The Cerebral Cortex of the Mouse

(A First Contribution—The "Acoustic" Cortex) *

Rafael Lorente de Nó

Instituto Cajal, Madrid, Spain

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Translated by Alfonso Fairén*, José Regidor†, and Lawrence Kruger§

†Instituto Cajal, Madrid, Spain; ‡Departamento de Morfología, Universidad de Las Palmas de Gran Canaria; §Department of Anatomy and Cell Biology, UCLA Medical Center, Los Angeles, California 90024

This article is part of a series of ongoing investigations, the results of which shall be reported in succession as "contributions," when sufficient data are harvested to justify their publication. In our research, we follow the same orientation as that set forth by our master in his last monograph (Cajal, 1922), since we also think that only the silver methods (silver chromate and reduced silver nitrate), with their enormous resolving power, can enable us to decipher some enigmas hidden in the cerebral cortex.

The white mouse was chosen as the object of study for two main reasons: first, the ease of obtaining young specimens and even fetuses; and, second, the assumption that the textural complexity of its cerebral cortex should necessarily be on a par with the low position this animal has been assigned in the zoological scale—a point emphasized by some previous authors, who have described a reduction in the number of cortical layers, and the total absence of some cerebral areas that are clearly distinguishable in higher animals.

That by descending the zoological scale the number of cerebral "fields" diminishes is a fact irrefutably settled, above all, by the research of Brodmann and his disciples. However, it is also certain that this process of reduction does not extend uniformly over all the [cortical] "areas." The reduction and disappearance of some [fields] is accompanied by the expansion of others and perhaps by the appearance of new fields related to the [specialized] cerebral functions the animal possesses. For example, in the monkey, the Regio temporalis already lacks fields 36, 37, 38, 41, 42, and 52 (Brodmann, 1909) and yet the Regio retrosplenialis, which is totally atrophic in man, is most amply developed in rodents, where field 29 can be subdivided into six portions—29a, 29b, 29c, 29d, 29e, and 29f—although these portions have a basically analogous structure (Cajal, 1922).

However, we cannot say the same when dealing with the intimate details of [cortical] structure. We do not believe in the "simplification" of the cortex. Indeed, a glance at the illustrations that accompany this article should be enough to become convinced of the enormous complexity of the Cortex cerebri in the mouse. The rich quantity of short-axon neurons, and the intricacy of the collateral branches of the neurons with a long axon, testify to both the incredible number of pathways for the nervous impulse and the modalities of interneuronal relations.

By comparing our illustrations with those of our master (Cajal, 1899a,b, 1900a,b, 1901, 1911) that refer to the human cerebral cortex, it is difficult to find a [single] detail that characterizes the latter. [In the human cortex,] we cannot prove the existence of special cells nor that of a greater number of layers—qualities that have been attributed to the human cortex. We can only note a greater number of cells [in the human cortex], but this in no way alters the fundamental architectural plan.

With this we do not pretend, by any means, to assume an essentially identical architecture of the cortex in a series of mammals. However, we will maintain that the differences and variations that we can observe are limited to what we have mentioned about the number of "areas"; the rest [of the differences] will remain
obscure until we possess more selective methods than those currently available.

We have stumbled across another problem, and one by no means less important: The proposal by Munk about the projection of the sensitive peripheral apparatuses on the brain was upheld, on theoretical grounds, by many scholars after him. It had illuminating experimental confirmation from Minkowski (1913) and the Vogts (1919). Today, there can be no doubt that the peripheral sensory organs project in an orderly manner onto the brain, in spite of the numerous relay stations of sensory excitation. However, once it reaches the gray matter and is distributed within it by way of Cajal fibers (Kölliker, 1896), this excitation, instead of being constricted and limited to a few neurons, is dispersed in such a manner that it is unlikely that one single cell is not influenced by a part of such excitation. Indeed, according to the law of "axopetal polarization" (Cajal, 1897a), which is now accepted by all, or almost all, authors, each short-axoned cell by its axon, and each cell with a long axis-cylinder by its axonic collateral apparatus, will relay this influence to an infinite number of neurons, which in turn will communicate in a novel manner to the others; the process is repeated in a continuously maintained fashion. What is the mechanism by which sensory impressions are restricted to a specific cerebral region?

A favorite subject of study for most neurologists, perhaps no organ has been more explored than the cerebral cortex. There are numerous works referring to it in the scientific journals of the last three decades. To summarize briefly what we know today, with appropriate acknowledgment to the illustrious scholars who devoted their attention to this, is an almost impossible task. Those interested in this question from a historical point of view should refer to the monographs on the subject written by Kölliker, Cajal, Bonne (1906), Brodmann (1902), and the Vogts (1919), and to the most recent book by Ariëns Kappers (1921); here we restrict ourselves to exact reference to details concerning our assertions.

Before initiating a description of the "acoustic area" of the mouse, we must discuss the "tectogenetic type" of Brodmann and other scholars.

Based on the data gathered during his investigations on the brain of a great number of animals and of their embryos, Brodmann formulated the hypothesis that all the neocortex derives from a unique "tectogenetic type," composed of six layers that correspond to those of the typical adult cortex. This six-layered phase may remain unchanged throughout the ontogenetic process, or may suffer a transformation, either by increasing [the number of layers (Schichtenvermehrung)] or by decreasing [it (Schichtenverminderung)], in all cortices of the neopallium. The fundamental tectogenetic type should be common to all mammals and to the entire neocortex. This idea formulated by the scholar of Berlin [Brodmann], defended in toto by some authors, has been refuted by others and modified by most; the lack of agreement is significant and must alert us, for in science it is a general law that a repeatedly modified concept ultimately is rejected. Albeit without sufficient evidence, we will dare to state the lack of homology in the development of the different areas; we do not accept a unique tectogenetic type, not even for Brodmann's homogenetic cortices (Vogt's Isocortex). The reason is obvious. In the neopallium there are areas where the granular layer (layer IV) is completely absent (e.g., the peristriate area, type 18 of Rose, in the mouse). We cannot assume that it has existed in earlier stages [of development], and, even less so, that the "granule cells" may have evolved to become cells of a different nature, as van'T Hoog (1920) proposes. Brodmann merely mentions a "Schichtenvermehrung" [enhanced lamination] and a "Schichtenverminderung" without giving us any further indications on the nature of this "Umwandlungsprozeß" [transformation]. However, van'T Hoog (1920) declares quite precisely that the granular neuron is the neuron par excellence, which can evolve to form a pyramidal cell or to remain as a granule, depending upon the circumstances. We invite the Dutch scholar to reconsider his thesis and to determine the manner of transformation, for it is not only the somatic shape—a fortuitous circumstance, in a sense—but the connections its axon establishes that characterize a neuron. His hypothesis also forces us to invoke complicated phases of transformation, which are only possible at the stage in which the cell has not yet acquired its definitive character, when it is inappropriate to apply a precise name other than that of layers of undifferentiated neuroblasts [1].

Under such circumstances, we can ask whether there is any firm basis on which to seriously sustain the [theory of the] tectogenetic type. We believe that there is none. The authors who have dealt with this subject have restricted themselves to findings based upon the method of Nissl, and thus speak of neurons as "grains" (granule cells), "pyramids," "corpuscles," etc., only examining the shape and size of the soma, and this assuredly is erroneous. For example, examine Figure 2, where certain large neurons in layer IV we should call "giant pyramids" based on their shape, but they can justifiably be called simply "short-axon neurons" in Figure 11.

In summary, we believe that a single general tectogenetic type does not exist, nor is there one architectural plan that can be applied to the whole cortex [2].
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As stated above, certain authors have modified the genetic type of Brodmann. With this [attitude], one can only evade the difficulties temporarily, since ultimately one can [raise the objections as mentioned above].

LOCALIZATION

We possess charts of the cerebral areas of the rodent’s brain, derived from the work of Brodmann (1909), Flores (1911), Isenschmid (1911), de Vries (1912), Rose (1912), and Fortuny (1914); the last four refer to the mouse. These maps are by no means superimposable, although it might logically be expected because the same methods are used by those authors. Fortunately, however, for the zone studied here by us, there is essential agreement except for the findings of Isenschmid.

In Figure 1 we represent a section of a cerebral hemisphere of a mouse, projected with the apparatus of Edinger. Zone A is the region under study in this work, and is the shaded region a, represented at higher magnification in Figure 2. On page 6 we reproduce Rose’s chart. Comparing our preparations with the drawings that accompany the monographs of other authors, it is evident that the structure of zone A (Fig. 1) is preserved within an area corresponding to the most anterior region of field p in Fortuny’s chart, to the posterior region of H (H 2) in I. de Vries’s chart, and almost exactly to Rose’s field 22.

We have called this cortex “acoustic,” in support of the opinion of Rose who, assuming it to be homologous to the human field 22, tacitly accepted its auditory function. Fortuny disagrees with this dictum, and wields an apparently very strong argument against it. He measures, in several specimens of mice, the number of fibers in the cochlear nerve and the number of cells per cubic millimeter in the cortex of area p. He finds that, although the wealth of cochlear fibers bears a relationship with the auditory acuity of the animal, the number of cortical cells is approximately constant. However, the measurements made by Fortuny refer to an area that is exceedingly large and that comprises several fields of totally different structure. We can [safely] assume that a quite different result would have prevailed if his numerical data had referred only to the anterior part of his field p (Rose’s 22). Thus, until the

FIGURE 1. Coronal section of a cerebral hemisphere of the white mouse, shown to illustrate the zone studied, A; a is the portion of cortex reproduced at a higher magnification in Figure 2.

