STEPHAN, H., and O. J. ANDY: Quantitative comparisons of brain structures from Insectivores to Primates. Amer. Zool. **4**, 59–74 (1964).

STEPHAN, H., et R. BAUCHOT: Le cerveau de Galemys pyrenaicus Geoffroy, 1811 (Insectivora Talpidae) et ses modifications dans l'adaptation à la vie aquatique. Mammalia **23**, 1–18 (1959).

STEPHAN, H., und R. BAUCHOT: Gehirn und Endocranialausguß von Desmana moschata L. (Insectivora, Talpidae). Morphol. Jb. **112**, 215–227 (1918).

Adresse der Autoren:

Dr. H. STEPHAN
Max-Planck-Institut für Hirnforschung
Neuroanatomische Abteilung
Frankfurt/M.-Niederrad, Deutschordenstr. 46

Prof. Dr. R. BAUCHOT
Laboratoire d'Anatomie et d'Histologie Comparées
Université de Paris
Paris 5e/France, 7, Quai St Bernard.

C. und O. Vogt-Institut für Hirnforschung der Universität Düsseldorf
in Neustadt (Schwarzwald)

Registration of the Myeloarchitecture of the Human Frontal Lobe with an Extinction Method

By

ADOLF HOPF

With 13 figures

(Received March 17, 1967)

One of the first aims of architectonics and especially of architectonic maps was to be "a help for orientation" as Brodmann wrote in 1909. The architectonic maps of BRODMANN and of v. ECONOMO and KOSKINAS (1925) are widely used though detailed architectonic descriptions of his areas were never given by BRODMANN. Studies with reference to those maps without accompanying architectonic investigations of the individual brain are of a very limited value since there exist considerable individual variations.

Architectonic studies are generally known as difficult and time consuming. That is especially true of cytoarchitectonics which are more commonly used. It is less well known that myeloarchitectonics need not require so much time as cytoarchitectonics. If one is well experienced in myeloarchitectonics most of the areas can be recognized with the naked eye or with the aid of a simple magnifier. So one is able to survey large regions of the cortex at a glance.

The first combined myeloarchitectonic and cytoarchitectonic description of the frontal lobe was given by CAMPBELL in 1905. He could differentiate 5 areas, namely the precentral, intermediate precentral, frontal, prefrontal and limbic areas.

The studies of ELLIOT SMITH (1907) can also be regarded as myeloarchitectonic in type. By macroscopic observation of the arrangement of the horizontal stripes (stripes of BAILLARGER 1840) in fresh brains, he found 17 different areas in the frontal lobe.

In 1910 O. VOGT gave a short but very detailed description of the myeloarchitecture of the human frontal lobe. He distinguished 6 regions with 66 areas. Since no pictures of the various areas were provided, and sometimes the difference between the areas was indicated only by one feature or a Latin name, this fundamental work was not suited for general use.

In 1937 VOGT's myeloarchitectonic division was further elaborated by STRASBURGER. He also published pictures of about every third area. However, this study also was not very easy to read for those who no longer had special training in myeloarchitectonics.

In 1956 a paper was published on the distribution of the main myeloarchitectonic features of the human frontal lobe (HOPF 1956). This was a part of a new approach to myeloarchitectonics with the aim to develop a more practicable and reliable method allowing the areas to be identified more easily and more quickly. The second aim was to give a survey of the distribution of the main myeloarchitectonic features in the whole cortex in order to determine general principles (HOPF 1955, 1956, HOPF and VITZTHUM 1957). It was found, *e. g.*, that all motor and all sensory areas possess a high content of thick myelinated fibers — or, in physiologic terms, of fibers with a high conduction rate — and that the fiber content decreases in a steplike manner with increasing distance from the motor and sensory areas.

A general survey of the myeloarchitecture of the human frontal lobe was given by BRAITENBERG in 1956.

The most comprehensive architectonic study of the human frontal lobe was published by SANIDES in 1962. He found a complete coincidence between cyto- and myeloarchitectonic areas. The same opinion was already expressed by GERHARDT (1938, 1940) in her studies on the parietal lobe. But the main contributions of Sanides were the correlation of the development of the gyri and the differentiation of the architectonic fields on the one hand, and the explanation of the architectonic gradations (VOGT) as based on two phylogenetically old "Urgradations" and a more recent poleward gradation directed to the frontal pole, on the other hand.

But all this work hitherto done was based on visual observation and consequently inevitably subjective to a certain degree. Therefore a new method of objective registration was developed.

Material and methods

The method that was developed has already been described in detail (HOPF '65, '66a, '66b). Therefore only a short description is given here.

Celloidin serial sections of a thickness of 40 μ, stained for myelin (Weigert-Wolters or Kulschitzky-Pal method) are used. Three cm wide photographic strips are taken of these sections at a magnification of 25 : 1. The photographic strips are oriented perpendicularly to the surface of the cortex. Only those parts of the cortex are suitable for registration which are flat or only slightly curved. The photographs are developed under constant conditions. The negatives are evaluated with the extinction recorder of Zeiss, which is otherwise used for the registration of electrophoretograms. All curves start on the left side at a zero point which lies always on the same horizontal plane. The surface of the cortex is indicated by an arrow. The length and shape of the curve on the left side of the arrow is without interest. It depends on whether there are meninges, small vessels or debris outside the cortex. The starting point (zero point) must therefore be a little more distant in some cases than in others.

Results

I. The myeloarchitectonic types of the human frontal cortex

The behavior of the two horizontal stripes of Baillarger (in layer 4 and 5b[1])) and the general content in myelinated fibers has been proved as most important for the delimitation and characterization of the myeloarchitectonic areas. These features are more easy to recognize and more reliable than many others.

In the frontal lobe one can find the following types:

1. the unistriate type (fig. 1a).
   The outer horizontal stripe of Baillarger in layer 4 is obvious because the neighboring layers 3 and 5a are less dense. A clear demarcation of the inner stripe of Baillarger in 5b is missing as 6a is about as dense as 5b.
   This type is characteristic of the first frontal gyrus, parts of the precentral gyrus, the medial orbital region, the paralimbic zone and the proisocortex of the anterior cingulate gyrus.
2. the propeunistriate type (fig. 1b).
   The outer horizontal stripe in 4 is well demarcated and the inner one in 5b a little better than in the unistriate type as 6a is not quite as dense as 5b. The propeunistriate[2]) type covers the dorsal part of the second frontal gyrus which more commonly consists of two convolutions.
3. the bistriate type (fig. 1c).
   This type was regarded by Vogt as the fundamental type of isocortex. Both horizontal stripes of Baillarger are very obvious since the neighboring layers stain rather lightly.
   One can find this type on the ventral part of the second frontal gyrus.
4. the unitostriate type (fig. 1d).
   Here the two stripes of Baillarger are united into a broad band. The usual decrease in the fiber content in 5a is missing. This type is characteristic of the lateral orbital region and, in a not completely developed form, of the posterior part of the third frontal gyrus.
5. the astriate and propeastriate type (fig. 1, e and f). The horizontal stripes of Baillarger cannot be observed in the astriate type. They are not well demarcated in the propeastriate ("nearly astriate") type since the neighboring sublayers 5a and 6a are rather dark. These types cover a large part of the precentral gyrus.

Figures 2 and 3 demonstrate that the different myeloarchitectonic types and areas can be recognized by macroscopic observation of sections stained for myelin.

