

MOTOR HEMIPLEGIA AND THE CEREBRAL ORGANIZATION OF MOVEMENT IN MAN

II. THE MYTH OF THE HUMAN EXTRAPYRAMIDAL SYSTEM

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SUMMARY — Following a brief review of the concept of extrapyramidal system, clinical and anatomic evidence is presented against its relative prominence in man. It is proposed that the greatest part of those structures traditionally labeled as extrapyramidal effects its respective functional activities by way of the pyramidal tracts themselves. Such structures, centered around the basal nuclei, the cerebellum and possibly, the limbic areas of the prosencephalon are, according to the present suggestion, indeed, *pre* pyramidal. This model is based upon the clinical analysis of patients and agrees with more than one century of anatomic verifications in human brains, favoring the notion of the singularity of the human brain.

Hemiplegia motora e organização cerebral do movimento no homem: II. O mito do sistema extrapiramidal humano

RESUMO — Após revisão sumária do conceito de sistema extrapiramidal, são apresentadas evidências clínicas e anatômicas contra sua importância relativa no homem. Propõe-se que as estruturas tradicionalmente agrupadas sob o rótulo extrapiramidal efetuam a maior parte de suas atividades funcionais, respectivamente, por intermédio dos próprios feixes piramidais. Tais estruturas — centradas nos núcleos da base dos hemisférios cerebrais, no cerebelo e, possivelmente, também, nas áreas límbicas do prosencéfalo —, de acordo com nossa proposição são, na verdade *pre*-piramidais. Esse modelo se baseia na análise clínica de pacientes, está de acordo com mais de um século de verificações anatômicas em cérebros humanos e depõe a favor da noção de singularidade do cérebro humano.

Anatomical and functional reorganization in the human brain — Contrary to the pyramidal system concept¹⁰⁹ which evolved in daily clinical practice, the concept of the 'extrapyramidal system' (EPS) was coined by Prus at a physiology laboratory in 1898¹²⁴. He investigated the means by which cortically induced epilepsy spread down to segmental levels. Working on dogs, Prus realized that the convulsions would not be affected by bilateral transections of the pyramidal tracts (PTs) at either mesencephalic or pontine levels, which led to the conclusion that epileptic volleys could be transmitted caudally through pathways distinct from the PTs. These, he proposed to call "extrapyramidal". It is noteworthy that Prus believed such EP pathways to follow a sequential multisynaptic course from the cerebral cortex to the spinal cord, due to a number of interruptions in subcortical and brainstem stations. He also suggested that such tracts would be responsible for the 'coordination and association' of movements. Contemporary studies have confirmed and extended Prus' views by showing the anatomical organization of the cortico-reticulospinal tracts¹³² and their crucial role in the propagation of cortical epilepsy to the segmental apparatus¹⁴⁹,

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as well as in the integration of body axis balance during standing and locomotion⁸³. Unfortunately, these conclusions may not be directly applicable to the human case, for they are entirely derived from animal experimental data.

Prus' studies did not receive widespread attention and lay unjustly forgotten by many, even today. The influential work of the Vogts¹⁵³, Wilson¹⁵⁷ and Hunt⁶⁹ independently revived the concept of an EPS in man, by defining in clinical language the syndromes of the pallidum, the putamen and the corpus striatum, respectively. These notions then gained wide acceptance and were soon incorporated into routine clinical parlance, albeit in a somewhat different meaning, for while Prus envisaged it primarily as a physiological concept, neurologists employed it strictly within a clinical and *presumed* anatomic context. So, in 1917, Hunt conceptualized the EPS as a group of descending tracts with departure points in definite brainstem nuclei — red nucleus, subthalamic nucleus, reticular formation, and locus niger —, in their turn under direct control from the basal ganglia⁷⁰. A final step was taken with the anatomic demonstration of the corticostriate connections, which paved the way for the suggestion that there existed a cortical level of organization at the top of the EP hierarchy⁵¹ (Fig. 1). Such a 'longitudinal' EPS concept — from cortex to cord — was

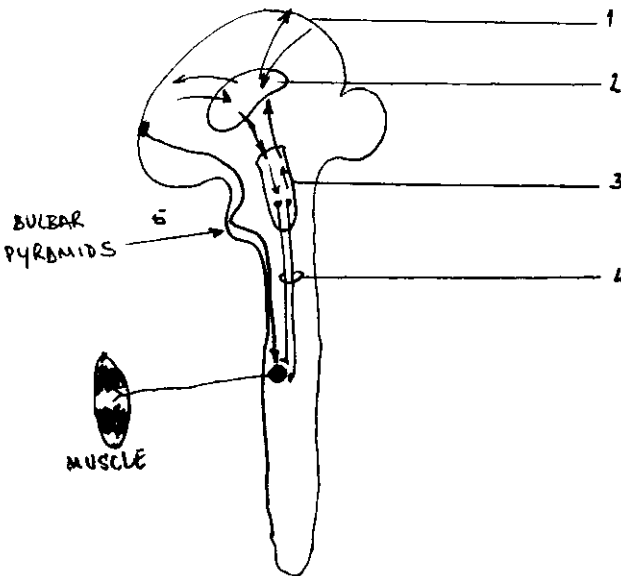


Fig. 1 — Classical schema of extrapyramidal system (EPS). 1 is the cortical EP level; 2, basal ganglia level; 3, brainstem level and 4, descending supra-spinal EP tracts. The cerebellar system, traditionally classified as EP too, is not represented. Note that the EPS, according to this model, is organized in parallel with the pyramidal system (5).

then explicitly formulated in clinical terms by Yakovlev in 1944¹⁶⁰. More recently, the cortical EPS was further fractionated in view of the development of the 'ventral striopallidum concept'⁶², which postulates that the EPS is the main avenue for the expression of limbic-related neural activity as well⁵⁴.