FIGURE 2. Cerebral cortex of the mouse (Rose’s area 22). Roman numerals indicate the layers we have differentiated. In layer IV, the dashed lines indicate the limits of the glomeruli.
Areal differentiation in the external surface of the mouse cerebral cortex (after M. Rose). The area studied is area 22.

corticopetal fibers from the [acoustic (medial)] geniculate body are followed to its cortical termination, we cannot determine with any certainty the acoustic function of the area in question. Nevertheless, we accept as sufficiently exact the cytoarchitectural criterion used by Brodmann and Rose for identifying this area. In any case, although we cannot positively affirm that it is acoustic, at least we are probably safe in assigning a sensory function to it.

Indeed, as Cajal demonstrated in 1899 [Cajal, 1899a], there are at least two types of cortices in the mouse: those that receive fibers coming from the corpus striatum, and others that lack or possess very few connections of this type. He assigned to the former the title of sensory or perception spheres, and among these we can find the one studied by us, whose layer IV consists of a very thick plexus composed of terminal ramifications of a copious stream of fibers penetrating the corpus striatum.

In the hope of shedding light on this important problem, we have embarked upon some specific research and tentatively shall continue to call this region "acoustic."

TECHNIQUE

We will be sparing in discussing methodology, for the methods are well known. When using the methods of Nissl and Weigert, we have stuck rigidly to the instructions included in all the current "Manuals" [3] and the Cajal reduced silver method [will] be described in greater detail in a communication to appear in the Zeitschrift für wissenschaftliche Mikroskopte. * There is no need to describe the silver chromeate procedure, and we will limit our technical considerations to some crucial information regarding the age of the animals. If one hopes to successfully pursue the pyramidal and afferent axons, together with the callosal fibers, one must use mice that are 8 to 10 days old; but if what one wants is to study, in its totality, the incredible collateral apparatus of the long axons and the extremely complicated terminal branching of the short axons, then it is necessary to use the brains of 18- to 25-day-old animals, when the myelinated plexuses have reached their full splendor.

DESCRIPTION OF THE CORTEX

Consistent with Isenschmid, Fortuyn, de Vries, and Rose, and in essential accord with Brodmann, we will differentiate six layers, without including the white matter. By accepting this stratification, now [considered] classic, we are merely following the mainstream, but without protest, and [not] without declaring again that such a stereotypical cortex is not applicable to all the [cortical] areas. What we cannot accept is the absolutely improper nomenclature that many authors defend. We propose the following:

I. Plexiform layer (Cajal) or molecular [layer] (Meynert) (lamina zonalis of Brodmann).

II. Layer of modified pyramidal cells (lamina granularis externa of Brodmann, lamina corpuscularis of Vogl).

III. Layer of small and medium-sized pyramidal cells (lamina pyramidalis of Brodmann).

IV. Layer of stellate cells and of glomeruli of exogenous fibers (lamina granularis interna of Brodmann).

V. Layer of large pyramidal cells (lamina ganglionaris of Brodmann). This layer should be divided into three subzones: external, medial, and internal (Vₐ, Vₐ⁻, and Vₐ, respectively).

VI. Layer of polymorphous cells (lamina multiformis of Brodmann). This layer can be divided into two subzones that correspond to those differentiated by Meynert and Cajal, among others: one superficial [subzone,] Vₐ, the subzone of medium-sized, globular pyramid cells and stellate neurons with callosal axons; and another deep [subzone,] Vₐ⁻, [the subzone of fusiform and triangular cells.]

As we shall see below, the principal criterion for a rational stratification is provided by the plexuses of fibers and of protoplasmic processes that occupy each layer.

Figure 2 is an illustration from a section stained with the Nissl method, as projected with the Edinger apparatus, and then completed from the [microscope] image. The limits of the layers, coinciding with those assigned by the above-mentioned authors [4], can be seen within it.

I. PLEXIFORM LAYER

The composition of this stratum does not vary, either in the animal series or in the different cortical areas.
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Therefore, we can add nothing to what has already been noted by Kölliker, Retzius, Bevan Lewis, Golgi, Martinotti, and, above all, by Cajal. The [neuronal] elements that inhabit therein, stained in our preparations, are:

1. The so-called Cajal cells, discovered by him in 1890, whose existence was verified by Retzius in man in 1893, and by Kölliker soon after that. They possess a [cell] body that can be pear-shaped, stellate, fusiform, etc., with long, spineous dendrites and a robust and extremely long axon, provided with angular, sharp collaterals (Fig. 15, K).

In spite of our efforts, we have been unable to trace the termination of the axons; Cajal, in man, followed its passage from one convolution to the next without showing any tendency to taper or to descend [to lower layers], and we, in the mouse, have followed it in the hemisphere; it is, then, likely that it terminates within the same layer.

Since we have carried out our observations on 15-day-old animals, the [developmental stages] described by both Retzius and Cajal in man have already disappeared. Sporadically, we were presented with a unique type, already observed by Cajal in human (acoustic cortex). Our master calls it rudimentary short-axonated corpuscle, and we follow his opinion (Fig. 7, E).

Brodmann (1910), when describing this layer, states that Cajal's cells do not exist there beyond the embryonic period, reducing its role to the production of amytelinic fibers, [and] therefore he christens them "fibroblasts." It requires little effort to demonstrate the error of the German scholar. It does not even require the examination of a Golgi or a Cox preparation, but just that of a simple Nissl preparation. In this, the cited elements can be found, with a form similar to that provided by the silver chromate method. These cells undoubtedly possess a high associative function.

Before completing this description, we should take into account some types of "Cajal cells" with complicated axons, which we have drawn in Figure 10, F. The dendrites, instead of remaining in layer I, descend to layer III and the axon splits into various branches, some of which are short and end promptly in pericellular arborizations, and others are long. These probably are a transition type toward:

2. Short-axon cells, only observed until now by Cajal, who has carried out an exhaustive description of them (Cajal, 1897b); in Figure 11, I, we depict some of these.

3. Terminal arborizations of the protoplasmic shafts of the cells in the inner strata. [These arborizations] have been described by almost all authors who have used the silver chromate method—Cajal (their discoverer), Retzius, Bevan Lewis, Kölliker, Azoulay, among others—and we have added nothing new thus far. Contrary to what is commonly believed, not all the [apical dendrites] reach the plexiform layer; apart from the stellate cells in layer IV, whose dendritic branches remain therein, a large number of cells from layers V and VI send their [dendritic] shaft provided with a terminal arborization to the protoplasmic plexus of layers Va or IV.

4. An extremely dense plexus of fibers, most of them unmyelinated, whose description follows below. Initially, we shall only review their components:

   a. Recurrent collaterals of pyramidal axons, those of stellate cells and, in general, [those of] all cells with long or semilong axons.

   b. Axonal terminal ramifications of cells with ascending axons.

   c. Projection and association fibers coming from the white matter.

   d. Arborizations of short-axon cells.

II. LAYER OF MODIFIED PYRAMIDAL CELLS

According to Rose (in his field 20), this layer is well differentiated. It contains few granule cells, and it is made up principally of polygonal cells, except for some medium-sized polymorphous elements. In area 22, the laminae granulares externa and pyramidalis are very cell-sparse and cannot be readily differentiated.

In sections stained by the Nissl method, [this layer] appears [to be] made up of two or three rows of tightly packed [cell bodies], which adopt a great number of forms—polygonal, stellate, fusiform, etc.—whose size is rather irregular, mixed with other minute, more or less spherical [cells] (Brodmann's granules).

In Golgi preparations, we find the following elements:

1. Modified pyramidal cells (Fig. 3, C). These are cells analogous in size to the pyramidal cells. Their somata adopt different forms: triangular, oval, stellate, etc. Their dendrites, always covered with collateral spines, arise either directly from the soma or by way of a thick stem, and although at their origin they follow numerous directions, they always end running together in two zones, layers I and III.

   The ascending dendrites, on reaching the molecular layer, become horizontal and cover great distances, usually ending near the pia mater. As a detail not without interest, we shall note that the terminal protoplasmic ramifications of these cells in the molecular layer is much more widely spread than that of the deep pyramids, whose [dendritic] shaft sprouts two or three branchlets of almost vertical trajectory.

   The descending dendrites form part of the protoplasmic plexus in layer III.
The axon, which can arise from any point on the soma or from a thick dendrite, orient toward the deep layers, behaving in exactly the same way as that of the small pyramids (see below).

We have intensively searched in Golgi and Cox preparations for the equivalent of the minute spherical cells (Brodmann’s granules) detected by the Nissl method. We have found that they are dwarf pyramids, with a spherical [cell] body and thin dendrites, and with an axon that is analogous to that of the aforementioned cells. Nothing can be more improper than naming them granules; the name of dwarf pyramids should be substituted [5].

Undoubtedly, the modified pyramids are the most abundant [neuronal] elements, but there also exist:

2. Large stellate cells. As Cajal has recently shown in the retrolaminal cortex, this unique type of cell forms a single stratum [Cajal, 1922], but in the area studied by us they are scattered into the second layer. The soma, which is somewhat larger than that of a pyramidal cell, emits dendrites in all directions (see Fig. 3, A and B); from the lowest part, a thick axon arises that, after abandoning numerous recurrent and horizontal collateral, reaches the white matter.

3. Short-axon cells. [These are] so numerous and with such a variety of forms that any description must be incomplete. Those [cell types] that seemed most noteworthy to us are [the following]:

a. Cells with a spherical [cell] body, delicate, spinous dendrites and a descending axon, branching mainly in layer IV (glomeruli), but also giving off collateral branches to layers I and V (Fig. 6, D and E).

b. Cells with a spherical [cell] body and thick, spinous dendrites lacking any precise orientation and an axon arborizing within the limits of this layer (Fig. 6, A). Both types of cells are larger in size than the neighboring pyramidal cells.