[1]) The layers in myeloarchitectonics are labeled with Arabic numerals according to Vogt and in cytoarchitectonics with Roman numerals because the coincidence cannot be presumed but has to be proved in any special case.

[2]) prope (Latin) means nearly.

II. Extinction curves of the individual areas of the frontal cortex

The areas from which the photographs and extinction curves are taken are indicated in fig. 4.

Gyrus frontalis superior (F1) and Gyrus centralis anterior (Ca)

The lower 3 curves in fig. 5 (curves A, B and C) are registered from the first frontal gyrus while the upper one (D) is from the precentral gyrus at the border of F1.

Curve A represents an analysis of the photograph at the base of this figures and curve D of the photograph at the top. In the 3 lower curves the outer horizontal stripe of Baillarger in layer 4 is obvious since the sublayer 5a is less dense. The same is also easy to recognize on the photograph at the base. An inner stripe of Baillarger in 5b is not demarcated since the curve ascends continuously. A zone of lighter staining in 6a is missing. This type of cortex is called unistriate (see also scheme in fig. 1a).

Curve A is taken from the oral part, curve B from the middle and curve C from the most caudal part of the first frontal gyrus. There is a stepwise increase in the fiber content from the frontal pole to the precentral gyrus or from a phylogenetic point of view a decrease in the direction of the (phylogenetic younger) frontal pole. This gradation, first described by Vogt, can be confirmed by the extinction curves. The plane enclosed between the baseline and the curve can be regarded as a measure of the myelin content. Absolute values cannot be expected since myelin stains are not quantitative methods in a strict sense. But with a uniform technique reliable relative values can be obtained which are sufficient for a characterization and differentiation of the areas.

In curve D a further gradation is obvious in two respects. The general fiber content increases and

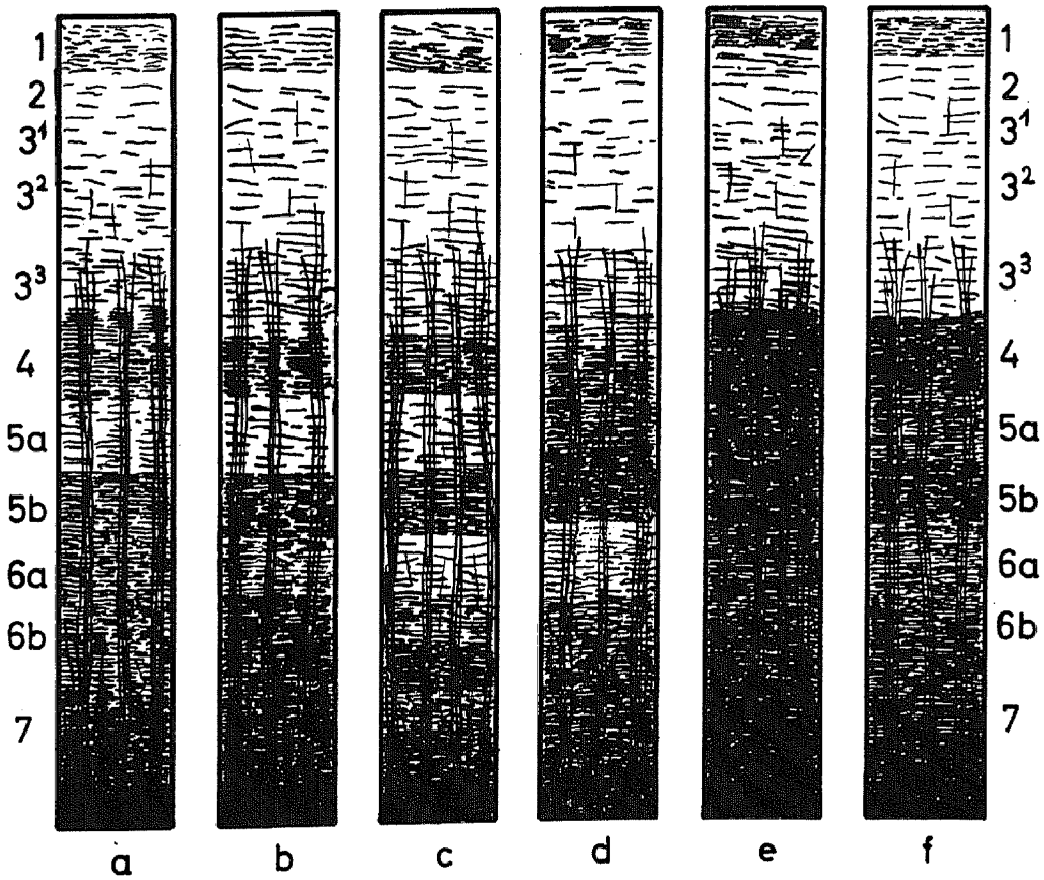

Fig. 1. Scheme of the myeloarchitectonic types of cortex found in the human frontal lobe. (a) unistriate type — only outer horizontal stripe in layer 4 well demarcated. (b) propeunistriate (nearly unistriate) type — inner horizontal stripe in 5b a little denser than 6a. (c) bistriate type: both stripes of Baillarger well demarcated. (d) unitostriate type — horizontal stripes (4 and 5b) united since 5a is no lighter in appearance. (e) astriate type — no horizontal striping. (f) propeastriate (nearly astriate) type — horizontal stripes not very obvious.

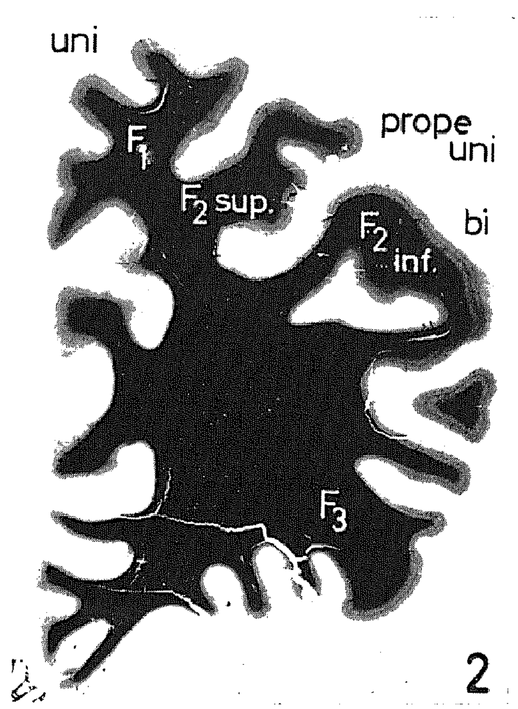

Fig. 2. Coronal section, 40 μ myelin stain. (Weigert-Wolters method) × 1. The areas of the first frontal gyrus (F1) are unistriate. The inner stripe of Baillarger is not demarcated from the deeper layers. In the superior part of the second frontal gyrus (F2 sup.) a propeunistriate type can be observed, the demarcation of the inner horizontal stripe from the relatively dark 6a is poorly indicated. In F2 inf. a bistriate type is obvious, the two horizontal stripes stand out well against the neighboring sublayers which are less dense. In the anterior part one cannot find a unitostriate type but some indications of this type can be seen. The horizontal stripes are close together, 5b is rather dark and 6a rather light. The orbital gyri are poor in fibers.