LS and PMH add evidence to the notion that what is traditionally thought to be the function of EP pathways are, in fact, *not*, as least in human beings. This led to the conclusion that, *in man, the PTs are the conveyors of most of those functional motor patterns classically attributed to an extrapyramidal mediation*. The residual motor functions which survive experimental pyramidotomy have for a long time been ascribed to the EPS. For several years, an operational model of such a system has been developed and the resultant picture has been transferred to the human case. However, efforts to apply these models to clinical practice have been hampered by apparently contradictory observations: most patients simply do not match the model. The remaining portion of this paper will attempt to show that this presumably happens as a consequence of looking at patients through monkeys' brains...

The available anatomic evidence^{79,103} consistently shows that EP pathways in the human cord are meager, scattered and inconspicuous. They all appear to form in brainstem nuclei, but their exact origin remains uncertain, though it seems that most do not descend beyond the upper half of the cervical cord. Presumably, these pathways

are made up of mesencephalic fibers coming from the interstitial nucleus of Cajal (interstitiospinal tract) and the superior colliculus (tectospinal tracts). They are possibly related to the effectuation of some head-and-eyes synergies (see table III). The vestibulospinal and rubrospinal tracts are very rudimentary and may be even lacking in some individuals^{106,141}. So the only probably significant EP pathways to reach the caudalmost levels of the human cord are the reticulospinal tracts (RSTs)¹⁰⁰, although they too may be relatively small in man^{101,102}. The existence of a 'reticular reflex' type of myoclonus⁵⁵, however, speaks for specific roles of RS pathways in relation to the skeletal musculature, besides the more classically acknowledged respiratory and vegetative ones^{29,99}.

The medial RSTs are the prolongation of the medial longitudinal fasciculus^{138,145}, running along the sulcomarginal zone of the cord, intermingled with Türck direct PTs and propriospinal fibers⁹⁰. Similarly, the lateral RS fibers do not make up any compact tract in the ventrolateral funiculus, where they descend scattered among other ascending regional fiber tracts^{6,118,134}. The terminations of the medial RS fibers at least, are, in a way, complementary to the lateral PT ones, for they preferentially end bilaterally in the medial motoneuronal and internuncial pools of the anterior horns thus indirectly influencing the activity of axial and proximal limb muscles¹⁰⁷. Then, the only bulky descending supraspinal pathways that can be sharply and readily identified are the PTs¹⁰³. Moreover, the considerable volume of the bidirectional propriospinal paths makes them easily demonstrable in human cords, as well¹⁰⁴.

Thus, as shown by LS cases, if (a) patients deprived of PTs are also deprived of most of those motor patterns traditionally labeled as EP, and if (b) anatomy has denied the existence of any comparatively significant descending supraspinal EP pathways, it is then suggested that in the human brain, after establishing specific thalamic links in non-overlapping specific nuclei, the main bulk of anatomic subsystems of fibers centered in basal ganglia and cerebellum proceed rostrally to the areas of the cerebral cortex from which the PTs originate. The role of the thalamus in this design must be critical for the redistribution of the incoming basal nuclear and cerebellar activity to precisely defined sectors of the precentral 'PT cortex'^{1,120,137}. Had one to summarize such concepts in just a few words, it might be said that the 'head nuclei' classically assumed to be extrapyramidal are, indeed, 'prepyramidal'.

A few authors in the beginning of the present century had already glimpsed the possibility of a dominant role for the PTs, in contrast to EP ones, in the generation of suprasegmental activity^{140,158}, but were apparently unable to grasp fully their respective functional importance. Only recently this became a possibility, once the LS as a concept crystalized^{48,117,123,152} and could be taken as a reliable model for pyramidotomies in man. Even in lower animal forms, this 'pyramidalization trend' can already be seen to coexist with the more massive EP descending pathways⁴⁰, and for mammals, including non-human primates, this stands as a conservative architectural layout. This anatomic schema fits surprisingly well with daily experience, sometimes in an almost exotic fashion¹⁵⁵: once the PTs are interrupted, the individual is immediately reduced to a segmental (reflex arc) and multisegmental (propriospinal) reflex pattern of motor behavior. In such cases, most cerebellar and basal ganglion activity is presumably prevented from reaching the segmental apparatus of the cord. Uni or bilateral hemiplegia are the semeiologic manifestations of this phenomenon, provided the interruption is complete and occurs above the bulbar pyramidal stage. Such rudimentary motor competence in LS agrees with the anatomic data pertaining to the equally sparse EP pathways in the human cord. Additional evidence can be invoked to strengthen this view, and this will be briefly revisited now.