This layer has been considered to be a clustering of special[ized] cells by almost all authors. Thus, Schaffer (1897), based upon rather old observations (1893), names it the layer of superficial polymorphous cells, considering its [neuronal] elements as homologous with those of the layer of vertical fusiform cells (or polymorphous [cells]) of Cajal (1891). The Hungarian scholar [Schaffer] already distinguished most cells present therein, which comprise short-axon cells, cells with a medium to long axon (which reaches the middle region of the cortex), and cells with a long axon that reaches the deepest layers and perhaps even the white matter. Bevan Lewis (1897) has a similar opinion and names [this layer] a [layer] of grains or polymorphous cells [6]. Brodmann, and almost without exception all authors after him, call it the superficial granular layer, but without giving the least detail of the relationships of their dendrites, of the axonal trajectories, etc. Vogt [and Vogt] dissent from this opinion, and describe this layer as formed by corpuscles (Körperchen) smaller than the granules in layer IV; they call it lamina corpuscularis or Körperchensicht.

In the retrolaminal cortex, which is where it acquires the largest development, Cajal finds it to be composed of bipolar cells with a long axon.

In our opinion, the cells in this layer do not possess any special characteristic. They are legitimate pyramidal cells, whose form has varied to adapt themselves to the function that they have to carry out. This modification is easily explained in terms of the laws of economy of time and matter, invoked by Cajal (1897a) to explain the longitudinal and transverse integration in the ganglia, and that of the tendency of the neural elements
to cluster together forming surfaces, to better capture
the nerve impulse, as shown by Ariëns Kappers (1914).

Indeed, the nerve fibers from which these singular
cells receive nerve impulses group together in two zones,
the molecular layer and the pyramidal layer [layer (III)];
to the same [two] layers, by virtue of tropic mechanisms
(neurotropism, according to Cajal; neurobiotaxis, ac-
cording to [Ariëns] Kappers), the dendrites extend from
layer II cells, while only the [cell] somata remain [within
the layer].

It is easy now to understand the variability of the form
of its cells according to the expanses they occupy
within the layer, and the small dimensions of the inter-
cellular spaces.

In brief: Layer II is nothing more than the upper
portion of the layer of the supragranular pyramids,
whose cells have been modified to occupy as little space
as possible.

III. LAYER OF SMALL AND MEDIUM-SIZED
PYRAMIDAL CELLS

This layer has several rows of pyramidal cells; among
them, a large number of short-axon neurons are inter-
mingled.

1. Pyramidal cells. We no longer need enter into
description of the types of small and medium-sized
pyramidal cells, since, thanks to the studies by Cajal,
Kölliker, Retzius, and Schaffer, among others, and to
the early, albeit very incomplete, studies by Golgi and
Martinotti, they are well known. We shall limit ourselves,
therefore, to the description of the axons. According
to this, the supragranular pyramids can be divided into
two classes:

a. Pyramids with a short, descending axon (Fig. 4,
A, B, C). The axis-cylinder descends vertically to
layer VI, in whose upper limit it breaks up into a loose
and very arborization, preceded generally with a
preterminal swelling (a1, b1, c1). Throughout its length,
the axon sprouts an abundant number of collaterals
at right angles, and in all directions. Some are recurrent,
toward layer I (discovered by Martinotti [1889]) and
layer III; others are horizontal, toward [layer] V. Layer
IV does not receive [axonal] collaterals from pyramidal,
or, if indeed it receives [some], it does so in very small
numbers since those [collaterals] existing there are the
recurrent ones, en route to layer III. The accumulation
of these collaterals in layers I, III, V, and VI gives rise
to a dense, close-knit plexus of straight fibrils that are
scarcely dichotomized, [and] that we will describe below.

b. Supragranular pyramids with long or callosal
axons. Judging by the evidence of our preparations,
these cells are less abundant than the latter, and they
inhabit the deeper regions of the stratum. The axon
(Fig. 5, D and E) does not possess more than one or
two recurrent collaterals; almost without tapering, it
reaches layer V, where it gives off two or three branch-
lets, and continues into layer VI, where it leaves, if
not just as many, only slightly fewer collaterals than
those of the aforementioned class [of pyramidal cells].
Finally, it reaches the white matter, where it joins the
fibers of the corpus callosum and reaches the opposite
hemisphere.

In spite of our efforts, we have never seen a su-
pragranular pyramid axon continue into the corpus
striatum, but we do not dare to deny the possibility of
its existence, since the Golgi method does not permit
negative assertions without an enormous number of
observations. Therefore, provisionally, we can leave
as settled that: The axons of the supragranular pyramids
always have a[n] [intracortical] trajectory; that is, either
they do not leave the area in which they originate, or
they join the corpus callosum to extend to the opposite
hemisphere.

Both classes of pyramids have been described by Cajal.
In 1890, our master said: "The descending axons of these
cells terminate at different levels of the middle and deep third
of the gray matter by free and varicose branches which lose
their individuality as [main] axons. Never have we seen the
arrival of an axon, not even in the smaller mammals such as
the mouse and the bat, at the white matter or the corpus
callosum." In 1891[1] he already alluded to pyramidal [cell]
axons that have entered the white matter. Both discoveries
were overlooked, in part because they were published in
foreign journals.*

The size of the pyramids varies over wide limits,
and it cannot be said that the deeper they are [located],
the larger they are. Small and large [pyramids] in-
termingle without any regular pattern, although it would
appear that the [large pyramids] predominate in the
deep regions of the stratum.

2. Short-axon cells. The majority of the cell types
of this class belong to layer IV, where we shall describe
them. Those that can legitimately be considered as
belonging to layer III are [the following]:

a. Cells with an ascending axon, ramified in the
plexiform layer; of these, some [that are] spherical also
send their dendrites to layer I (Fig. 7, D), and others
[that are] fusiform or polygonal maintain their dendrites
in layer III (F and H).

b. Cells with a bitufted axon (Fig. 7, C), with a
stellate or fusiform [cell] body, whose axon rami
fies in a multitude of ascending and descending branches
that, by being provided with collateral fibrils, form a
densely woven vertical plexus stretching from the con-

* Translators' note: See Cajal (1891) for source.
Fines of layer I to those of layer Vc. Undoubtedly, they represent the bitufted cells of Cajal; like these, their axonal ramifications are destined for embracing the [apical dendritic] shafts of the large infragranular pyramids.

Cells that are destined for bringing together a large number of pyramids in a synergic action are the following:

c. **Large stellate cell** (Fig. 7, G), whose axon follows a horizontal trajectory and breaks up into a plexus of vertical fibers, always enclosed within the limits of layer IV.

d. **Stellate cell**, whose vertical axon ascends, forming a plexus of horizontal branches, and finally reaches layer I, where it divides into two tangential fibers (Fig. 6, B).

e. **Stellate cell**, [a] very abundant [one], whose vertical, ascending axis-cylinder emits thick collateral branches along its course, reaches the plexiform layer, and divides into several tangential fibers. Both from the axon and from its collaterals, numerous vertical twigs sprout, which end in thin round balls covering layer III, in much the same way as the branches of a weeping-willow tree (Fig. 13, E).

**IV. LAYER OF STAR CELLS AND OF GLOMERULI OF EXOGENOUS FIBERS**

[This layer] reaches such an unusual and complex level of development in the acoustic area that, in spite of repeated attempts, we have been unable to unravel the tangle of nerve fibers and dendrites existing therein.
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According to Rose, the *lamina granularis interna* is readily apparent. I. de Vries, in his more complete description, states that the cells group together in small fields of elliptical or quadrate form, clearly visible in Van Gieson-stained preparations.

The Nissl method shows that the most abundant element is a small cell, a little smaller than the supra-granular pyramids, [that is] poor in protoplasm and of variable form. These are the granules of some authors. However, [the Nissl method also shows that] large cells are also numerous, [and these] have abundant protoplasm and a structure that corresponds to that of the short-axon neurons.

Figure 2 demonstrates that de Vries's observation cannot be more accurate. Layer IV is divided by vertical columns, extending throughout its height as quadrate-shaped pale territories. Even though both the columns and the pale territories are made up of the same [nervous] elements, the columns would appear to be richer in large neurons (or [those] with a short axon).

The Golgi method allows [us] to expand this description and to conduct a study in depth of the [nervous

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**Figure 5.** Cells with a callosal axon from layers III and IV. D and E, supragranular pyramids; d and e, their axons; A, B, and C, star-pyramids; a, b, and c, their axons. The limits of the glomeruli have been marked in layer IV. The arrow indicates the course of the fibers of the corpus callosum.

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elements] that constitute the zone in question. Although infrequent, in those sections where the chrome-argentie reaction took place preferentially in layer IV, leaving layers III and V free [of staining], [layer IV] appears composed of clusters of neurons, separated by pale vertical bands, as is shown in Figure 8. The cellular masses correspond to the pale territories of the Nissl method, and the bands to the columns shown by the same method. As we shall see below, the dendrites of the neurons of each cluster do not extend toward their neighbors, and the fibers of Cajal, which are the carriers of sensory impulses, branch out almost exclusively in this layer so that, in general, each afferent fiber produces final branches only for one of the just-described clusters. In this way, fibroprotoplasmic [i.e., axodendritic] associations are built up, which are totally analogous with the well-known [associations of this type] in the olfactory bulb. This analogy is the reason why we have named them glomeruli. We shall expand below on the role of these notable formations. For the moment, we just shall simply offer the hypothesis that they are homodynamic groups of neurons.

In what follows, we shall briefly enumerate the characteristics of each type of neuron:

1. Star [spiny stellate] cells (granules) (Fig. 9, A, B, C, D). We assume that these [neuronal elements] are homologous with the stellate corpuscles with a long axon described by Cajal in man and cat visual cortex. It is true that those we have seen are smaller, but as far as shape and [axonal branching pattern] are concerned, the identity is absolute. It may well be that the differences in volume correspond to the differences in the sizes of the animals studied. In the visual cortex of the mouse, there exist in [its] layer IV, if in a somewhat modified form, these same elements that we are going to describe. The soma is small, and its sparse protoplasm is distributed around the nucleus as a narrow crown [that is] reddish and transparent. Arising from the soma [there are] two, three, or four long, tenuous and spinous, profusely ramified dendrites, and a single axon. The manner in which the dendrites are distributed is quite special: All of them are oriented toward the center of the glomerulus, where the cell becomes the origin of the above-mentioned associations (Fig. 8). Accordingly, the form of the [cell] body varies (being either mitral, fusiform, stellate, inverted mitral, etc.), depending on the location of the cell within the glomerulus. Attempting to describe all the [possible] forms that the cell bodies may adopt would be an unreasonable task. But, merely by stating that the cells at the center of the glomerulus send out their dendrites in all directions, while those that are on its periphery send them in one
unique direction, toward the center [of the glomerulus],
we have formulated the law governing the somatic mor-
phology.