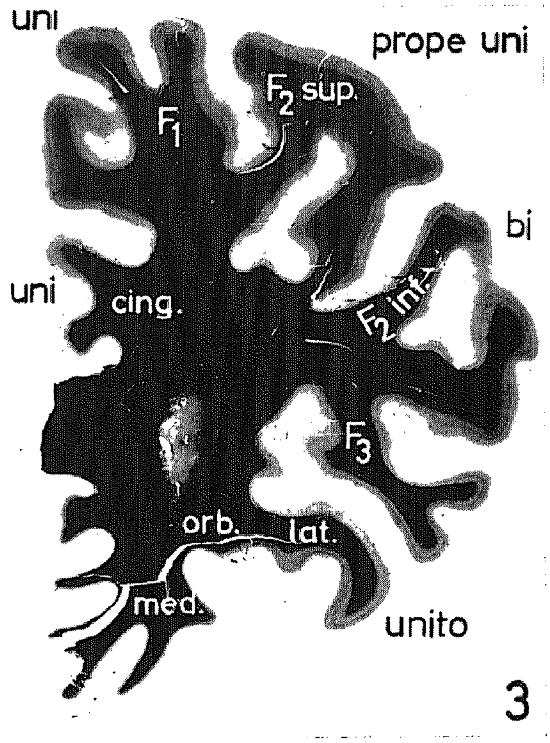

Fig. 3. Coronal section, same technique and same magnification as figure 2. The section is of a more caudal level. In F1 and F2 the same types can be recognized. In the lateral orbital gyri a unitostriate type with no obvious decrease in staining intensity in 5a, a dark 5b and an unusually light staining 6a can be observed. The medial orbital gyri are very poor in fibers. In the cingulate gyrus, a unistriate type, a poorly developed outer horizontal stripe and an increase in the fiber content in a dorsal direction is easy to recognize.

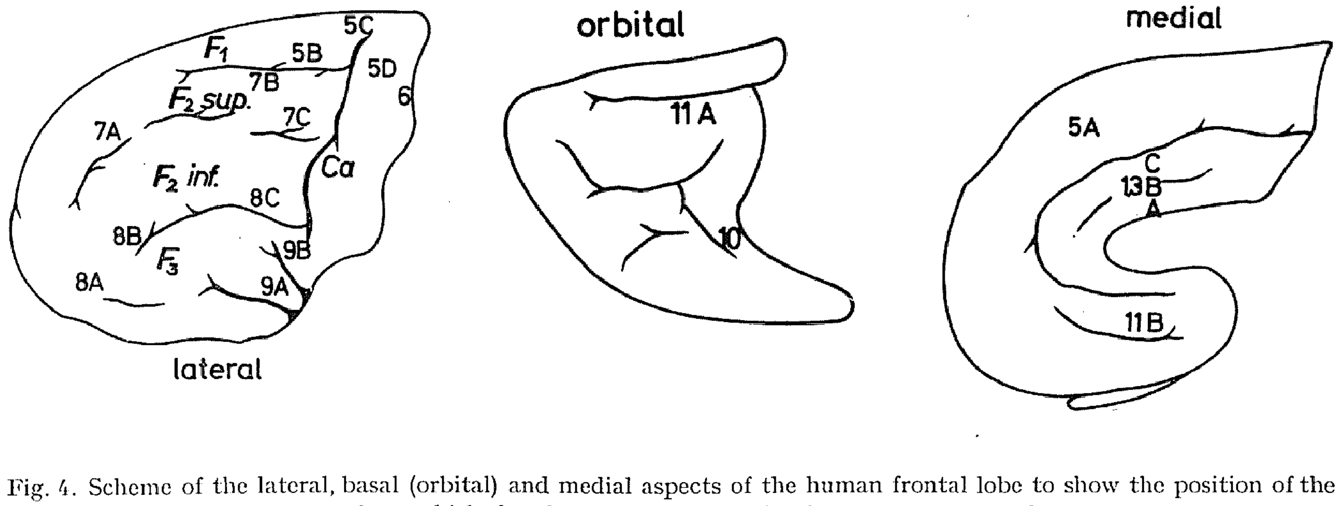

Fig. 4. Scheme of the lateral, basal (orbital) and medial aspects of the human frontal lobe to show the position of the areas from which the photographs and extinction curves were made.

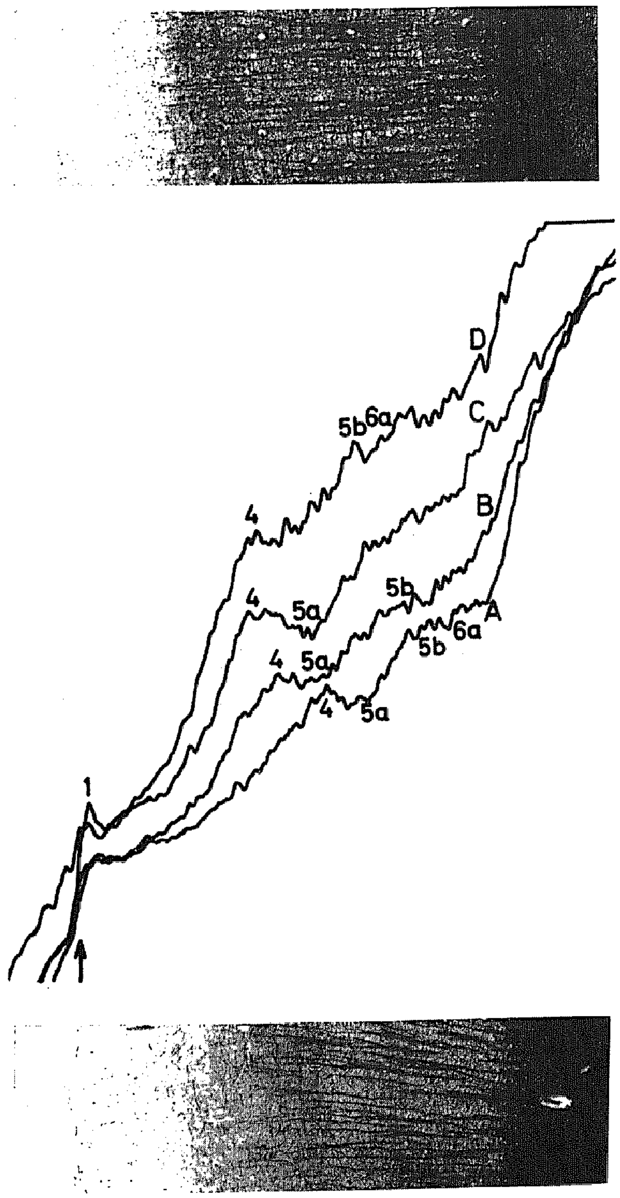

Fig. 5. Figures 5 to 11 and 13 are photomicrographs with the corresponding extinction curves taken from coronal sections 40 μ thick, stained for myelin (Weigert-Wolters method). × 25, reduced for publication $^4/_5$ = 20 ×. The photographs are turned 90° to the left so that the surface of the cortex is not at the top but on the left side. In this way a direct comparison of the photomicrographs and the extinction curves is possible. The surface of the cortex is indicated by an arrow. The number of the areas are those used by Vogt, Strasburger, Hopf, and Sanides for the areas of the human frontal lobe.