First, as conventionally recognized by neurosurgeons and neuropathologists, if most of the classic diseases known as 'extrapyramidal' — resting and action tremors, chorea, athetosis, cortical reflex myoclonus, ballismus, torsion dystonia — are to become clinically apparent, a critical amount of structural integrity of the PTs must remain^{19,59,71,113,125,128,146,147}. Conversely, a natural or artificial injury inflicted on the PTs will turn a dyskinetic movement into the stereotyped Wernicke-Mann hemiplegic attitude. Similarly, if any of the well known post-hemiplegic disorders of movement is to supervene at all, again a critical amount of the PTs must be functionally patent^{21,39}. It is as if the abnormal physiologic activity generated at a given subcortical or brainstem locus, and which emerges embodied in a particular type of

purposeless movement, were effected through the PTs, after being relayed to the precentral motor cortices from specific thalamic links.

Second, the observation that the hemiplegia resulting from surgical hemispherectomies¹²⁶ or from cerebral degenerative hemiatrophies with or without anatomic PT involvement^{73,116,140} is identical to that which supervenes after a restricted PT injury, even in infancy¹⁶³, reassures us that this tract is, indeed, the main way out for the most meaningful lot of all descending suprasegmental activity. This may become even clearer if we contrast the effects of hemispherectomies carried out on other animal species¹⁵⁴, for in them the residual motor abilities is considerably more preserved than in man.

The third statement is implicit in the clinical picture of LS and derives from considerations regarding the mechanism of recovery from a PT lesion in the internal capsule⁴⁴, in the ventral pons⁴² or in the spinal cord¹⁰⁶. There is scanty, though concise, evidence that the variable degrees of recovery commonly seen to occur in such cases depend on the PTs of the unaffected side and probably not on EP pathways, as may be the case in some non-human primates⁸³. This fact has been cogently demonstrated^{2,4,44}. One recently reported patient was rendered hemiplegic by an internal capsular infarct⁴⁴, yet was mildly hemiparetic and able to walk less than one month later. Then, the other internal capsule suffered an infarction and she became immediately locked-in, only capable of moving the left toes in response to commands. Unfortunately, her neuro-ophthalmologic examination is not cited on this short report. It appears that in such cases the healthy PT is responsible for recovery, which cannot be obviously assigned to any 'EP pathways' for these simply do not exist at such rostral levels. Besides, once locked-in, patients with verified extensive PT destruction so remain for an indefinite length of time, even for years, again pointing to the exclusion of efficient recovery mechanisms outside the main PTs injury.

Finally, one particular aspect of cerebellar symptoms deserves comment, namely, the well-known ipsilaterality of signs which occur after a cerebellar injury. In man, by far the main set of efferent fibers from the cerebellum is grouped in the superior cerebellar peduncles, which completely decussate in the ventral mesencephalon before heading for specific ventrolateral thalamic nuclei. In turn, efferent fibers ascend to the precentral cortex from the thalamus. As cerebellar symptoms are *ipsilateral* to a lesion situated at any point from the cerebellar cortex up to the superior peduncle decussation, and *contralateral* to a lesion lodged at any point from the ventrolateral thalamus^{52,67} up to the recipient cortical areas of this nucleus¹¹¹, there must be a decussation along the cerebellar pathways other than the superior peduncle one. It is suggested that this second decussation is implicit in the pyramidal decussation itself, the cerebellar motor control being directly exerted at the cortical motor level. This view gains further support from the virtual absence of rubrospinal tracts in man^{106,141}, thus excluding EP pathways from the mediation of cerebellar function to the segmental apparatus, at least in ways similar to those known to be operative in other mammals.

The above considerations should not be taken to imply an unconditional absence of EP pathways in man. Only their comparative smallness in our species should be stressed. Additionally, most of their functions in other species seems to have been taken over by the PTs, as if a process of structural brain reorganization, for which quantitative data have been collected since the last century (for a review, see Holloway⁶⁶), had happened in the furnaces of phylogenesis. Table 3 gave us some idea of the kind of motor pattern that falls within the domain of the human EPS. The main goal of specifying functions within each one of these fiber systems is still a program-in-execution whose success will depend on the collaborative work in the general field of the clinical neurosciences. As stated elsewhere¹¹², descending motor systems are, after all, heterogeneous functional systems which may simultaneously conduct distinct types of activity generated at related functional systems within the encephalon. For example, as has been speculated, there may be some 'basal ganglion factors' in the PTs, just as there may be some 'cerebellar' ones, too. Perhaps, the columnar connections of each specialized afferent path within the cortex are as non-overlapping as they have been shown not to be at the thalamic level either and, then, each corresponding efferent PT axon might be differentially tied, in the long run, to a well defined subcortical subsystem^{119,162}.

Closing remarks — Refinement or challenging of these ideas will probably be soon forthcoming, for they may all be testable today. It seems that a key factor to shape their future development will necessarily lie on the revival of the methods for the study of secondary degenerations within the nervous system, unfortunately seldom used now. An immense treasure in brains has been going to waste for decades because the majority of reported clinicoanatomic case-studies limits itself at pointing to the location and histologic type of the gross lesions found at autopsy. To the clinical researcher, it is not enough to even sharply localize holes within the brain, no matter by which technic: it is as essential to have in hands a trusty Ariadne's thread, a detailed holographic map, as it were, of the linkages set up by the injured sites. Studies such as these, moreover, could be beautiful complements to PET and SPECT measurements eventually made previously *in vivo*. Thanks to the centenary wisdom embodied in the clinical method and the glamour of modern biomedical technologies, Neurology has become, after all, a fascinating enterprise which can be enjoyed from even apparently trivial phenomena of daily practice, as is the case with hemiplegia. In the near future, patients should also profit from these efforts by means of new and more effective therapeutic strategies devoted to the alleviation of motor symptoms.