The axon, which is thick at its base, may arise
either directly from the cell body or, more often, from
a thick dendrite, and runs toward the deep regions
without reaching the white matter. In the confines of
layer VI, it repeatedly divides to produce a loose and
widespread arborization that embraces the whole lamina
multiformis. However, before arriving at this stratum,
[the axon] has emitted abundant (more than 10) recurrent
collaterals [destined] for layers III and IV, and horizontal
[collaterals] for layer V. Most of the recurrent collaterals
enter either into the glomerulus where the cell is located
and from which they proceed, or into the surrounding
[glomeruli], where they ramify.

Undoubtedly, this is the same case as that described by
Cajal for Purkinje cells, whose collaterals establish links with
the neighboring homologous cells, but here it is even more
evident, due to the special disposition [of the cells] as glomeruli
or isodynamic groups.

Let us comment in passing on the role played by the
[axonal] collaterals. Its function has been disdained by most
authors, but it has received the special attention of some
scholars. The opinions can be reduced to two: that of Len-
hossék and Schaffer, and that of Cajal. The former consider
that "the initial collaterals form, with the dendrites, a special
physiological class, [designed] for reception; only the terminal
collaterals have the [functional] significance of transmission
apparatuses." Cajal considers that all the collaterals play the
same role: that of transmitting part of the impulse carried by
the axon to the nearby cells, whether these are of the same
or of a different nature. For example, the axon of the Purkinje
[cell] gives off collaterals for the homologous cells of the
same lamella and for certain pericellular plexuses described
by him in the granular layer (Cajal, 1912). Our belief is that
the opinion held by Cajal is correct; [that is,] the first and
the last collaterals must share an identical function, because
the first or the fourth or fifth collateral may arrive at the
plexiform layer, and frequently one of the last collaterals
divides into branches, [which are] ascending to layer I while
remaining horizontal in the lower layers. In addition, nothing
is more evident than the fact that the [axonal] collaterals may
establish connections with different cellular categories. For instance, the collaterals of the above-described star (stellate) cells distribute into the glomeruli and into layers V and VI, establishing relationships with cells of such different nature as the pyramids, polymorphous [cells], and granules.

2. Star-pyramids. Although less than half [of the star (spiny stellate) cells], a notable portion of them possess a thin apical dendrite that, after crossing layer III, ends by two thin protoplasmic branches in the lamina zonalis; these cells, which are a mixture of star cell and pyramid, we call the star-pyramids (Fig. 5, A, B, C). The axon [arborizes] in a manner analogous to that of typical star cells, filling all the cortex with collateral branchlets; but it also emits a thin fiber to the corpus callosum, and it is not infrequent to find that the branch directed toward the white matter bifurcates and that one of the daughter branches extends toward the corpus callosum while the other goes in the opposite direction, but without ever reaching beyond the corpus striatum.

We do not know whether it is coincidental to have consistently found the axon of the star cells with only an intragriseal trajectory, and that of star-pyramids with a callosal branch. To be certain, these observations will need to be repeated a hundred-fold. Thus, this constitutes no more than a provisional characterization.

3. Fusiform cells with a long axon. In Figure 10, and in Figure 15, F, we have brought together the extreme examples of these [cells] observed in our Golgi preparations. We are dealing with a cell that exists in all the sensory cortices (acoustic, visual, sensory-motor, etc.) and is distributed over layers III, IV, and V, with different shapes depending upon the level in which it is located. It has a fusiform [cell] body that emits ascending and descending dendrites. The [ascending dendrites] usually reach the plexiform layer, while the [descending dendrites] do not end far from the soma. If the cell is located in layer III, the [descending dendrites] do not leave [this layer], but if the dendrites emerge from a cell in layer IV, they extend to [the layer] of the large pyramids. The axon also varies somewhat according to the position of the cell body, following the law of Cajal, according to which the axis-cylinder always produces branching collaterals in the nucleus of origin. Therefore, the upper cells (A, C) disperse most of their collateral apparatus within the pyramidal cell layer, while the deeper cells (B, D) do not possess recurrent collaterals, except for layer IV. For the remainder, the axonal trajectory is the same: After giving off 10 to 15 collateral branches in layers V and VI, they reach the white matter where, unfortunately, we have been unable to follow them (Fig. 10, A, B, C, D, and E; Fig. 15, F).

4. Displaced pyramids. Last, and for the sake of completeness, we must mention the presence of some pyramids that are completely analogous with [the pyramids in layer] III, but [that] appear to be rather scarce.

5. Short-axon cells. Perhaps it is in the layer of star cells where the short-axon cells are in greatest numbers and where they acquire their greatest magnitude. Their number and the variety of their morphology make a systematic description difficult. For the moment, we will disregard many of them, and will limit ourselves to mentioning those cells that appear to us to be most frequent and most characteristic.

a. Pyramids with axons arborized in layer V (Fig. 17, B).

b. Giant cells with a pyramidal soma, from which four or five dendrites sprout in all directions, although never far distant from the cell body, and a descending axon, which soon bifurcates. Each branch of the bifurcations breaks up into a handful of fibers distributed in layers I, III, and V (Fig. 11, C).

We state, definitively, that the examination of the dendrites is sufficient to determine whether a cell has a large or a short axon. In the former, the protoplasmic prolongations, which are uniform in thickness, are covered by many collateral spines, while the short-axon cells have dendrites resembling a rosary, whose thin parts are completely smooth in contour and whose thick parts are spinous, like the roots of vegetable tuberules.

c. The quadrangular cell is medium-sized and distributed in layers III and IV, with an ascending axon that extends into layer I, from which numerous descending fibers sprout, which repeatedly divide and subdivide to produce a plexus that extends over layers III, IV, and V (Fig. 7, A and B).
d. Colossal cells, with a fusiform or triangular [cell] body, with dendrites in the layers of large pyramids and of star cells, and an ascending axon that reaches the lamina zonalis. In its ascending course, the axon gives off some four, five, or more very large horizontal branches, which create a plexus that encompasses the entire layer of supragranular pyramids (Fig. 11, A, B, D, E, F, H). These cells, which are easily recognized in Nissl preparations by their size, inhabit layer IV and superficial regions of layer V (Fig. 11, H).

e. Quadrangular cells, a little smaller than the [cells described] above, are typical of layers IV and V. Their form is similar to the former, but differ in that the axon, instead of arborizing [around] a central trunk, dichotomizes several times until it terminates in the upper limits of layer III. In Figure 12, we give an account of the main types of these cells and the distribution of their axons.

f. Medium-sized cells with an ovoid or fusiform [cell] body that emits a long descending dendrite that reaches layer VI and several ascending [dendrites] in a fan-like arborization. The ascending axon produces a very dense plexus of small expanse, where there is hardly space left for the bodies of the pyramids and the star cells. This cell, which inhabits layers III, IV, and V A, modifies its form somewhat according to the position it occupies, but it always adheres to the plan described. We show some [examples] in Figure 13. In
A, B, and D we have only drawn the primary and secondary branches [of the axon], while in C we have attempted to provide an account of the very intricate plexus formed by the totality of their fibers.

g. Medium-sized, stellate cells with a glomerular axon. While in the [medium-sized cells described above], the ascending axon distributes itself over other strata, in these [cells] both the dendrites and the axon remain in layer IV and, even within the same glomerulus. The illustrations given in Figure 6, C, and Figure 7, I, enable us to omit a detailed description. Their customary location is the central region of the glomerulus, and their axons form an arborization that reproduces the form of [the glomerulus] while surrounding and contacting all the neurons of the cluster and impinging upon all of them simultaneously.

h. Finally—although in reality they do not form part of this layer—we shall mention the presence of some medium-sized cells in the lamina ganglionaris, whose axons ascend to layer IV where they distribute over neighboring glomeruli (Fig. 7, K).

V. LAYER OF LARGE PYRAMIDAL CELLS

This is a broad lamina, easily evident in Nissl preparations by its relative paucity of cells and the consequent increase of intercellular spaces, in addition to the greater size of its neurons. According to Rose, in area 21 it
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can be subdivided into three sublayers: The superficial and deep ones [are] pale, and the middle one [is] made up of large pyramidal cells. In area 22, it is much richer in cells.

