here
excitatory

mechanism by which acetylcholine release affects striatum is largely unknown

To NS Parvalbumin+

To NS SOM/NOS

To Patch MSN

To Matrix Direct MSN

To Matrix Indirect MSN

Parvalbumin/ GABA Interneuron

strong capacity to uptake exogenous GABA
medium size

- aspiny
- identified by Ca-binding parvalbumin
- round somata
- smooth, often varicose dendrites
- very branched axonal arborization
- axon forms baskets on somata of spiny projection neurons
- widely-spaced, connected by gap junctions
- axons ramify strictly locally (100-150 m) or extended (>300 m)
- inhibitory

To Patch MSN

To Matrix Direct MSN

To Matrix Indirect MSN

To NS SOM/NOS

To NS Parvalbumin+

SOM/NOS Interneuron

- medium, aspiny (like GABA/parvalbumin striatal interneurons)
- longer, less-branched dendrites than GABA/parvalbumin with a more-extended axonal field
- stains for NADPH-diaphorase, nitric oxide synthase (NOS), somatostatin (SOM), and neuropeptide Y
- distributed in striatum in a gradient: higher in ventral areas and lower in dorsal
- located in both patch and matrix
- axons preferentially distributed in matrix
- although no intense GABA/GAD staining in somata, axons contain GABA
- inhibitory

To Patch MSN

To Matrix Direct MSN

To Matrix Indirect MSN

Patch MSN

- lots of dendritic spines
- composes 95% of striatal neurons
- GABA as neurotransmitter
- soma diameter = 12-20 m
- 7-10 main dendrite branches
- dendrites span 200 m (in diameter)
- extend local axon collateral in striatum
- can have long (~1mm) axon
- receive excitatory inputs from cortex, thalamus, and amygdala (asymmetric synapes on dendritic spines)
- receive responsiveness-modifying inputs from SNr (dopamine) and striatal interneurons (GABA from medium, acetylcholine from large)
- corticostriatal afferents have asymmetrical synapses, small rounded vesicles connecting mostly to dendritic spine heads
- have axon collaterals in striatum that make synapses with interspine shafts or necks of spines of other spiny projection neurons

inhibitory

project to GPe and STN (purple)
beginning of indirect pathway
contain enkephalin
contain D2 receptors (Gerfen et al., 1990)

Patch:
cells develop earlier than matrix neurons
receives early post-natal dopamine input which becomes homogenous through development (Tennyson et al., 1972)
stains for acetylcholinesterase (Graybiel and Ragsdale, 1978)
opiate receptor binding markers (Herkenham and Pert, 1981)

To SN Ventral Tier Dopaminergic Neurons

Indirect Matrix MSN

lots of dendritic spines
composes 95% of striatal neurons
GABA as neurotransmitter
soma diameter = 12-20 m
7-10 main dendrite branches
dendrites span 200 m (in diameter)
extend local axon collateral in striatum
can have long (~1mm) axon
receive excitatory inputs from cortex, thalamus, and amygdala (asymmetric synapes on dendritic spines)
receive responsiveness-modifying inputs from SNr (dopamine) and striatal interneurons (GABA from medium, acetylcholine from large)
corticostriatal afferents have asymmetrical synapses, small rounded vesicles connecting mostly to dendritic spine heads
have axon collaterals in striatum that make synapses with interspine shafts or necks of spines of other spiny projection neurons
inhibitory

project to GPe and STN (purple)
beginning of indirect pathway
contain enkephalin
contain D2 receptors

To GPe Parvalbumin+

To GPe Parvalbumin-

Direct Matrix MSN

lots of dendritic spines
composes 95% of striatal neurons
GABA as neurotransmitter
soma diameter = 12-20 m
7-10 main dendrite branches
dendrites span 200 m (in diameter)
extend local axon collateral in striatum
can have long (~1mm) axon
receive excitatory inputs from cortex, thalamus, and amygdala (asymmetric synapes on dendritic spines)

receive responsiveness-modifying inputs from SNr (dopamine) and striatal interneurons (GABA from medium, acetylcholine from large)
corticostriatal afferents have asymmetrical synapses, small rounded vesicles connecting mostly to dendritic spine heads
have axon collaterals in striatum that make synapses with interspine shafts or necks of spines of other spiny projection neurons
inhibitory

project directly to GPi and SNr (blue), which directly output to the thalamus
beginning of direct pathway
contain substance P and dynorphin
contain D1 receptors

matrix cortical afferents Gerfen 1992
general cortical afferents Selemon and Goldman-Rakic 1985, Donoghue and Herkenham 1986, McGeorge and Faull 1989