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REFERENCES

1. Asanuma C, Thatch WT, Jones EG — Distribution of cerebellar terminations and their relation to afferent terminations in the ventral thalamic region of the monkey. *Brain Res Rev* 5:237, 1983.
2. Atwood CE — A case of double hemiplegia. *J Nerv Ment Dis* 35:513, 1908.
3. Babinsk J — Du phénomène des orteils et de sa valeur sémiologique. In: *Oeuvre Scientifique*. Masson, Paris, 1934.
4. Barlow T — On a case of double hemiplegia with cerebral symmetrical lesions. *Br Med J* 2:103, 1879.
5. Barnes S — Degenerations in hemiplegia: with special reference to a ventrolateral pyramidal tract, the accessory fillet and Pick's bundle. *Brain* 24:463, 1901.
6. Barnhart M, Rhines R, McCarter JC, Magoun HW — Distribution of lesions of the brain stem in poliomyelitis. *Arch Neurol Psychiat* 59:368, 1948.
7. Bauer G, Gerstenbrand F, Hengl W — Involuntary motor phenomena in the locked-in syndrome. *J Neurol* 223:191, 1980.
8. Beal MF, Richardson EP — Primary lateral sclerosis. *Arch Neurol* 38:630, 1981.
9. Bennet AH, Campbell CM — Case of brachial monoplegia due to lesion of the internal capsule. *Brain* 8:78, 1895.
10. Berman SA, Hayman LA, Hinck VC — Correlation of CT cerebral vascular territories with function: I. Anterior cerebral artery. *Am J Neuroradiol* 1:259, 1980.
11. Berman SA, Hayman LA, Hinck VC — Correlation of CT cerebral vascular territories with function. III. Middle cerebral artery. *Am J Roentgenol* 142:1035, 1984.
12. Berthand G, Blundell J, Musella R — Electrical exploration of the internal capsule and neighbouring structures during stereotaxic procedures. *J Neurosurg* 22:333, 1965.

13. Bouchard C — Des dégénérationes secondaires de la moelle épinière. Arch Gén Méd (Paris) 7:561, 1886.
14. Brion S, Gulot G — Topographie des faisceaux de projection du cortex dans la capsule interne et dans le pédoncule cérébral. Rev Neurol 110:123, 1964.
15. Brion S, Plas J — Les lésions du cortex moteur dans la sclérose latérale amyotrophique. L'Encéphale 12:81, 1986.
16. Brouckaert L, Sieben G, de Reuck J, Vandeer Eecken H — The syndrome of the anterior inferior cerebellar artery. Acta Neurol Belg 81:65, 1981.
17. Brown WJ, Fang HCH — Spastic hemiplegia in man associated with unilateral infarct of the corticospinal tract at the pontomedullary junction. Trans Am Neurol Ass 81:22, 1956.
18. Bubis JJ, Landau WM — Agenesis of the pyramidal tracts associated with schizencephalic clefts in rolandic cortex. Neurology 14:821, 1964.
19. Bucy PC, Buchanan DN — Athetosis. Brain 55:479, 1932.
20. Buge A, Escourolle R, Hauw JJ, Rancurel G, Gray F, Tempier P — Syndrome pseudo-bulbaire aigu par infarctus bilatéral limité du territoire des artères choroidiennes antérieures. Rev Neurol 135:313, 1979.
21. Charcot JM — De l'hémichorée post-hémiplégique. In: Oeuvres Complètes, vol. 3. Delahaye & Lecrosnier, Paris, 1886.
22. Charcot JM, Joffroy A — Deux cas d'atrophie musculaire progressive avec lésions de la substance grise et des faisceaux antéro-latéraux de la moelle épinière. Arch Physiol Norm Pathol 2:628, 1869.
23. Charcot JM, Pitres A — Les Centres Moteurs Corticaux Chez L'Homme. Rueff et Cie., Paris, 1895.
24. Chia L — Locked-in state with bilateral internal capsule infarcts. Neurology 34:1365, 1984.
25. Chokroverty S, Rubino FA — «Pure» motor hemiplegia. J Neurol Neurosurg Psychiat 38:896, 1975.
26. Chokroverty S, Rubino FA, Haller C — Pure motor hemiplegia due to pyramidal infarction. Arch Neurol 32:647, 1975.
27. Currier RD — The medial medullary syndrome. J Univ Mich Med Cen 42:96, 1976.
28. Damasio H — A computed tomographic guide to the identification of cerebral vascular territories. Arch Neurol 40:138, 1985.
29. Davis JN — Autonomous breathing: report of a case. Arch Neurol 30:480, 1974.
30. Dehaene I, Dom R — A mesencephalic locked-in syndrome. J Neurol 227:255, 1982.
31. Dehaene I, Dom R, Martin JJ — Le syndrome «locked-in»: étude clinique de dix cas. Acta Neurol Belg 84:12, 1984.
32. Dehaene I, Martin JJ — «Locked-in syndrome»: a clinico-pathological study of two cases. Eur Neurol 14:81, 1976.
33. Dejerine J — Sur l'origine corticale et le trajet intra-cérébral des fibres de l'étage inférieur ou pied du pédoncule cérébral. C R Soc Biol 5:193, 1893.
34. Dejerine J — Le faisceaux pyramidal direct. Rev Neurol 6:253, 1904.
35. Dejerine J, Sottas J — Notes sur un cas de paraplégie spasmodique acquise, par sclérose primitive des cordons latéraux. C R Soc Biol 2:776, 1895.
36. Dejerine J, Thomas A — Sur les fibres pyramidales homolatérales et sur la termination inférieure du faisceaux pyramidal. Arch Physiol Norm Pathol 8:277, 1896.
37. Denny-Brown D — The Cerebral Control of Movement. Liverpool UP, Liverpool, 1966.