A—C are extinction curves of unistriate areas of the first frontal gyrus, well demarcated outer horizontal stripe in layer 4, but no demarcation of the inner horizontal stripe in 5b since 6a is dark; the curves ascend continuously. *A* area 35, anterior part of F1, curve registered of photograph at the base, *B* area 37, middle part of F1, *C* area 38, posterior part of F1, *D* area 39, precentral gyrus, nearly astriate, (propeastriate), curve corresponding to photograph at the top. Increasing fiber content (gradation) from A to D.

especially the fiber content of sublayer 5a so that the demarcation of the outer horizontal stripe in 4 is also not very clear. The curve does not descend at 5a but also it does not show a continuous ascent. Instead there is a plateau. This poor demarcation of both stripes of Baillarger is called a propeastriate (or nearly astriate) type.

The next step of that gradation is seen in fig. 6. The content of myelinated fibers is extremely high. No horizontal striping is obvious. That is the astriate type characteristic of Vogt's area 42 (Brodmann's area 4).

Gyrus frontalis medius (F2)

Figure 7 is taken from the upper part of the second frontal gyrus. In all 3 curves the outer horizontal stripe in 4 is well demarcated against 5a. Also the inner stripe of Baillarger in 5b is more obvious than in F1 since the curve does not ascend

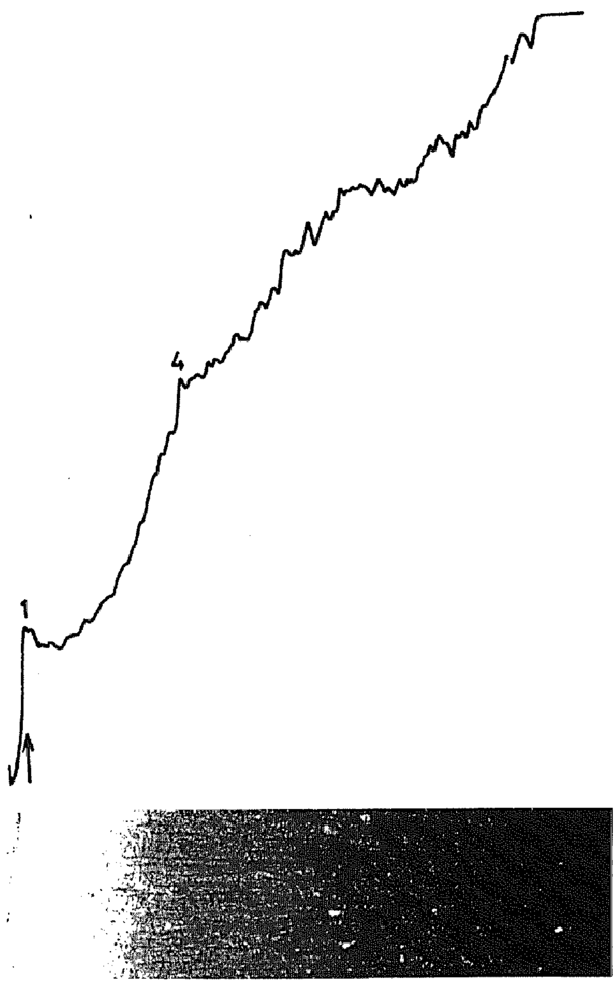

Fig. 6. Area 42 (corresponding to Brodmann's area 4, v. Economo and Koskinas' area FA γ) on the precentral gyrus. No horizontal striping — astriate type with extremely high content of myelinated fibers.

continuously but shows a plateau or a little descent in 6a. The unistriate type is not more fully developed, we have a nearly unistriate or propeunistriate type. A gradation in the fiber content is obvious. The lower curve (A) is taken from the oral part of the superior second frontal gyrus, the upper (C) from the caudal and the curve between them (B) from an intermediate part of this gyrus. The photograph at the base corresponds with the lower and that at the top with the upper curve.

The next step is reached on the inferior part of the second frontal gyrus as is demonstrated in fig. 8. The decrease of the fiber content in 6a is now as pronounced as in 5a so that the two horizontal stripes stand out well against the neighboring sublayers. This is the bistriate type. Curve C derives from the posterior part, curve A from the anterior (polar) part and curve B from an intermediate part of the lower second frontal gyrus. There is again a stepwise decrease towards the frontal pole that constitutes a gradation. The total fiber content and the caliber of the myelinated fibers is very low in the area near the frontal pole so that the horizontal stripes are not very distinct in the photograph (at the base) and only small elevations in the extinction curves are observable.

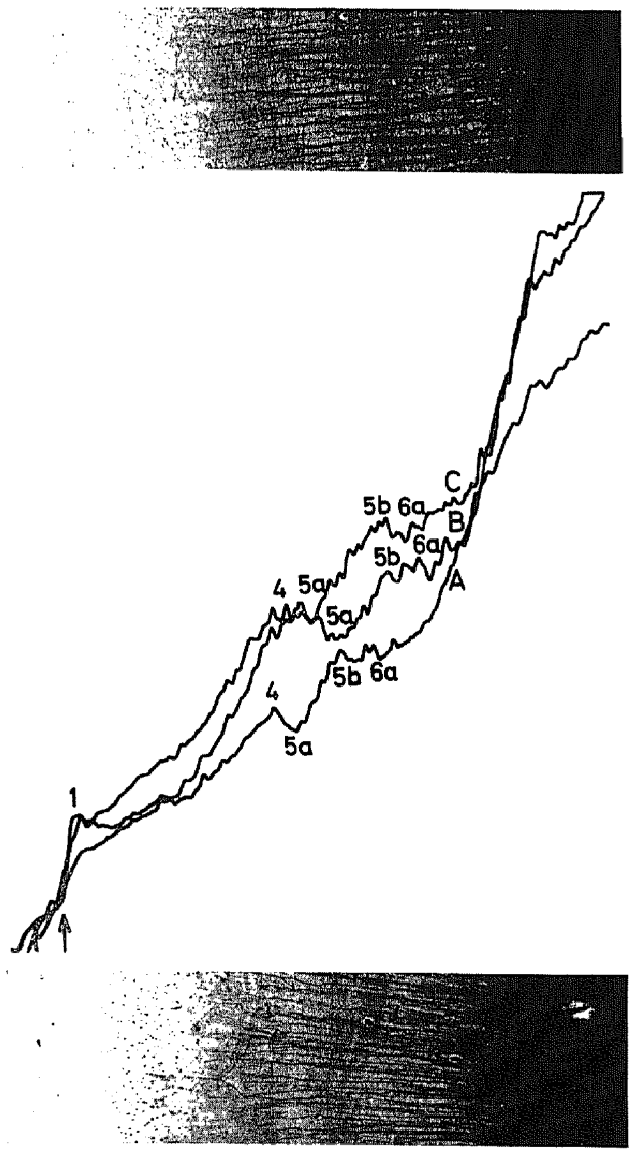

Fig. 7. Propeunistriate (nearly unistriate) areas of the superior (dorsal) part of the second frontal gyrus. Well demarcated outer stripe of Baillarger in layer 4, less well demarcated inner stripe of Baillarger in 5b, since 6a is nearly as dark as 5b. *A* area 49, anterior part of F2 sup., photograph at the base, *B* area 45, middle part of F2 sup., *C* area 44, posterior part of F2 sup., photograph at the top. Increasing fiber content from A to C.