In Figure 14, taken from a thionine-stained section, the three sublayers described by Rose appear with clarity. The superficial layer, Va, is the poorest in cells and is made up of small pyramids (b), medium-sized [pyramids] (k), and neurons with ascending short axons (c, d). In the middle [layer, Vb, we find small and medium-sized pyramids together with the large or giant pyramids (a), whose protoplasmic prolongations stain poorly with thionine, producing a finely granulated background. Finally, in the deep [layer] (Vc) the cells are more abundant than in the superficial one, encompassing within it: small pyramids (f), medium-sized [pyramids] (k), neurons with ascending short axons (g and h), and, on the border with [layer] VI, certain medium-sized stellate [neuronal] elements that are rich in protoplasm (e) and that, as we shall see further on, give rise to the thick fibers of the corpus callosum. Silver chromate, which in young mice reveals a pre-
dilection for these elements, allows us to classify them in the following way:

1. Large pyramids. In general, we can apply the old descriptions by Cajal, Kölliker, Retzius, etc. Yet they reveal certain peculiarities worthy of note, which we set forth as follows: The [cell] body surpasses in size all other cortical cells, without reaching the dimensions of its counterparts in the motor area; even among the other [types of] pyramids in the layer, there are [cells] of the same size [as the large pyramids]. It is not the size, but the number of dendrites they produce that is their characteristic feature. Actually, 12 or 14 dendrites (7) leave the soma in all directions. A robust, ascendent [apical] shaft produces 15 or 20 more dendrites in this layer, so that one cell alone gives off 30 to 35 protoplasmic branches, which cover a vast area. The [apical] shaft, which extends toward the plexiform layer where it ends in the well-known manner, reveals certain regional variations. As it passes through layer V it is thick and spiny, and emits 10 or 12 collateral branches, but when it arrives at layer IV this production of branches ceases abruptly—if there are any at the beginning,

![Diagram](image_url)

Figure 11. Giant short-axon cells from layer IV. A, B, C, D, E, and F, cells with ascending axon and horizontal collaterals; G, pyramidal cell with an ascending, arcuate axon [this cell is not visible in the figure]; H, a cell similar to [A–F], located in layer V; I, short-axon cell from layer I.
Figure 12. Short-axon cells from layer IV. Note the variations of form related to position within the layer.

Figure 13. Short-axon cells. A, B, C, and D, cells with an ascending axon. In A, B, and D, only the primary and secondary branches have been drawn, while in C the complete arborization [appears]. E, cell from layer III; F, dwarf cell from layer V.
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if present, they are not numerous). Bearing in mind the law of dynamic polarization of [van] Gehuken and Cajal, and, above all, the comments on the same subject made recently by the latter (Cajal, 1915), there can be no doubt that the immense majority of the inputs that the pyramids receive come from the fibrillar plexuses in layers V, III, and I, and that [the pyramids] have very little to do with the afferent fibers that arborize in layer IV. The very thick axon descends almost vertically and emits a few collaterals (three or four). It continues as a myelinated fiber in the white matter. Its ultimate course is unknown, but it passes into the corpus striatum and we lose it there—not without having seen it to emit some thick collaterals arborizing in this region. However, we cherish the hope of finding, in very young animals or in fetuses, its final destination, [whether this may be] the pyramidal tract or [some] thalamic or mesencephalic nuclei. Most of the large pyramids are found in the middle sublayer, VIb, although there are some in the deep [sublayer,] Vic. There are none in the superficial [sublayer,] Va.

2. Medium-sized pyramids. Their number surpasses that of the large [pyramids], since they make up approximately two-thirds of the stratum. They are distributed in all the subzones, without revealing any particular preference. The [cell] body emits four or five dendrites, [which are] oriented in all directions, and by a delicate [apical] shaft continues upward, extending up to the plexiform layer. When this [apical dendrite] belongs to [one of the] smallest [cells] of this class (Fig. 15, A, B, C, H), it does not produce dendrite collaterals. But when it belongs to somewhat larger [pyramids] (Fig. 15, D, and E), it emits five or six collaterals analogous to those of the large pyramids, but always in less quantity. According to [the branching pattern of] the axon, we can divide [the pyramids] into the following categories:

a. A small or medium-sized pyramid, with a [an apical] shaft with no horizontal branches and an axon that produces only two or three collaterals—some destined for the plexiform layer (layer I)—and extends to the white matter and the corpus striatum (Fig. 15, A, H).

b. A pyramid analogous to the former, but whose axon bifurcates in the white matter into two branches, one [directed to] the corpus callosum and the other extending to the corpus striatum (Fig. 15, C).

c. A medium-sized pyramid, whose axon gives rise to a large number of collaterals—some 8 or 10, most of which are recurrent—and goes to the corpus callosum (Fig. 15, B).

d. An elongated pyramid whose [apical] shaft possesses four or five horizontal branches, and whose axon, with only two or three collaterals, extends into the striatum (Fig. 15, E).
Figure 15. Layer of large pyramidal cells. A, H, E, pyramids with a projecting axon; B, [pyramid] with a callosal axon; C, [pyramid] with an axon bifurcated into a callosal and a projecting branch; D, [pyramid] with a complex axon; F, fusiform cell with a long axon (analogous to those of Fig. 10); K, Cajal cell.
c. An elongated pyramid, in many ways similar to the former, but differing in that its axon bifurcates into three branches in the middle region of layer VI: one central branch \( (d_2) \) to the striatum, and two lateral branches \( (d_1, d_3) \) that, after following an extremely long horizontal path, become ascending and reach the zone of the small pyramids (layer III) after emitting some [collateral] branches in layer V (Fig. 15, D).

3. Small pyramids (Fig. 16). Although they are found in all the zones, they appear to be most abundant in the lower sublayer \( (Ve) \). The [cell] body, which is pyramidal, quadrate, or globular, does not surpass the size of that of [pyramidal] cells in layer III. It produces three or four slender dendrites and an [apical] shaft. The [apical] shaft, very thin, ascends vertically and sometimes reaches the molecular layer; in others (approximately half [of the cases]), it ends in layer IV, where it breaks up into three or four branches that join the plexus of the glomeruli.

These are the varieties of small pyramids:

a. Pyramids with an [apical] shaft [that reaches] the plexiform layer (Fig. 16, E) or the granular layer

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**Figure 16.** Small pyramids from layer V (subzone \( Ve \)). A, pyramid with an [apical] shaft arborizing in layer IV and a projecting axon; C and D, pyramids with a callosal axon; B, [pyramid] with a bifurcated axon; E, small pyramid with a projecting axon.
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[Layer IV] (Fig. 16, A), whose axon gives no more than one, two, or three collaterals, and continues as a myelinated fiber of the cornu radiata.

b. A pyramid with an [apical] shaft to the plexiform layer (Fig. 16, D) or to the granular layer (Fig. 16, C), whose axon sprouts countless collaterals that cover all the cortex with their terminal branches and, in particular, layer III, without excluding some [collaterals] destined for the plexiform [layer]. Ultimately, the axis-cylinder becomes extremely thin and joins the corpus callosum. On occasion, the extreme slenderess of the axis-cylinder conveys the impression that it ends inside the gray matter.

c. A similar pyramid (Fig. 16, B), but one whose axon bifurcates in the white matter. One of the branches joins the corpus callosum, and the other (b1), although it never abandons the white matter, at a great distance from the main trunk ascends and penetrates into the cortex again.

From what we have said, we can deduce that there are two basic types of infragranular pyramids: first, the pyramids whose axon has a few collaterals and extends into the corpus striatum; and second, the pyramids whose axon has many collaterals and, with a much reduced [diameter], passes into the corpus callosum or ends in the gray matter.

4. Cells with short axons. When we dealt with the granular layer [above], we described the main categories. We shall now provide an account of other types:

a. A Dwarf, spherical cell with dendrites arborized in a fanlike fashion in layer IV, and the axon bifurcates into an ascending and a descending branch. Both branches break up into analogous loose and widespread arborizations (Fig. 13, F).

b. A thick, spherical cell with dendrites [that sprout] in all directions, and an axon forming into a widespread arborization, enclosed within the limits of layer V (Fig. 17, A). Undoubtedly, this cell plays the important role of joining, in a synergic action, the activities of a great number of neurons (pyramids, etc.), also [exerting] an excitatory [action] on them.

5. Cells with ascending axons. These shall be described later, when we will deal with layer VI.

THE [DENDRITIC] PLEXUS OF LAYER V

All the protoplasmic prolongations of the cells described, plus the [apical dendritic] shafts and their ramifications from certain types of cells in layer VI, form a tightly interwoven plexus of which we provide a very incomplete representation in Figure 18. In those cases where many cells have been fully impregnated, the abundance of [dendrites] is such that there is hardly any space between for the [cell] bodies. However, partial impregnations enable us to discover the nature of the constituent components of this plexus, which we have described in preceding pages.

In the visual cortex, the dendritic branches that produce the plexus in question reveal a defined orientation—they are approximately horizontal (Cajal)—but in the "acoustic" cortex, a pattern cannot be recognized. The dendrites intertwine together in most diverse directions. Only in partial impregnations of the middle sublayer, where, as shown above, the largest pyramids group together, the basal dendrites of these [pyramids] and the [dendrites] arising from the [apical] shaft[s] resemble the plexus of the visual cortex. However, since other countless dendrites from other sources intermingle with these, any organized pattern is obscured and only an inextricable tangle remains.

In the superior part—that is, on its borders with the granular layer—the dividing line is clearly defined, but in the inferior part, imperceptible gradations into the plexus of layer VI, although less dense, render it nonetheless no easier to analyze.

VI. LAYER OF POLYMORPHOUS CELLS

The [available] descriptions of this layer are rather incomplete, and the ideas that are generally accepted with respect to their functional significance are totally unacceptable, as the following description demonstrates.

We are not attempting, by any means, to provide a complete account; the technical difficulties [involved] are exceptional, and the problems in making observations seem insurmountable. The Golgi method has failed almost completely; it is rare to obtain a good impregnation of the cells in this layer. If we add to this the frequency with which the axon is truncated in the section in one of its countless turns, then we can have some idea of the triumph represented by an observation of, on the one hand, the complete [cell] body and its dendritic branches, and, on the other hand, the axon and its collaterals. However, examination of several dozens of sections that have been satisfactorily impregnated enables us to add some details to what it is known currently.

Our findings permit us to reach some conclusions, which are not without interest by reason of their contradiction of what is generally accepted. We conclude that more than two-thirds [of the fibers] of the corpus callosum emanate from this layer. The cells that produce the immense majority of association fibers (U-fibers, etc.) also belong to this layer. Very few projection fibers originate there, and, from these, a large portion arborize in the corpus striatum.