38. Dohrman GJ, Nowack WJ — The upgoing great toe: optimal method of elicitation. *Lancet* 1:839, 1973.
39. Dooling E, Adams RD — Pathological anatomy of post-hemiplegic athetosis. *Trans Am Neurol Ass* 99:206, 1974.
40. Edinger L — On the importance of the corpus striatum and the basal fore-brain bundle, and on a basal optic-nerve root. *J Nerv Ment Dis* 14:674, 1887.
41. Englander RN, Netsky MG, Adelman LS — Location of human pyramidal tract in the internal capsule: anatomic evidence. *Neurology* 25:823, 1975.
42. Fisher CM — Bilateral occlusion of basilar artery branches. *J Neurol Neurosurg Psychiat* 40:1182, 1977.
43. Fisher CM — Pure spastic paralysis of cortico-spinal origin. *J Can Sci Neurol* 4:251, 1977.
44. Fisher CM — Bilateral capsular infarcts: the mechanism of recovery from hemiplegia. *J Neuropathol Exp Neurol* 37:613, 1978.
45. Fisher CM, Curry H — Pure motor hemiplegia of vascular origin. *Arch Neurol* 13:30, 1965.
46. Fisher MD — Personal communication (Jul 11th, 1988).
47. Fisher MD, Smith TW, Jacobs R — Pure motor hemiplegia secondary to a saccular basilar artery aneurysm. *Stroke* 19:104, 1988.
48. Flügel KA, Fuchs HH, Druschky KP — Das «locked-in» — Syndrome: Pseudokoma bei Basilaristhrombose. *Dtsch Med Wschr* 102:465, 1977.
49. Freund HJ: Premotor areas in man. *Trends Neurosc* 7:481, 1984.
50. Freund HJ, Hummelsheim H — Premotor cortex in man: evidence for innervation of proximal limb muscles. *Exp Brain Res* 53:479, 1984.
51. Fulton JF — *The Physiology of the Nervous System*. Ed 2. Oxford UP, London, 1949.
52. Garcin R — Syndrome cérébello-thalamique par lésion localisée du thalamus avec une disgression sur le «signe de la main creuse» et son intérêt sémiologique. *Rev Neurol* 93:142, 1955.
53. Gombault M — Sclerose symétrique des cordons latéraux de la moelle et des pyramides antérieures dans le bulbe. *Arch Physiol Norm Pathol* 4:509, 1871.
54. Haber SN, Groeneweger HJ, Grove EA, Nauta WJH — Efferent connections of the ventral pallidum: evidence of a dual striato-pallidofugal pathway. *J Comp Neurol* 235:322, 1985.
55. Hallett M, Chadwick D, Adam J, Marsden CD — Reticular reflex myoclonus: a physiological type of human post-hypoxic myoclonus. *J Neurol Neurosurg Psychiat* 40:253, 1977.
56. Halsey JH, Downie AW — Decerebrate rigidity with preservation of consciousness. *J Neurol Neurosurg Psychiat* 29:350, 1966.
57. Hanaway J, Young RR — Localization of the pyramidal tract in the internal capsule of man. *J Neurol Sci* 34:63, 1977.
58. Harvey DG, Torack RM, Rosebaum HE — Amyotrophic lateral sclerosis with ophthalmoplegia. *Arch Neurol* 36:15, 1979.
59. Hassler R, Mundinger F, Reichert T — Pathophysiology of tremor at rest derived from the correlation of anatomical and clinical data. *Confin Neurol* 32:79, 1970.
60. Hawkes CH — «Locked-in» syndrome: report of seven cases. *Br Med J* 4:379, 1974.
61. Hayman LA, Berman SA, Hinck VC — Correlation of CT cerebral vascular territories with function: II. Posterior cerebral artery. *Am J Roentgenol* 137:13, 1981.
62. Heimer L, Wilson RD — The subcortical projections of the allocortex: similarities in the neural associations of the hippocampus, the piriform cortex and the neocortex. In: *Golgi Centennial Symposium Proceedings*. Raven Press, New York, 1975.