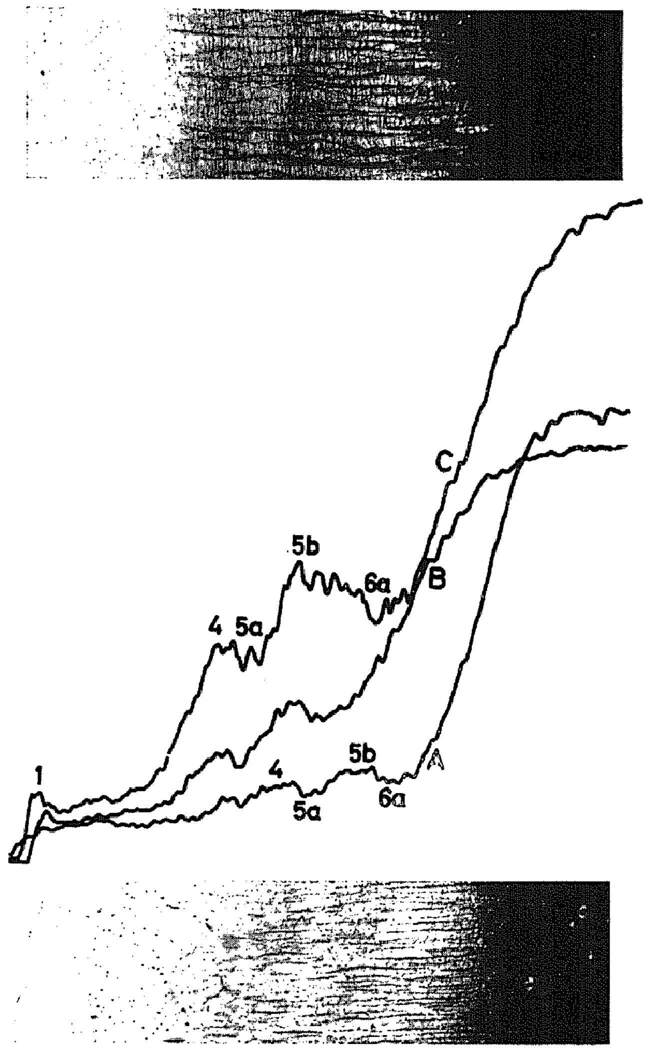

Fig. 8. Bistriate areas of the inferior (ventral) part of the second frontal gyrus. Both horizontal stripes are obvious since 5a and 6a are less dense. *A* area 51, anterior part of F2 inf., registered from the photograph at the base, very poor in myelinated fibers, *B* area 53, middle part of F3 inf., *C* area 55a, posterior part of F3 inf., photograph at the top. Steplike increasing fiber density (gradation) from A to C.

Gyrus frontalis inferior (F3) and Gyrus orbitalis lateralis (O1)

The lower curve (A) of fig. 9 is taken from the caudal part of pars triangularis of the third frontal gyrus. The most striking new myeloarchitectonic feature is a further fiber decrease in 6a so that this sublayer is even less dense than 5a which also is not so well pronounced. The two horizontal stripes show a certain tendency to unite and this type is therefore named propeunistriate.

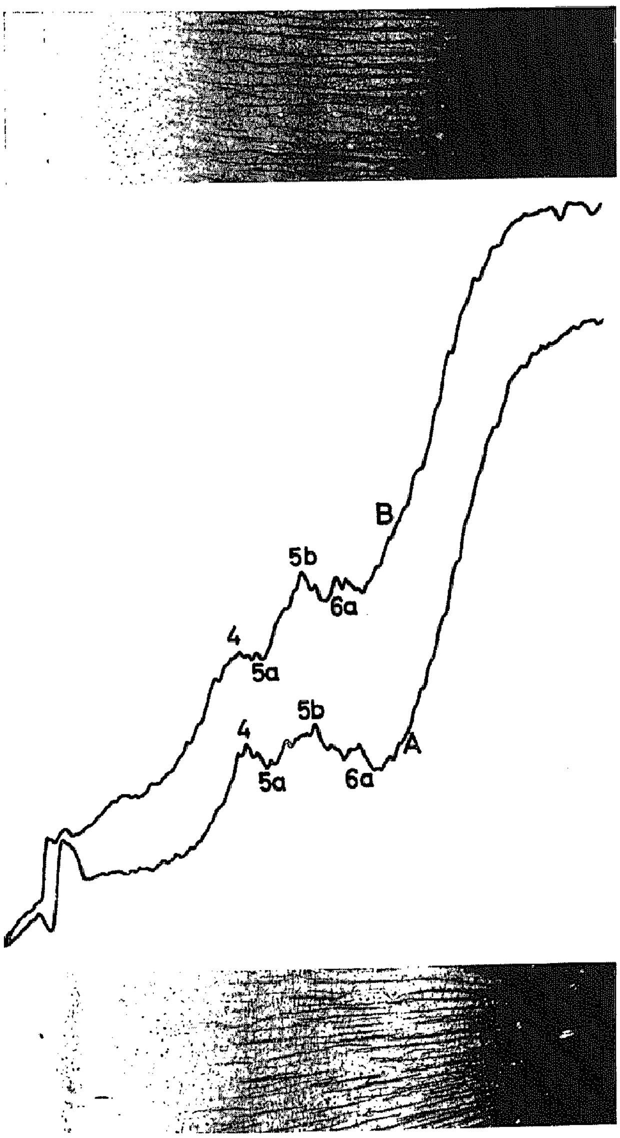

Fig. 9. Areas of the third frontal gyrus. *A* area 59, pars triangularis of F3, lower photograph, *B* area 56b, pars opercularis of F3, upper photograph. In A the two horizontal stripes are obvious but 5a is very thin and denser than 6a. Therefore it is nearly a unitostriate type (propeunitostriate). In B the decrease in staining intensity in 5a is very slight and also in 6a, in the latter because of the close proximity to the unistriate precentral gyrus. The area is nearly unistriate (propeunistriate) and nearly unitostriate as are the neighboring areas of F3.

The upper curve (B) is also very interesting from the point of view of gradation. The area is situated in the most caudal part of the third frontal convolution or in other words in the immediate neighborhood of the precentral gyrus which is unistriate and propeastriate in its anterior part. The upper curve shows the unistriate type not completely developed. It is propeunistriate because there is more of a plateau than a real descent in 6a as a consequence of the neighboring precentral gyrus. The poorly developed sublayer 5a, on the other hand, is characteristic of F3.

A fully developed unitostriate type is found in fig. 10. This area covers a posterior part of the lateral orbital gyrus. Therefore it lies near the allocortical prepiriform region. That is the reason why the first layer is so dark. There is no longer a separation into an outer and an inner horizontal stripe but these stripes are united to form a broad band.

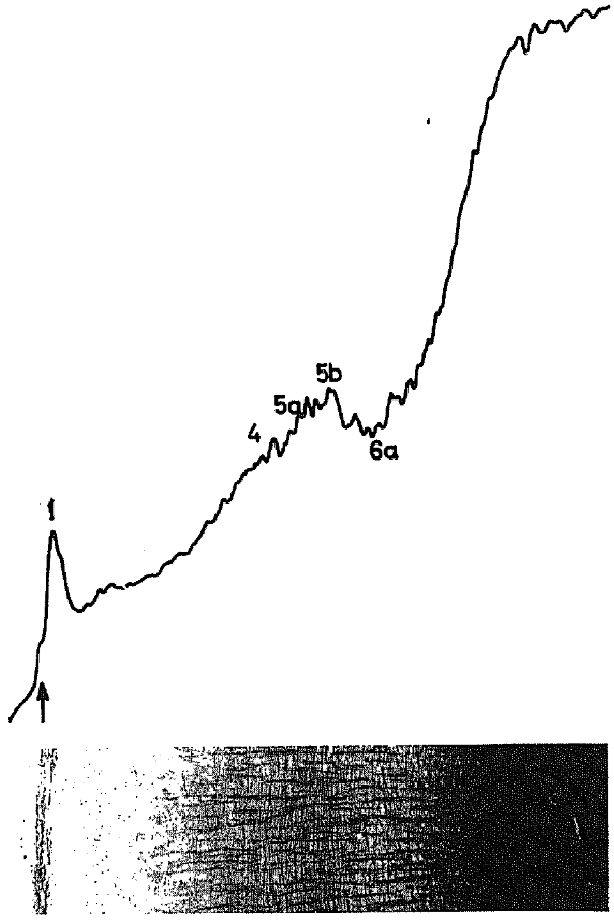

Fig. 10. Area 64 of the lateral orbital gyrus. There is no added decrease in staining intensity in 5a. The two stripes of Baillarger are united. 6a is less dense than 5a. This is the typical unitostriate type. The density of layer 1 is related to the proximity of the allocortex.