To GPi Output

To SNr Output

To GPe Parvalbumin+

To GPe Parvalbumin-

GABA MSN

To SNr

http://www.ncbi.nlm.nih.gov/pubmed/3085570

To GPi

http://www.ncbi.nlm.nih.gov/pubmed/3085570

GABA MSN

To GPi

http://www.ncbi.nlm.nih.gov/pubmed/ 14653187

To GPe

http://www.ncbi.nlm.nih.gov/pubmed/ 3085570

Parvalbumin+

moderately large somata
3-5 primary dendrites (with secondary and tertiary segments)
aspinous, some varicosities
long dendrites (300-400 m)
GABA as neurotransmitter
forms symmetric synapses
inhibitory

discoidal dendritic field (dendrites spread mainly in plane parallel to border between GPe and striatum)
parvalbumin-positive
axon collaterals to STN, GPi, SNr

To STh Nucleus Projection

To GPi Output

To SNr Output

To NS Parvalbumin+

Parvalbumin-

moderately large somata
3-5 primary dendrites (with secondary and tertiary segments)
aspinous, some varicosities
long dendrites (300-400 m)
GABA as neurotransmitter
forms symmetric synapses
inhibitory

dendrites in more of a 3D distribution
parvalbumin-negative
projects mainly to STN (but not all)

To STh Nucleus Projection

To GPi Output

To SNr Output

To Neostriatum

Calretinin/GABA Inter

Ventromedial (Choline)

To Auditory Cortex

http://www.ncbi.nlm.nih.gov/pubmed/1372116

Dorsolateral (GABA)

To Pendunculopontine Tegmental Nucleus

http://www.ncbi.nlm.nih.gov/pubmed/1372116

To STh Nucleus Projection

http://www.ncbi.nlm.nih.gov/pubmed/1372116

GABAergic Output

GABA as neurotransmitter
striatal afferents form small synapses directed mostly to distal parts of dendrites, and very infrequently to somata
pallidal afferents form symmetric, relatively large synapses directed mostly to perikarya or to proximal dendrites
STN afferents are excitatory (glutamate), with asymmetric, synapses directed mostly directed to distal parts of dendrites
projects to intralaminar nuclei of thalamus, and nuclei that project to frontal cortical areas

very similar to SNr GABA neurons, except for ultimately what body parts they control

To Thalamus

To Cortex

ACh Projection

To Neocortex

http://www.ncbi.nlm.nih.gov/pubmed/1372118

To Habenula

http://www.ncbi.nlm.nih.gov/pubmed/1372118

Glutamergic Projection

medium ovoid or polygonal somata, 10-20 m in diameter (in rats)
3-4 primary dendrites with secondary and tertiary dendrites
infrequent spines located preferentially on distal parts of dendrites
dendrites generally distribute in an ovoid area in frontal and sagittal planes
dendrites extend farther in rostro-caudal dimension than dorso-ventral dimension
dendrites distribute roughly equally in medial-lateral dimension as rostro-caudal dimension
immunoreactive for glutamate
forms asymmetric synapses with GPi, GPe, SNr
excitatory projections to GPi, GPe, SNr, sparse projection to striatum
inputs from cortex are excitatory, asymmetric synapses, distributed mainly to dendrites
inputs from GPe are inhibitory, large symmetric synaptical contact, distributed about evenly among soma, proximal dendrites, distal dendrites

To GPe Parvalbumin+

To GPe Parvalbumin-

To GPi Output

To SNr Output

GABAergic Interneuron

GABAergic Output

GABA as neurotransmitter
striatal afferents form small synapses directed mostly to distal parts of dendrites, and very infrequently to somata
pallidal afferents form symmetric, relatively large synapses directed mostly to perikarya or to proximal dendrites
STN afferents are excitatory (glutamate), with asymmetric, synapses directed mostly directed to distal parts of dendrites
projects to intralaminar nuclei of thalamus, and nuclei that project to frontal cortical areas
wef
very similar to GPi GABA neurons, except in which body part they ultimately control

To Thalamus

To Cortex

ACh Projection

http://www.ncbi.nlm.nih.gov/pubmed/1724071

To Superior Colliculus

Dorsolateral (GABA)

http://www.ncbi.nlm.nih.gov/pubmed/1372117

To Inferior Collliculus

Ventromedial (GABA/Dopamine)

http://www.ncbi.nlm.nih.gov/pubmed/1372117

To Amygdala

To Neostriatum

Dopamine Projection

projects to striatal matrix (Gerfen et al., 1987)
striatal projections mostly to dendritic shafts and spine necks, likely to modulate excitatory input to spines (CITE)

To Direct Matrix MSNs

To Indirect Matrix MSNs

To Ventral Tier Dopamine

D**opamine Projection**

projects to striatal patch (Gerfen et al., 1987)
striatal projections mostly to dendritic shafts and spine necks, likely to modulate excitatory input to spines (CITE)

To Patch MSNs

Probable Dopamine Projection

To NS Parvalbumin+

To NS SOM/NOS

Callout