63. Hines M — The motor cortex. *Johns Hopk Hosp Bull* 60:313, 1937.
64. Hirayama K, Tsubaki T, Toyokura Y, Okinaka S — The representation of the pyramidal tract in the internal capsule and basis pedunculi. *Neurology* 15:337, 1962.
65. Ho KL — Pure motor hemiplegia due to infarction of the cerebral peduncle. *Arch Neurol* 39:524, 1981.
66. Holloway RL — The evolution of the primate brain: some aspects of quantitative relations. *Brain Res* 8:1, 1968.
67. Hommel M, Gaio JM, Pollack P, Borgel F, Perret J — Hémiparésie ataxique par lacune thalamique. *Rev Neurol* 143:602, 1987.
68. Huang CH, Broe G — Isolated facial palsy: a new lacunar syndrome. *J Neurol Neurosurg Psychiat* 47:84, 1984.
69. Hunt JR — Progressive atrophy of the globus pallidus. *Brain* 40:58, 1917.
70. Hunt JR — The efferent pallidal system of the corpus striatum: a consideration of its function and symptomatology. *J Nerv Ment Dis* 46:211, 1917.
71. Jane JA, Yashon D, DeMeyer W, Bucy PC — The contribution of the precentral gyrus to the pyramidal tract of man. *J Neurosurg* 26:244, 1967.
72. Johns DR, Tierney M, Parkes SW — Pure motor hemiplegia due to meningovascular neurosyphilis. *Arch Neurol* 44:1062, 1987.
73. Josephy H — Cerebral hemiatrophy (diffuse sclerotic type of Schob). *J Neuropathol Exp Neurol* 4:250, 1945.
74. Karp JS, Hurtig HI — «Locked-in» state with bilateral midbrain infarcts. *Arch Neurol* 30:176, 1974.
75. Kertesz A, Geschwind N — Patterns of pyramidal decussation and their relationship to handedness. *Arch Neurol* 24:326, 1972.
76. Knopman DS, Rubens AB — The validity of computed tomographic scans findings for the localization of cerebral functions. *Arch Neurol* 43:328, 1986.
77. Kojewnikoff A — Cas d'esclérose latérale amyotrophique, la dégénération des faisceaux pyramidaux se propageant à travers tout l'encéphale. *Arch Neurol (Paris)* 6:356, 1883.
78. Kuypers HGJM — Corticobulbar connexions to the pons and lower brain-stem in man. *Brain* 81:364, 1958.
79. Kuypers HGJM — A new look at the organization of the motor system. *Prog Brain Res* 57:381, 1982.
80. Lapresle J, Claudio-Lacroix C — Paralyse limitée de la main due a une métastase du cortex moteur. *Rev Neurol* 140:278, 1984.
81. Lassek AM, Evan JP — The human pyramidal tract. *J Comp Neurol* 84:11, 1946.
82. Lawrence DG, Kuypers HGJM — The functional organization of the motor system in the monkey: I. The effects of bilateral pyramidal lesions. *Brain* 91:1, 1968.
83. Lawrence DG, Kuypers HGJM — The functional organization of the motor system in the monkey: II. The effects of lesions of the brain-stem pathways. *Brain* 91:15, 1968.
84. Lazzarino LG, Nicolai A — Infarctus de l'artère choroidienne antérieure révélé par une hémiplegie motrice pure. *Presse Méd* 16:1004, 1987.
85. Levine DN, Black P, Kleinman GM, Ojemann R — Acute quadriplegia due to bilateral cerebral metastases. *Neurology* 31:343, 1981.
86. Macpherson J, Wiesendanger M, Marangoz C, Miles TS — Corticospinal neurones of the supplementary motor area of monkeys: a single unit study. *Exp Brain Res* 48:81, 1982.

87. Mariani C, Spinnler H, Sterzi R, Vallar G — Bilateral perisylvian softenings: bilateral anterior opercular syndrome (Foix-Chavany-Marie syndrome). *J Neurol* 223:269, 1980.
88. Marie P, Boutier H, Bertrand I — Étude anatomique d'un cas de sclérose latérale amyotrophique a prédominance hémiplégique. *Bull Mém Soc Méd Paris* 47:481, 1923.
89. Marie P, Guillain G — Existe-t-il en clinique des localisations dans la capsule interne ? *Sem Méd* 26:209, 1902.
90. Marie P, Guillain G — Le faisceaux pyramidal direct et le faisceaux en croissant. *Sem Méd* 3:17, 1903.
91. Marie P, Guillain G — Le faisceaux pyramidal homolatéral: le côté sain des hémiplé-giques (étude anatomo-clinique). *Rev Méd* 23:797, 1903.
92. Mauguière F, Desmedt JE — Circumscribed lesions of thalamocortical motor or sensory projections documented by SEPs. *Neurology* 37 (suppl 1): 218, 1987.
93. Meienberg O, Mumenthaler M, Karbowski K — Quadriparesis with nuclear oculomotor palsy and total bilateral ptosis mimicking coma: a mesencephalic «locked-in syndrome ?» *Arch Neurol* 36:708, 1979.
94. Meyer JS, Herndon RM — Bilateral infarction of the pyramidal tracts in man. *Neurology* 12:637, 1962.
95. Minckler J, Klemme RM, Minckler D — The course of the efferent fibers from the human premotor cortex. *J Comp Neurol* 81:259, 1944.
96. Mott FW — A case of amyotrophic lateral sclerosis with degeneration of the motor path from the cortex to the periphery. *Brain* 18:21, 1895.
97. Mott FW — Hemiatrophy of the brain and its results on the cerebellum, medulla and spinal cord. *Brain* 23:239, 1900.
98. Nardelli E, Iannucci A, Rizzuto N — Bilateral infarction of the pyramidal tracts. *Acta Neurol* 33:130, 1978.
99. Nathan PW — The descending respiratory pathway in man. *J Neurol Neurosurg Psychiat* 26:487, 1963.
100. Nathan PW — Personal communication (Dec 23th, 1987).
101. Nathan PW — Personal communication (Jul 3rd, 1988).
102. Nathan PW — Personal communication (Jun 24th, 1988).
103. Nathan PW, Smith MC — Long descending tracts in man: I. Review of present know-ledge. *Brain* 78:248, 1955.
104. Nathan PW, Smith MC — Fasciculi proprii of the spinal cord in man: review of pre-sent knowledge. *Brain* 82:610, 1959.
105. Nathan PW, Smith MC — Effects of two unilateral cordotomies on the motility of the lower limbs. *Brain* 96:471, 1973.
106. Nathan PW, Smith MC — The rubrospinal and central tegmental tracts in man. *Brain* 105:223, 1982.
107. Nauta WJH, Feirtag M — *Fundamental Neuroanatomy*. Freeman & Co, New York, 1986.
108. Obeso JA, Marti-Masso JF, Carrera N, Astudillo W — Pure motor quadriparesis secondary to bilateral capsular hematomas. *Arch Neurol* 37:248, 1980.
109. Oliveira-Souza R — Hemiplegia and the cerebral organization of movement in man: I. The «pyramidal concept»: a restatement. *Arq. Neuro-Psiquiat* (São Paulo) 47:8, 1989.
110. Oliveira-Souza R, Esbérard CA — Locked-in syndrome: a pathophysiologic analysis of two cases (in Portuguese). *Rev Bras Neurol* 21:11, 1985.