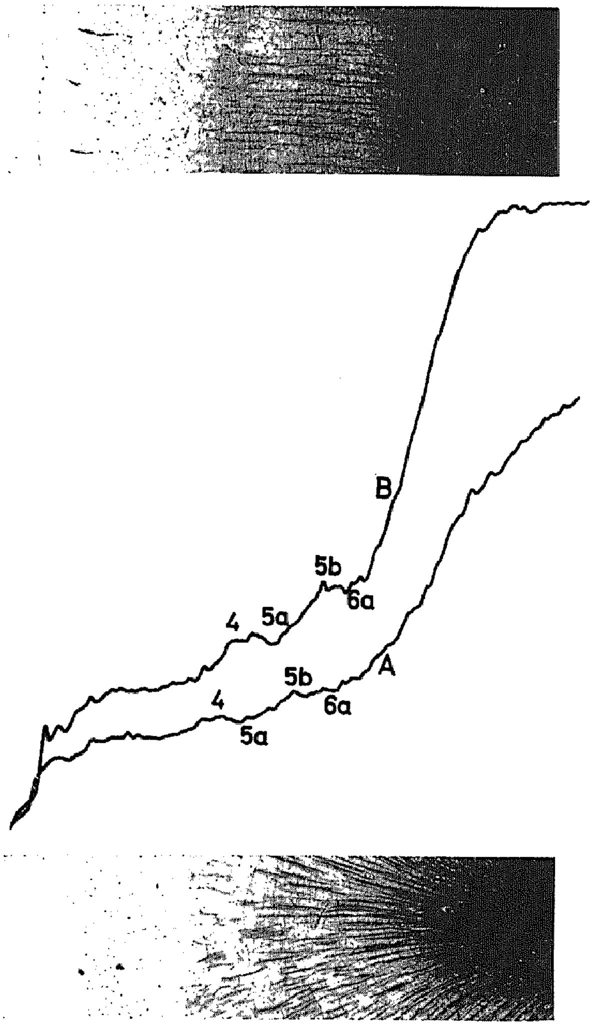

Fig. 11. Unistriate areas of the medial orbital and ventral paralimbic zone. The outer horizontal stripe is well demarcated in both areas since 5a is less dense. But the inner border of 5b is not distinct, the curve ascends farther in 6a. The lower area (A) is very poor in fibers because of the influence of the neighboring limbic region. *A* area 10, ventral paralimbic zone, lower photograph, *B* area 5, medial orbital gyrus, upper photograph.

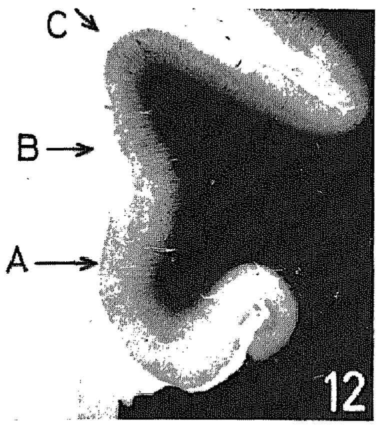

Fig. 12. Position of the photograms and extinction curves of figure 13. $\times 2\,{}^1/_2$.

The lighter appearance in sublayer 6a, expressed by the descending course of the extinction curve, is very clear.

Gyrus orbitalis medialis and Gyrus paralimbicus

The upper curve in fig. 11 is taken from the gyrus orbitalis medialis (fig. 4). The outer horizontal stripe in layer 4 is well demarcated but not the inner one. There is an interruption of the ascending course of the curve in sublayer 6a but not a real descent. The area is unistriate.

The lower curve belongs to an area of a small gyrus between the medial part of the gyrus rectus and the anterior limbic gyrus (fig. 4). It is difficult to find a suitable point for the extinction measurement of this area because the convolution covered by it is always small and the layers are markedly curved. The area is a part of the ventral paralimbic zone of SANIDES and distinctly 'influenced' by the fiber poor and unistriate proisocortex of the anterior cingulate gyrus. The outer stripe of Baillarger is as poorly developed as in the anterior cingulate gyrus. There is a lighter appearance in 5a. The inner stripe is not well demarcated from sublayer 6. The area is unistriate.

Gyrus cinguli anterior

In the depths of the sulcus corporis callosi is situated a rudiment of the archicortex. The phylogenetically old paleocortex and archicortex were named by VOGT *allocortex* because of their different myeloarchitecture. They are "*supraradiate*" while the neocortex (*isocortex* of VOGT) is "*euradiate*". Euradiate means that the radiate fiber bundles are well developed up to the border of the sublayers 3^3 and 3^2. In the supraradiate allocortex on the other hand fine radiate fibers traverse the whole thickness of the cortex. Many of them are "*descendent supraradiate*".

The areas on the anterior cingulate gyrus near the allocortex are infraradiate, *i. e.*, their radiate fiber bundles terminate at the border of sublayers 5b to 5a. The dorsally adjoining areas are medioradiate. The radiate fiber bundles are a little longer than those of the infraradiate type but shorter than those of the euradiate type. They terminate mostly somewhere in layer 4. The cortex of the anterior cingulate gyrus was called *mesocortex* by ROSE (1927), and later *proisocortex* by VOGT (1956). Fig. 12 shows the places from which the photographs of fig. 13 are taken and the curves registered.

A gradation is easy to recognize. The myelin fiber content increases in a dorsal direction. The lower area is infraradiate. One can follow the radiate fiber bundles in the photograph only up to the border of 5b with 5a. The upper area is not more distinctly medioradiate but weakly euradiate. There are fiber bundles in 4 and some single radiate fibers in 3^3. The outer horizontal stripe is very poorly developed in the lowest area and better in the other ones. The inner horizontal stripe is not demarcated from 6a, the curve ascends continuously. The 3 areas are therefore unistriate.

Discussion

In spite of the large number of publications, many problems of architectonics are still unsolved. What is lacking or questioned (Bailey and v. Bonin 1951) is mainly the objectivity of the different criteria used by the various authors.

It is not commonly known that the differences in myeloarchitecture are sometimes more pronounced than those in cytoarchitecture and that often they can be observed by macroscopic observation. Therefore, myeloarchitectonics are suitable for a precise and quick localization of lesions in the cortex (Hoeft 1957, Hopf 1957, Kleist 1960, Hoffmann 1964). With the new extinction method the existence and reliability of some myeloarchitectonic features can be objectively demonstrated. Most valuable in myeloarchitectonic studies is the relative fiber density of the two horizontal stripes of Baillarger in relation to each other and to the neighboring sublayers as well as the general content in myelinated fibers. These characteristics also can be registered in the extinction curves.