The method of Nissl proves that the old description of Meynert is also applicable, and this is what Cajal
used in 1890 for the mouse and the rabbit. [Thus], the
lamina multiformis is made up of two sublayers: an
external one (VIα) [composed] of globose cells, and
an internal one (VIβ) [composed] of triangular and
fusiform cells. In the first [of these, layer] VIα, we find
(Fig. 14) pyramidal or globose cells (l), large stellate
(cells) (e) with a callosal axon, a few scattered medium-
sized pyramids (k), and numerous neurons with ascen-
ding axons (m, p, r, h). The second, [layer] VIβ,
is made up of small cells of different shapes (ovoid,
fusiform, stellate, triangular, etc.) (o), and a very small
number of cells with ascending axons (n, q). Needless
to say, a substantial number of short-axon neurons
whose characteristics are [not well revealed] with the
Nissl method mingle with the [neuronal] elements in
both subzones.

The way in which the different cells group together
varies from one [sub]layer to another. In [layer] VIα,
the intercellular spaces are small and the cells cluster
without apparent order, but in [layer] VIβ, they form
horizontal rows separated by clear bands. As noted by
Isenschmid, this pattern is due to the arrangement of
the myelinated fibers that run across the stratum in
transverse and sagittal directions. The Golgi method
emphasizes the differences between the two sublayers
to a greater extent than the method of Nissl, thus ne-
cessitating separate description.

VIα. SUBZONE OF MEDIUM-SIZED
PYRAMIDAL CELLS AND GLOBOSE CELLS,
AND OF STELLATE [NEURONS] WITH A
CALLOSAL AXON

The following varieties of cells can be studied here:
1. Small and medium-sized pyramids. It is an im-
possible task to describe all the different types of cells
of this category, because of the variety of [their] shapes, but I believe they can be reduced into three classes:

a. An elongated pyramid, with [apical] shaft [reaching] the plexiform layer and with dendritic branches in layer V. The axon emits up to three collaterals and enters, as a myelinated fiber, into the radiated fascicles of the corpus striatum (Fig. 19, A).

b. A globose pyramid with abundant basilar dendrites and an [apical] shaft reaching the plexiform layer. The axon emits two or three collaterals extending into the corpus striatum (Fig. 19, E).

c. A pyramid that is almost completely analogous to the latter, whose only difference is that its [apical] shaft ends in layer V (the upper sublayer, Va; Fig. 19, C).

2. Pyramids with arciform axons (Fig. 19, B and D, and Fig. 20, C). Discovered by Cajal (1899a) in the human visual cortex, these appear to be a consistent component of cortical organization, since Cajal also detected them in the visual cortex of the cat (Cajal, 1921), and we have observed them in all cerebral areas of the mouse. Its [cell] body is spherical and emits four or five thick, short, spiny dendrites, and an ascending [apical] shaft that provides, if any, horizontal branches into layer V, and ends in the granular layer (layer IV) by dividing into three or four branches. The axon, emerging from the [cell] body or from a thick dendrite, has a characteristic branching pattern: At regular intervals it gives off horizontal and ascending branches and frequently bifurcates into two fibers of this type, one a descending collateral that in turn bifurcates repeatedly. The horizontal branches are extremely long (we have followed them over 1.5–2 mm without finding their end), and they sprout a large number of ascending and descending secondary branches. The axonal ascending collaterals spread out over layers V, III, and I.

Sometimes the axon, by virtue of emitting collaterals, becomes exhausted within the gray matter (Fig. 19, D), but in other [cases] it continues as a slender fibril that enters the corpus callosum and runs to the other hemisphere (Fig. 19, D, and Fig. 20, C). These cells are preferentially located in the upper third of the stratum; it is worth noting that we described rather similar forms in the layer of large pyramids (layer Vc) (Fig. 16, C and D).

3. Stellate cells with callosal axons (Fig. 20, A, B, C). Here we are dealing with a somewhat abundant cell that inhabits all levels of subzone VIa; it also occupies the most internal regions of [layer] Vc, although less commonly. It is of medium size, similar to the pyramids of layer V. Its shape, somewhat variable, frequently approaches a stellate form. Its soma is rich in protoplasm, and a large number of long dendrites...
emerge, moderately ramified and with sparse spines. Among the dendrites, one is longer and thicker than the rest and, like an apical shaft, follows an ascending course toward the upper strata; but always after emitting one, two, or three branchlets to layer V, it ends in sublayer Va, never reaching the granular layer.

The axons, always derived from the soma, descend, emitting numerous collaterals and join the corpus callosum, where they are thickest. The collaterals are very long and thick, and possess secondary branches that fully cover VI and V. Among those particularly worthy of mention are the ascending branches, some of them ending in the layer of small pyramids ([layer] III) (a), and others, which are quite consistent, reaching the plexiform layer ([layer] I), where they take the form of tangential fibers (a, b, c) [Fig. 20].

4. Triangular and fusiform cells (Fig. 21, A, B, E). The stratum derives its name from these cells, since, apart from being their most characteristic neuronal element, they are also the most abundant. They inhabit the superficial and deep regions alike, although with slightly different features (as seen in Golgi preparations), according to the [sublayer] in which they are distributed. The [cell] body adopts every imaginable form, from that of the multipolar cell to a true pyramid; long, spiny, slightly ramified dendrites sprout from the soma in all directions. (There also are differences from one cell to another in the number of dendrites, since we can find, side by side, one cell with no more than three or four dendrites and another with 6, 10, or more.) These dendrites, which never are absent, are the ascending and descending ones. The descending dendrites

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**Figure 19.** Pyramids from layer VI. A, C, E, pyramids with a projecting axon; B and D, pyramids with an arciform axon.
extend into the deepest limits of the layer and even enter the white matter, while the ascending dendrites are usually reduced to an apical shaft provided with some branches. The final destiny of the [apical] shaft has been the subject of some discussion among authors. Both Cajal and Bonne believe that it always reaches the plexiform layer, while Kölliker and Retzius believe it ends deeper [than layer I]. Nor can we be very confident. The well-known limitation[s] of the Golgi method—[the] impregnation of the peripheral and the deep portions of the tissue pieces with unequal intensity, and the difficulty that exists in distinguishing when a [neuronal] process has been cut because of a defect of impregnation and when it really ends—oblige us to avoid definitive conclusions. However, we have never observed any shaft of this type reaching the plexiform layer and although we have seen several cases that give undoubted signs of their termination, we believe that (without denying the possibility that they continue further on) we can say that the [apical] dendrites of these cells do not reach the plexiform layer ([layer] I), but end in the granular layer, by way of a poor but widespread ramification.

The same thing does not [necessarily] occur in all regions of the cortex. As a rule, we can state that the [apical] dendrite of the triangular and fusiform cells ends in the same layer in which the projection fibers arborize. Thus, for example, in the sensory-motor region where, as Cajal proved, the corticopetal projection fibers end in layer III, the [apical] processes of the triangular cells also reach this layer.

In its traverse through layer V, and particularly in the upper subzone ([layer] Va), the dendrite emits arborizing branches that contribute to the formation of the dendritic plexus described above.

In Figure 21, we have drawn some cells of this class. A and B are drawn in isolation to show their collateral axonal apparatus, and the E's have been grouped together in the same manner as they have been observed, in order to illustrate the dendritic apparatus.
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The axon always follows a straight course with some collaterals (the higher the cell is in the layer, the more collaterals it emits) and joins the corpus callosum. In a few cases, it bifurcates within the white matter (Fig. 21, A). One of the branches then moves to the other hemisphere; the other, $a_2$, goes in the opposite direction, and, without abandoning the white matter, it ascends and re-enters the cortex.

There is another category of cells that is not very different from the one we have just described. We give an account of it in Figure 21, D. It is characterized by a pyramidal or stellate cell body whose ascending dendrites never extend beyond layer V, and whose axon does not leave the cortex, but rather breaks up into three or four horizontal branches that are very long and provided with abundant secondary ascending branches, located mainly in subzone VIb.

5. Short-axon cells. Most of these belong to the category of cells with an ascending axon, while the rest can be reduced to two types:

a. A spherical cell with long, slender, spinous dendrites (Fig. 17, C). The axon ascends near its origin, but soon bifurcates into two horizontal branches, which again divide into another three or four that are also horizontal. Each of these axonal branches shows, at intervals, knots or thickenings from which numerous fibrils emerge, creating a widespread, hairy plexus that covers the entire layer VI. This type, analogous to those described in layer V (Fig. 17, A), exists in all regions of the lamina multiformis, but it becomes smaller and its ramifications less widespread [as its location becomes nearer] to the white matter.

b. Triangular, fusiform [and variously shaped] cells, with slender dendrites and an axon that breaks up into

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**Figure 21.** Cells from layer VI, subzone VIa. A, B, E, triangular cells; C, pyramid with an arciform axon; D, cell whose axon breaks up into several horizontal, intracortical branches.
poor ramifications, sometimes enclosed in the lamina multiformis, and sometimes extending toward the lamina ganglionaris (Fig. 17, D).