111. Oliveira-Souza R, Espérard CA, Duarte ACG, Silva MAC, Lima OMP, Miranda LI — Corticocerebral ataxic hemiparesis (in Portuguese). *Rev Bras Neurol* 23:31, 1987.
112. Oliveira-Souza R, Gusmão DL, Figueiredo WM, Duarte ACG — Pure spastic hemiplegia of pyramidal origin (in Portuguese). *Arq Neuro-Psiquiat (São Paulo)* 46:77, 1988.
113. Oppenheim DR — A case of striatal hemiplegia. *J Neurol Neurosurg Psychiat* 30:134, 1967.
114. Ozaki I, Baba M, Narita S, Matsunaga M, Takebe K — Pure dysarthria due to anterior internal capsule and/or corona radiata infarction: a report of five cases. *J Neurol Neurosurg Psychiat* 49:1435, 1986.
115. Pagni CA, Ettore G, Infuso L, Marossero F — EMG responses to capsular stimulation in the human. *Experientia (Basel)* 20:691, 1964.
116. Papez JW, Vonderahe AR — Infantile cerebral palsy of hemiplegic type: a case with pyramidal and somaesthetic deficit. *J Neuropathol Exp Neurol* 6:244, 1947.
117. Patterson JR, Grabois M — Locked-in syndrome: a review of 139 cases. *Stroke* 17:758, 1986.
118. Peers JH — The pathology of convalescent poliomyelitis in man. *Am J Pathol* 19:673, 1945.
119. Penney JB, Young AB — Striatal inhomogeneities and basal ganglia function. *Movement Disorders* 1:3, 1986.
120. Penney JB, Young AB — Speculations on the functional anatomy of basal ganglia disorders. *Ann Rev Neurosci* 6:73, 1983.
121. Pinheiro RSA — Radiologic demonstration of degeneration of corticofugal tracts after cerebrovascular accidents (in Portuguese). *Radiol Bras* 21:11, 1988.
122. Pitres A — Recherches anatomo-cliniques sur les scléroses bilatérales de la moelle épinière consécutives à des lésions unilatérales du cerveau. *Arch Physiol Norm Pathol* 3:142, 1884.
123. Plum F, Posner J — *The Diagnosis of Stupor and Coma*. Ed 3. FA Davis, Philadelphia, 1980.
124. Prus J — Die Leitungsbahnen und Pathogenese der Rindenepilepsie. *Wien Klin Wschr* 11:857, 1898.
125. Putnam TJ — The operative treatment of diseases characterized by involuntary movements. *Publ Ass Nerv Ment Dis* 21:666, 1942.
126. Ralston BL — Hemispherectomy and hemithalamectomy in man. *J Neurosurg* 19:909, 1962.
127. Reznick M — Neuropathology of seven cases of locked-in syndrome. *J Neurol Sci* 60:67, 1983.
128. Rhein JHW, Potts CS — Post-apoplectic tremor (symmetrical areas of softening in both lenticular nuclei and internal capsules). *J Nerv Ment Dis* 34:757, 1907.
129. Ropper A, Fisher CM, Kleinman GM — Pyramidal infarction in the medulla: a cause of pure motor hemiplegia sparing the face. *Neurology* 29:91, 1979.
130. Ropper A, Fisher CM, Kleinman GM — Pyramidal infarction in the medulla. *Neurology* 29:1556, 1979.
131. Ross ED — Location of the pyramidal tract in the internal capsule by whole brain dissection. *Neurology* 30:59, 1980.
132. Rossi GF, Brodal A — Corticofugal fibers to the brain-stem reticular formation: an experimental study in the cat. *J Anat (London)* 90:42, 1956.