In the human frontal lobe all of the types described in qualitative myeloarchitectonic studies could be confirmed. There is no question that the behavior of the horizontal stripes of Baillarger is different, for instance, in the first, the second and the third frontal convolution. Also the steplike decrease in the myelin fiber content in the direction of the frontal pole could be objectively confirmed. In this way a large number of areas in the frontal lobe can be distinguished.

The structural differences between the superior, middle and inferior frontal gyrus seem to be more obvious in myeloarchitectonics than in cytoarchitectonics. They were overlooked in many cytoarchitectonic studies though they exist here too, as Sanides has shown (1962). Differences in cytoarchitecture were described mostly in a caudo-oral direction because the increase of granule cells in the fourth layer is easy recognizable in this direction. But many other cytoarchitectonic criteria are not less valuable (Sanides 1962).

The increase in granule cells is correlated with a decrease in the myelin fiber content in the direction of the frontal pole. Sanides (1964) demonstrated that "high fibrillarity always corresponds to magnocellularity and low fibrillarity to parvocellularity". This statement is true of the human frontal lobe but not of other lobes as pointed out formerly by Hopf (1955, 1956). In the parietal lobe,

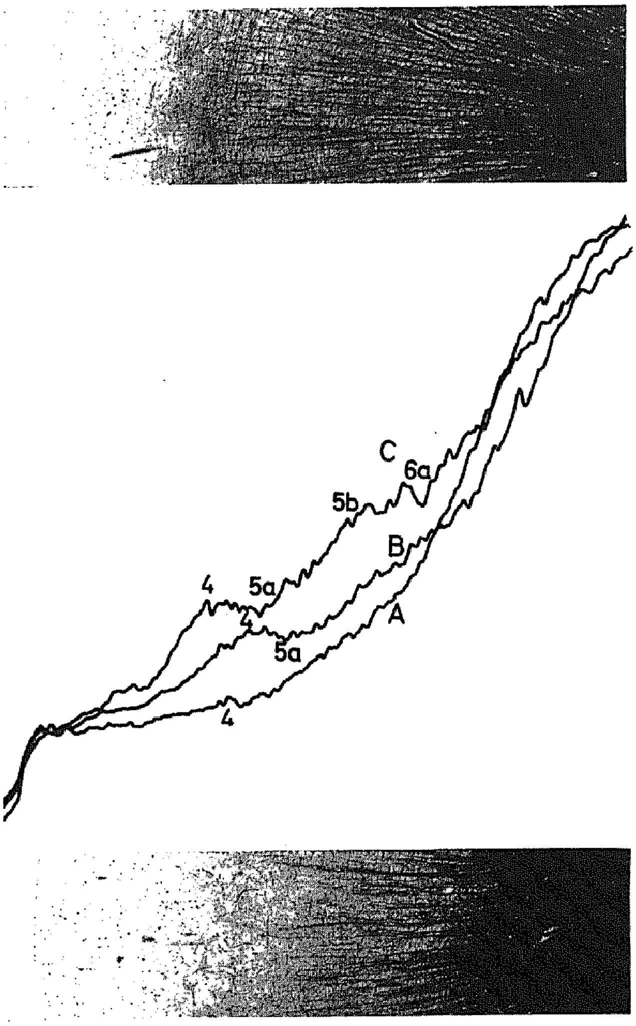

Fig. 13. Unistriate areas of the anterior cingulate gyrus. *A* area 23, photograph at the base, *B* area 27, *C* area 31, photograph at the top. With increasing distance from the corpus callosum there is a steplike increase (gradation) in the myelin fiber content. The outer stripe of Baillarger is well demarcated but not the inner one since the extinction curve ascends continuously from 5b to the white matter.

e.g., the granular somatosensory areas of the postcentral gyrus have the highest fiber content and in the temporal lobe the auditory areas in the gyri of Heschl.

Therefore a simple correlation between cytoarchitecture and myeloarchitecture does not exist. The high content in thick myelinated fibers is characteristic of primary regions or in other words of motor and sensory fields. The functional necessity for a high conduction rate seems to be the common feature of these systems. The secondary regions, the so-called association areas, the areas with a "higher" function have thinner myelinated fibers. In this respect these youngest regions of the neocortex resemble some older parts of the brain more, especially the proisocortex of the anterior cingulate gyrus and the proisocortex of the dorsal insula from which a medial and lateral "Urgradation" of the frontal lobe originate according to SANIDES. The caliber of the myelinated fibers seems therefore to be influenced by different factors, *e. g.*, by the lenght of the fiber too, and cannot be interpreted exclusively from a phylogenetic point of view.

Generally in thickly myelinated fiber systems and cortical fields the myelogenesis starts earlier in ontogenesis. There are only a few exceptions, *e.g.*, on the anterior cingulate gyrus (HOPF 1956). The principle of gradation in the sense of VOGT is very obvious in the human frontal lobe. The influence of the different gradations on the architecture of the frontal areas has been elaborated by SANIDES (1962, 1964). Many of these gradations could be objectively registered in the extinction curves.

A very rapid increase in the myelin fiber content takes place in a dorsal direction from the posterior part of the anterior cingulate gyrus in the direction of the precentral gyrus (figs. 13A, B, C, 5D, 6). More anteriorly, this increase is less pronounced and from the ventral part of the proisocortex of the anterior cingulate gyrus a steplike decrease in the fiber content in the direction of the paralimbic zone (fig. 11A) can be observed.

In the immediate ventral neighborhood of the anterior insula one can find the relatively dark lateral orbital areas 62—64 of VOGT. The high myelin fiber content of these areas is in sharp contrast to the laterally adjoining insular cortex, which is very poor in fibers, as well as to the medially adjoining medial orbital areas, which are also very poor in fibers. From these adjoining regions an influence in this respect cannot be stated. The same is true of the frontopolar zone because it has a low fiber density and especially since the orally adjoining lateral orbital areas 60 and 61 are still darker than 62—64. In some cytoarchitectonic features Sanides could demonstrate an 'insular influence'.

These examples may show that not all architectonic features can be explained by gradations on a pure phylogenetic basis though these influences are very important. Our former (1954, a—c, 1955, 1956) and present studies seem to point out that one should be careful in regarding architectonic principles found in one lobe or region as conclusive for others. The statement should be limited to the region of the brain and the species studied. The architecture of an area is determined by many factors: phylogenetic, functional and others. None of these should be overestimated. The gradation first stated by VOGT, phylogenetically interpreted and regarded as the general and most important principle by SANIDES and objectively proved by the new extinction method, is one of the most fascinating principles of frontal lobe structure.

Summary

The myeloarchitecture of the human frontal lobe was studied with an extinction writer. Striplike photonegatives taken of myelin preparations at a magnification of 25 and oriented perpendicularly to the surface of the cortex were used for registration. With a standardized technique reliable results could be obtained. The different myeloarchitectonic types described in former qualitative studies could be confirmed by this quantitative method. There is a steplike decrease (gradation in the sense of Vogt) in the myelin fiber content from the precentral gyrus toward the frontal pole. The three frontal convolutions are different in the behavior of the horizontal stripes of Baillarger. In the superior frontal gyrus only the outer stripe is well demarcated (unistriate type). In the middle frontal gyrus two horizontal stripes are recognizable; in the upper convolution of this gyrus the demarcation of the inner one is not so good (propeunistriate type) as in the lower convolution of the middle frontal gyrus (bistriate type). In the inferior frontal gyrus, especially its orbital part the two horizontal stripes are more or less united to form a single broad band (unitostriate and propeunitostriate type). A clear horizontal striping is missing on the posterior part of precentral gyrus (astriate type) which has the highest content in thick myelinated fibers.