6. Cells with ascending axons. Although these exist in all cortical regions, they reach maximum development and seem to be most numerous in layers V and VI. We have found the following varieties:

a. A fusiform cell with its axon reaching the plexiform layer (Martinotti cell; Fig. 22, A, B, C). It inhabits the layer of the large pyramids and the polymorphous layer. Its [cell] body is fusiform and is directed in a radial fashion, with polar dendrites; in the smaller varieties, the soma does not possess dendrites (A), but in the large varieties, it is provided with [primary dendrites] of a number proportionate to its size (B, C). The axon, which frequently sprouts from the polar, marginal dendrite, is thin and directed toward the lamina zonalis. When it arrives there, it either limits itself to bending or bifurcating, giving off one or two tangential [axonal collaterals] (A), or it divides into a tuft of variable

![Figure 22. Medium-sized cells with an ascending axon from layers V and VI.](image-url)
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complexity (B, C). At its origin, the axon may emit one or two collaterals for layer V. In layer III, it consistently sprouts slightly ramified and not very long branches. Finally, as already shown by Cajal, descending collaterals arise from its terminal ramification in the molecular layer. These collaterals may reach the lamina pyramidalis or continue even further.

b. A small, spherical cell with long, slender dendrites [oriented] in all directions and a thin ascending axon that, after giving off an enormous number of collaterals in layer V, crosses the granular layer without further division to reach, ultimately, the lamina pyramidalis, where it ends in a sparse ramification (Fig. 22, E). This type [is common] in the [sublayer] of large pyramids.

c. A small polygonal cell (Fig. 22, D) with countless extremely long and spineless dendrites. Its axon provides two very sparse plexuses in layers V and III. However, in some circumstances, it extends no further than layer V. This type [is common] in layer VI.

d. A large spherical cell located in the deepest region of layer VI. It has four or five short, spineless dendrites and an axon that is extremely noteworthy. [The axon] emits four or five collaterals in layer VI and extends into the plexiform [layer]. It changes its appearance according to the regions [that it traverses]. In the laminae granularis it is smooth, but in the laminae pyramidalis and ganglionaris, it is covered with very short, angular collaterals that are crowned by a thin bouton. [These collaterals] undoubtedly serve to contact the dendrites and [apical] shafts of the pyramids (Fig. 22, F).

e. A giant, spherical cell (Fig. 23, A) that is located in the layer of the large pyramids, with long, thick dendrites and an axon that reaches the plexiform layer, where it divides into three or more horizontal [collaterals]. In the layer of the large pyramids, [the axon] possesses collateral branches, and the fibers that sprout from it in the plexiform layer also possess descending collaterals, some of which [are] extremely long (a), reaching the lamina ganglionaris.

f. A pyramidal cell that is typical of sublayer V1a, with innumerable dendrites and a fairly thick axon that tapers out in layer V, where it leaves numerous collaterals behind. It extends toward the plexiform [layer] to turn into a tangential fiber (Fig. 23, C).

g and h. Large, ovoid cells with ascending and descending polar dendrites and an axon branching into a rich and widespread plexus in the layer of small pyramids (Fig. 23, B) or both there and in the granular [layer] (Fig. 23, D).

The first author who mentioned the existence of cells whose axons go toward the superficial zones of the cortex was Golgi. However, it was his disciple, Martinotti, who in a brief article (Martinotti, 1889) first described the arrival of the axons of cortical cells in the plexiform layer. Cajal carried out a fine study of the cells with ascending axons in 1891, where he demonstrated that, not all [of these cells] extended their axon to the plexiform layer; rather, many [of them] ended in deeper regions. Later, Kölliker (1896) described a few more types and drew attention to their variability in morphology and their abundance. However, he could not identify the cell drawn by Martinotti. Would it then be correct to name these cells with ascending axons after this author? We do not believe so, and therefore, we have reserved [this name] for those [cells] that most resemble the drawing by [Martinotti] and that were specifically described by Cajal in 1891 (Fig. 6, b, of the work of this scholar). Finally, we must say that the immense majority of the types described by us already have a rather precise, if incomplete, designation in the works of Kölliker and Cajal.

VIIb. SUBZONE OF FUSIFORM AND TRIANGULAR ELEMENTS
[Subzone VIIb is illustrated in] Figure 24

1. The main [neuronal] element is a small cell whose form is rather irregular and whose dendrites, which are finely spiny and repeatedly ramified, acquire considerable length. Their length and their constant changing of direction make it very difficult to find their destination. We believe, however, that they do not extend beyond layer V [or], at the most, the deepest parts of [layer] IV. Based on the axons, we can classify them as follows:

a. Axons that penetrate into the white matter, traveling a long distance within it and dividing up into several branches that re-enter the cortex (Fig. 24, A, D).

b. Axons that, after giving off four or five recurrent collaterals, extend into the corpus striatum, where they ramify (Fig. 24, B).

With this new class of afferent fibers, [we can state that] the corpus striatum receives three kinds of impulses: first, those brought by the terminal ascending fibers discovered by Cajal in 1894; second, those contributed by the collaterals of the large pyramids (Cajal, 1891); and third, those transmitted by the axons of the polymorphous cells just described.

c. Axons bifurcated into two ascending branches; from one of these, a thin fibril sprouts that enters the corpus callosum.

d. Axons bifurcated in the white matter into a projection fiber and a U-fiber (e) (Fig. 24, E) [8].

2. Short-axon cells. These are not very numerous and present the same characteristics as those described in subzone V1a. It now appears that the lamina multiformis possesses a very small quantity of cells with
projection axons; most of its constituent axons are either long association callosal fibers or short (U-fibers).

VII. THE WHITE MATTER

Beneath the lamina multiformis and between this layer and the corpus striatum, we find a new layer, the white matter, which in Nissl sections is characterized by the presence of strings of minute nuclei, accompanied by sparse protoplasm (glia of the white matter). Among these nuclei, we can see some displaced polymorphous cells. The fibrillar components are of three types: first, projection fibers; second, interhemispheric or callosal association fibers; and third, fibers of interregional association or U-fibers.

1. Projection fibers. It is unnecessary to point out that some of these are afferent fibers—that is, they come to the cortex from the thalamic foci—and others are efferent—that is, they arise in the cortex and end in different subcortical nuclei. Briefly, it should be re-
membered that the efferent fibers come (a) from certain types of pyramids in layer V (Fig. 15, A, C, D, E, H; Fig. 16, A, E); (b) from a small number of large cells in layer VIa (Fig. 19, A, C, E); (c) from some cells in layer VIb (fibers for the corpus striatum) (Fig. 24, B). As for the destination of the first two classes, nothing definitive can be stated. We shall accept, as most authors do, that those fibers coming from the largest pyramids go on to form part of the cerebral peduncle and the pyramidal tract, and that the remainder end in the thalamic and mesencephalic nuclei (extrapyramidal tracts?).

We do not know the origin of the efferent fibers. The termination, variable from one [type] to another, is represented in Figure 25. Using this diagram, we can classify them in the following way:

a. Fibers ending in the granular layer ([layer] IV), with some branches in the region of small pyramids ([layer] III) (a) [in Fig. 25].

b. Fibers that reach the lamina zonalis, travel a certain distance within it, and then descend, dividing and subdividing, down to layer IV (b) [in Fig. 25].

c. Fibers that ascend vertically, give off some collaterals to layer IV, and ramify in layer III (k) [in Fig. 25].

d. Fibers that bifurcate. One of the branches continues in the white matter until it reaches other cortical areas; the other enters directly into the gray matter, leaving some collaterals in layer VI, and ascends vertically until it reaches the lamina zonalis, where it is converted into a tangential fiber (c) [Fig. 25]. The penetrating branch often takes on the appearance of an axon collateral (d) [Fig. 25], and on occasion both branches of the bifurcation penetrate the same cortical region (e) [Fig. 25].

The fibers of the first class (a) were discovered by Cajal in 1891 and shortly thereafter confirmed by Kolliker, who called them "Cajal fibers" (Ramón'sche Fasern) in honor of their discoverer. The existence of fibers in the white matter, which go directly to the lamina zonalis, was considered very probable by Cajal in [1900b] (in the human acoustic cortex).

Do these fibers contribute impulses of the same nature, or are they conductors destined to transmit impressions of different kinds for each of them? This is a question of undeniable theoretical importance, which only makes it more painful for us to admit our incapacity to solve the problem. Yet, although we cannot state anything with certainty, at least it is permissible to
suspect that the functions of the four types of conductors are different.

Fibers of the first three classes are the most abundant and have characteristic patterns of ramification in each cerebral area. It seems to us that they are responsible for bringing specific sensory or sensitive impressions to the cortex. The fibers of the fourth class, [which are] perhaps collaterals of the first three classes, would inform a cortical area about the excitation received by the neighboring areas. [This is achieved in an incomplete fashion—that is, without connecting with the granules, [which are] the neural elements that apparently modify and distribute the excitation. In support of this hypothesis, we have the fact that many association fibers also end in the molecular layer, as Cajal already demonstrated in 1896. Since the manner in which the fibers of the classes a, b, and c ramify is peculiar to each cerebral area, we believe it would not be superfluous to outline the characteristic features of the fibers in this area.

Fibers of the first class take a horizontal or oblique path in layer VIb and cross through layers VIa and V in a radial direction. They reach the granular layer, where they ramify until they create a dense plexus. But—and this is what is most striking—the main portion of the dividing branches is distributed in layer IV and,
even more so, within a single glomerulus. There are only a few branchlets for layer III. In Figure 26, A, a, we represent, in isolation, the axonal plexus of one fiber, and in B [we illustrate] the ensemble of arborizations of a great number of fibers [labeled as] b, b. In the not infrequent cases where the branches of the [axonal] arborizations are completely impregnated, layer IV appears divided into ovoid fields, full of fine reddish fibrils packed so close together that they hardly leave space for the cell bodies. Each field B [in Fig. 26] corresponds to a glomerulus, and the spaces that exist between these [D] are a little poorer in fibers, although they maintain the general features of the glomerular zones. The study of these plexuses shows us that the bulk of class a fibers enter in relationship with the granules, and only the thin collateral branchlets contact the supragranular pyramids.

The data we possess about class b [axons] are less copious. The fact that there exist some fibers such as c (Fig. 26) that, after arriving in layer II, turn around to descend to the granular layer, may make us suppose that we are dealing with analogous conductors to the ansiform fibers of the cerebellum, discovered by Cajal in 1895 and confirmed somewhat later by Smirnow in 1898. The abundance of fibers with the form labeled e and f (Fig. 26), and [the fact] that they constitute a plexus that is analogous to what we have described in layer III, enable us to identify these [fibers] as a special class of conductors destined to acquire connections in the laminae pyramidalis and granularis interna. As for the fibers of the third class (e), they are the least abundant, and in Figure 26, d, we show the terminal ramification of one of them. Nothing concrete may be said concerning the abundance of fibers of the fourth class (d), because of the difficulties in examining them; the fact that they are never impregnated [in isolation] makes comparative study impossible. However, we believe that they are not as abundant as the preceding [classes].