133. Rossi I, Roussy G — Un cas de sclérose latérale amyotrophique avec dégénération de la voie pyramidale suivie au Marchi de la moelle jusqu'au cortex. *Rev Neurol* 9:393, 1906.
134. Russel JRS — Contribution to the study of some of the afferent and efferent tracts in the spinal cord. *Brain* 21:145, 1898.
135. Shafey S, Scheinblum A, Scheinberg P, Reinruth OM — The ventral pontine syndrome. *Trans Am Neurol Ass* 93:21, 1968.
136. Sharrard WJW — The distribution of the permanent paralysis in the lower limb in poliomyelitis. *J Bone Joint Surg* 37:540, 1955.
137. Schell GR, Strick PL — The origin of the thalamic inputs to the arcuate premotor and supplementary motor areas. *J Neurosci* 4:539, 1984.
138. Schoen JHR — The corticofugal projection on the brain stem and spinal cord in man. *Psychiat Neurol Neurochir* 72:121, 1969.
139. Soisson T, Cabanis EA, Iba-Zizen MT, Bousser MG, Laplane D, Castaigne P — Hémiplégie motrice pure et tomodensitométrie. *J Neuroradiol* 9:304, 1982.
140. Spielmeyer W — Hemiplegie bei intakter Pyramidenbahn (intrakortikale Hemiplegie). *Muench Med Wschr* 29:1404, 1906.
141. Stern K — Note on the nucleus ruber magnocellularis and its efferent pathway in man. *Brain* 61:284, 1938.
142. Stovring J, Fernando LT — Wallerian degeneration of the cortico-spinal tract region of the brain stem: demonstration by computed tomography. *Radiology* 149:717, 1983.
143. Strümpell A — Ueber einen Fall von primärer systematischer Degeneration der Pyramidenbahn mit den Symptomen einer allgemeinen spastischen Lähmung. *Deut Zeitschr Nervenhlk* 3:225, 1894.
144. Takano T, Kimura K, Nakamura M, Fukunaga R, Kusunoki M, Etani H, Matsumoto M, Yoneda S, Abe H — Effect of small deep hemispheric infarction on the ipsilateral cortical blood flow in man. *Stroke* 16:64, 1985.
145. Thomas A — Recherches sur le faisceau longitudinal postérieur et la substance reticulée bulbo-protubérantielle, le faisceau central de la calotte et le faisceau de Helweg. *Rev Neurol* 11:94, 1903.
146. Thompson PD, Dick JPR, Day BL, Rothwell JC, Berardelli A, Kachi T, Marsden CD — Electrophysiology of the corticomotoneurone pathways in patients with movement disorders. *Movement Disorders* 1:113, 1986.
147. Thurel R, Nehllil J — Traitement des mouvements involontaires par électrocoagulation dans la capsule interne de la partie correspondant du faisceau pyramidal. *Rev Neurol* 63:36, 1940.
148. Tower S — Pyramidal lesion in the monkey. *Brain* 63:36, 1940.
149. Tower S, Hines M — Dissociation of the pyramidal and extrapyramidal functions of the frontal lobe. *Science* 82:376, 1935.
150. Trelles JO, Trelles L, Urquiaga C — La spasticité dans l'hémiplégie par lésions de la pyramide bulbaire. *Rev Neurol* 129:105, 1973.
151. Türck L — Uber sekundäre Erkrankung einzelner Rückenmarkstränge und ihre Fortsetzungen zum Gehirn. *Z Ges Ärzte Wien* 2:289, 1853.
152. Virgile RS — Locked-in syndrome. *Clin Neurol Neurosurg* 86:275, 1984.
153. Vogt C — Quelques considérations générales a propos du syndrome du corps strié. *J f Psychol u Neurol (Leipzig)* 18:207, 1911.
154. Walker AE, Fulton JF — Hemidecortication in chimpanzee, baboon, macaque, potto and coati: a study in encephalization. *J Nerv Ment Dis* 87:677, 1938.

155. Walters AS, Katchen M, Fleishman J, Chokroverty S, Duvoisin R — Role of the basal ganglia and cerebral cortex in tardive dyskinesia: evidence from cerebrovascular accident. *J Neurol Neurosurg Psychiat* 50:367-8 (1987).
156. Weintraub MI, Glaser GH — Nocardial brain abscess and pure motor hemiplegia. *New York St J Med* 70:2117, 1970.
157. Wilson SAK — Progressive lenticular degeneration: a familial nervous disease associated with cirrhosis of the liver. *Brain* 34:295, 1912.
158. Wilson SAK — Die Pathogenese der unwillkürlichen Bewegungen mit besonderer Berücksichtigung der Chorea. *Deut Zeitschr Nervenhlk* 107:28, 1928.
159. Winkelman NW — Two brains showing the lesions producing cerebral monoplegia. *Arch Neurol Psychiat* 12:241, 1924.
160. Yakovlev PI — Anatomoclinical report of a case of carbon monoxide poisoning, with survival for forty-nine years: correlation of evolution of extrapyramidal symptoms and structural organization of motor pathways of the forebrain. *Arch Neurol Psychiat* 51:494, 1944.
161. Yakovlev PI, Rakic P — Patterns of decussation of bulbar pyramids and distribution of pyramidal tracts on two sides of the cord. *Trans Am Neurol Ass* 91:366, 1966.
162. Yoshida M, Yajima K, Uno M — Different activation of the two types of the pyramidal tract neurones through the cerebello-thalamocortical pathway. *Experientia (Basel)* 22:331, 1966.
163. Young RSK, Coulter DL, Allen RJ — Capsular stroke as a cause of hemiplegia in infancy. *Neurology* 33:1044, 1983.