Zusammenfassung

Die Myeloarchitektonik der menschlichen Stirnhirnrinde wurde mit einer Extinktionsmethode studiert. Streifenförmige Photonegative mit einem Abbildungs-

maßstab von 25 : 1, die radiär zur Rindenoberfläche orientiert waren, wurden für die Registrierung verwendet. Mit einer standardisierten Technik konnten zuverlässige Ergebnisse erzielt werden. Durch diese quantitative Methode konnten die bei früheren qualitativen Studien beschriebenen myeloarchitektonischen Typen bestätigt werden.

Von der Präzentralwindung in Richtung des Frontalpoles konnte eine stufenweise Abnahme (Gradation im Sinne von VOGT) des Markscheidengehaltes festgestellt werden. Die drei Frontalwindungen unterscheiden sich in dem Verhalten der Horizontalstreifen von Baillarger. In der oberen Frontalwindung (F_1) ist lediglich der äußere Baillarger'sche Streifen gut abgegrenzt (unistriärer Typ). In der mittleren Frontalwindung (F_2) sind beide Baillarger'schen Streifen erkennbar. In dem oberen Windungszug (F_2 sup.) ist die Abgrenzung des inneren Baillarger'schen Streifens weniger gut (propeunistriärer Typ) als in dem unteren Windungszug (F_2 inf.). Letzterer ist bistriär. In der unteren Frontalwindung (F_3), besonders in ihrem orbitalen Anteil sind beide Baillarger'schen Streifen mehr oder weniger zu einem breiten Band vereinigt (unitostriärer oder propeunitostriärer Typ). Eine deutliche Horizontalstreifung fehlt im hinteren Abschnitt des Gyrus praecentralis (astriärer Typ). Hier findet sich der höchste Gehalt an dick myelinisierten Fasern.

Literature Cited

BAILEY, P., and G. v. BONIN: The isocortex of man. University of Illinois Press, Urbana, Illinois (1951).

BAILLARGER, J. G. F.: Recherches sur la structure de la couche corticale des circonvolutions du cerveau. Mém. Acad. roy. de med. **8**, 149—183 (1840).

BRAITENBERG, V.: Die Gliederung der Stirnhirnrinde auf Grund ihres Markfaserbaus (Myeloarchitektonik). In: „Das Hirntrauma". E. Rehwald (ed.) Thieme, Stuttgart (1956).

BRODMANN, K.: Vergleichende Lokalisationslehre der Großhirnrinde. Johann Ambrosius Barth, Leipzig (1909).

CAMPBELL, A. W.: Histological studies on the localization of cerebral function. University Press, Cambridge (1905).

ECONOMO, C. v., and G. N. KOSKINAS: Die Cytoarchitektonik der Hirnrinde des erwachsenen Menschen. Springer, Berlin and Wien (1925).

GERHARDT, E.: Der Isocortex parietalis beim Schimpansen. J. Psychol. Neurol. (Leipzig) **48**, 329—386 (1938).

GERHARDT, E.: Die Cytoarchitektonik des Isocortex parietalis beim Menschen. J. Psychol. Neurol. (Leipzig) **49**, 367—419 (1940).

HOEFT, H.-J.: Klinisch-anatomischer Beitrag zur Kenntnis der Nachsprechaphasie (Leitungsaphasie). Deutsch. Zschr. Nervenheilk. **175**, 560—594 (1957).

HOFFMANN, J.: Ein Fall von konstruktiver Apraxie mit myeloarchitektonischer Bestimmung der Erweichungsherde. J. Hirnforsch. **7**, 335—361 (1964).

HOPF, A.: Die Myeloarchitektonik des Isocortex temporalis beim Menschen. J. Hirnforsch. **1**, 208—279 (1954a).

HOPF, A.: Zur Frage der Konstanz und Abgrenzbarkeit myeloarchitektonischer Rindenfelder. Deutsch. Zschr. Nervenheilk. **172**, 188—206 (1954b).

HOPF, A.: Zur architektonischen Gliederung der menschlichen Hirnrinde. J. Hirnforsch. **1**, 442—496 (1954c).

HOPF, A.: Über die Verteilung myeloarchitektonischer Merkmale in der isokortikalen Schläfenlappenrinde beim Menschen. J. Hirnforsch. **2**, 36—54 (1955).

Hopf, A.: Über die Verteilung myeloarchitektonischer Merkmale in der Stirnhirnrinde beim Menschen. J. Hirnforsch. **2**, 311—333 (1956).

HOPF, A.: Architektonische Untersuchungen an sensorischen Aphasien. J. Hirnforsch. **3**, 275—530 (1957).

HOPF, A.: Objektive Registrierung der Myeloarchitektonik der Hirnrinde. Naturwissenschaften **52**, 479 (1965).

HOPF, A.: Messungen des Markfasergehaltes der Hirnrinde. Zeiss Mitt. **4**, 10—25 (1966a).

HOPF, A.: Über eine Methode zur objektiven Registrierung der Myeloarchitektonik der Hirnrinde. J. Hirnforsch. **8**, 301—314 (1966b).

HOPF, A., and H. GRÄFIN VITZTHUM: Über die Verteilung myeloarchitektonischer Merkmale in der Scheitellappenrinde beim Menschen. J. Hirnforsch. **3**, 79—104 (1957).

KLEIST, K.: Myeloarchitektonik und Pathologie des Scheitellappens. Arch. Psychiat. Nervenkr. **200**, 329 bis 338 (1960).

ROSE, M.: Gyrus limbicus anterior and Regio retrosplenialis (Cortex holoprotoptychos). Vergleichende Architektonik bei Tier und Mensch. J. Psychol. Neurol. (Leipzig) **35**, 65—173 (1927).

SANIDES, F.: Die Architektonik des menschlichen Stirnhirns. Springer, Berlin, Göttingen, Heidelberg (1962).

SANIDES, F.: The cyto-myeloarchitecture of the human frontal lobe and its relation to phylogenetic differentiation of the cerebral cortex. J. Hirnforsch. **6**, 269—282 (1964).

SMITH, G. E.: A new topographical survey of the human cerebral cortex. J. Anat. (London), **41**, 237—254 (1907).

STRASBURGER, E.: Die myeloarchitektonische Gliederung des Stirnhirns beim Menschen und Schimpansen. J. Psychol. Neurol. (Leipzig) **47**, 461—491, 565—606 (1937).

VOGT, C., und O. VOGT: Allgemeinere Ergebnisse unserer Hirnforschung. J. Psychol. Neurol. (Leipzig), **25**, 279—461 (1919).

VOGT, C., und O. VOGT: Weitere Ausführungen zum Arbeitsprogramm des Hirnforschungsinstituts in Neustadt/Schwarzwald. J. Hirnforsch. **2**, 403—427 (1956).

VOGT, O.: Die myeloarchitektonische Felderung des menschlichen Stirnhirns. J. Psychol. Neurol. (Leipzig), **15**, 221—238 (1910).

Author's Address:

Prof. Dr. A. HOPF
C. u. O. Vogt-Institut für Hirnforschung
7828 Neustadt (Schwarzwald)