2. Fibers of long association (corpus callosum). Various authors disagree on this subject, although, in general terms, it was clarified by Cajal and Kolliker over 25 years ago. Cajal said in 1891:

"In summary, the callosal commissure seems to contain, first, the direct axons of cells probably belonging

![Figure 26. Projection fibers, and their plexuses, present in the "acoustic" cortex. a, glomerular fiber; c, an ansiform or displaced [glomerular fiber]; b, b, fibers of similar type, which form the plexus B in layer IV; D, interglomerular space; e and f, fibers arriving into layer I from the white matter that break up into a descending plexus in layers I and III; d, fiber arborizing in layer III.]

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to all layers of the cortex, except the giant cells and cells of the superficial layer; second, the collateral branches or the branches of bifurcations of axons of the cells of projection or of association.

"We think that only some cells of each cortical layer send collaterals or [direct] axons to the corpus callosum; these cells which warrant the name callosal, are mixed throughout with cells that, from [the nature of] the terminations of their axons, may be designated by the name of cells of association or of projection.

"If our point of view is confirmed by subsequent research, there will exist a striking analogy between the corpus callosum and the anterior commissure of the spinal cord; this includes, like the corpus callosum, direct axons arising from cells in all [parts of] the gray matter of the spinal cord, and the collaterals of fibers of the white matter, representing for the spinal cord the association and projection fibers of the brain."

These are the sources of origin of the direct callosal fibers alluded to in the passage transcribed: first, small pyramids; second, some medium-sized and large pyramids; third, some cells (pyramids) from the layer of the polymorphous cells. The collateral callosal fibers derive from projection axons emerging from the large pyramids and [from] the polymorphous cells, and [also from] association fibers of the fasciculus arcuatus. The termination of the callosal fibers, which is much more difficult to determine [than their origin], seems to be made of free branchlets spread out across the cortex. Apart from the [passage] above, our master [had] already ascertained at that time that the callosal fibers supply collaterals that penetrate into the cortex, and therefore [that] they put areas of different nature into relation.

That is, the corpus callosum exerts both types of association: homotopic and heterotopic. Kölliker (1886) confirmed most of the data gathered by Cajal, and accepted as highly probable that the termination of the callosal fibers and the fibers of association is represented by certain slender axons that, after emitting some branches in the gray matter, reach the lamina zonalis to form part of the plexus existing there. Van Valkenburg (1913), de Vries (1912), Nissl (1911), and Monakov (1914), among others, have attempted to solve this problem experimentally, and they have all arrived at essentially the same conclusion: The infragranular pyramids are the main source of callosal fibers. Recently, Villaverde (1921b) has been able to determine that, in the area giganto pyramidalis of the rabbit, after interruption of the corpus callosum, there are altered cells in layer V and neighboring regions of layers III and VI. Previously, using the method of Marchi, he demonstrated that the callosal fibers reach the superficial layers of the cortex (Villaverde, 1921a).

The following is what we have observed:

Origin. On previous pages, we have described the different cell varieties from which the fibers of the corpus callosum arise, and we have confirmed all those found by our master and by Kölliker. The sources of origin of the aforementioned association pathway are: (1) small and medium-sized [supragranular] pyramids (Cajal), but only those of the second variety, that is, [those] that have few intragranular collaterals (Fig. 5, D and E); (2) star-pyramids (Fig. 5, A, B, and C); (3) some varieties of infragranular pyramids with a direct callosal axon or with a callosal collateral (already seen by Cajal and Kölliker) (Fig. 15, C; Fig. 16, B, C, and D); (4) layer VI stellate cells with callosal axons (Fig. 20); (5) medium-sized pyramids in layer VI (Cajal) (Fig. 19, B; Fig. 21, C); (6) layer VI triangular and fusiform cells (Fig. 21, A, B, and E); (7) certain cells in the sublayer VIB (Kölliker) (Fig. 24, C).

Termination. The callosal fibers, when they reach the other hemisphere, give off undivided collaterals that reach the lamina zonalis (f) [in Fig. 25] or leave some branches in the layers that they cross (g). After sprouting these collaterals, the callosal fiber reaches another region of the cortex, bends at a right angle, and penetrates into the gray matter. Once it has entered completely into the cortex, it is very difficult to pursue these fibers, because they are so slender and long. In some cases we have been fortunate to have seen them divide at acute angles several times. [On these occasions] one of the branchlets, apparently a direct continuation of the original fiber, reaches the plexiform layer to continue there as a tangential axon (Fig. 25, h).

3. Fibers of short association or interregional [fibers]. These are the representatives of U-fibers and cerebral bundles of association that exist in higher mammals. Their origins have been described previously in these pages, and rather than repeating what has already been said, we will limit ourselves here to enumerating their sources of origin: (a) some—very few, it seems—star-pyramids from layer IV (Fig. 5, A); (b) some pyramids from layer V (sublayer Vc) (Fig. 16, B, D); (c) the immense majority of the cells in layer VI, especially in subzone VIB (Fig. 24). The [pattern of arborization] of the fibers of association is always the same. They run in the white matter intermingled with projection and callosal fibers. Periodically, they sprout collaterals that penetrate the gray matter, and after a journey of varying length, they ascend and enter the cortex. The manner in which these [fibers] end is not completely known to us. On occasion, we have seen them arrive at layer III and ramify there, but only after emitting branches in other layers. However, at other times we have not been able to follow them further than layer VI. We were not able to decide whether this was due to a defect in impregnation, or if in fact the fiber did not extend beyond that point.
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We have mentioned the [neuronal] elements that constitute the cerebral cortex of the mouse. Based on this description, we can reach some conclusions, which we list below. However, this material is inadequate for providing an outline of the trajectory of the nerve currents. In order to achieve this, it would first be necessary to know what parts of the axon are capable of transmitting impulses. Although, thanks to the concordant research by Flechsig, Held, Kölliker, and Cajal, we know with a certain approximation the distribution of the myelin, there are still many steps to pursue along this path. In addition, a systematic study of the unmyelinated plexuses (of collaterals and arborizations of the short axons) that fill the cortex is absolutely essential. We are now gathering together the material that we shall use to discuss the (ectogenetic type[s]) and to analyze the current theories on the functional organization of the cortex. Both matters will be dealt with in the second part of this work. *

CONCLUSIONS

1. The cerebral cortex of the mouse presents a highly complex texture, which renders it comparable to that of the higher mammals and even to the human cortex.

2. The “acoustic” cortex possesses some characteristic traits, including:
   a. The existence of an enormous layer of granule cells ([layer] IV) distributed in the form of glomeruli.
   b. The considerable development of the layer of large pyramids, and the relatively small size of the largest cells of this type.
   c. The presence of afferent fibers with a glomerular, [terminal] arborization.

3. The lamina granularis externa is no more than the external portion of the lamina pyramidalis, modified in the sense that it can better collect the impulses while occupying minimal space.

4. There are two types of supragranular pyramids: [those] with a short descending axon, and [the pyramids] with a callosal axon.

5. In layer IV, two types of granules can be differentiated: the granule cells themselves [i.e., star cells], with short axons, and the star-pyramids, with callosal axons.

6. In layer V there are four types of pyramids: [those] with an intracortical axon (the ascending arciform [axon] of Cajal); [those] with a callosal axon; [those] with a projection axon; and [finally those] with an axon bifurcated into a callosal branch and a projection branch.

7. The cells in layer VI generally do not possess a projection axon, but rather an association axon, either short or interregional, or long or callosal.

8. Four different types of afferent fibers reach the cortex. Most arborize in layers I, III, and IV, but they also emit branches in layers V and VI.

9. [The fibers of] the corpus callosum arise from all the cortical layers.

10. The corpus striatum receives terminal fibers originating in subzone VIa.

Madrid, May 1922

LORENTE'S FOOTNOTES

[1] During correction of the proofs, we had the occasion to examine a large number of phases of the cortical histogenesis and to follow the major steps of the process of migration and “perfecting” or remodeling of the granule cells. These, from the beginning of their migration, that is, from their departure from the ventricular lining, possess a specific form, as do the pyramids. Thus, the transformation of granule[s] into pyramid[s], as invoked by van'T Hoog in support of his thesis, would be the imitation of one cell [type] into a completely different one. This would imply a reabsorption of expansions and a creation of new connections, totally unexplained.

[2] Consistent with the previous footnote, we can be assured that the architectural plan is already established from the beginning of the modeling of the cortex. In, undoubtedly, there are absolutely different cortices in the adult stage, how could we accept that their initial phases of development are identical?


[4] Since there is variability, depending upon the [length of fixation] in alcohol, in the thickness of the cortex and of the intercellular spaces, we believe it necessary, in order to compare our figure with others*, to state that the brain in toto was fixed in 96% alcohol for 4 days, maintained for 1 day in absolute alcohol, and sectioned after embedding in celloidin. Section[s] are of 17 μ[m].

[5] During correction of the proofs, we have discovered the existence of some short-axon cells whose soma is spherical and whose size corresponds to that of the granules [revealed by] the Nissl method. The axon [forms] a poor arborization, close to the cell body. Both types of dwarf cells are very rare.

[6] This author confused the horizontal cells of Cajal with some of the [cells] belonging to this layer; he provides an otherwise superb description.

[7] [The reader should] take into account, when examining the plates, that [only some] of the branches, those oriented in the plane of section, [are represented].

[8] The manner in which collaterals of the axon behave is worthy of note; [periodically] it exhibits a brush of thin fibrils, in the manner of a pericellular nest.

[9] Certainly with extreme rarity, silver chromatine has come to settle into these cells, thus revealing their exact morphology. We shall deal with these [cells] in a succeeding monograph.

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