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Cerebral Visual Impairment in Periventricular Leukomalacia: MR Correlation

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PURPOSE: To evaluate the involvement of central visual pathways in cases of periventricular leukomalacia, and to correlate the neuroradiologic findings with the degree of visual acuity. **METHODS:** The MR brain examinations of 27 preterm children affected by cerebral palsy resulting from periventricular leukomalacia and without significant ophthalmologic lesions were reviewed retrospectively to search for possible involvement of the optic radiations and/or of the calcarine cortex. The data were compared with the degree of visual acuity estimated by means of the Teller Acuity Cards test. **RESULTS:** Seventeen (63%) of the 27 patients had cerebral visual impairment, which correlated strongly with MR lesions. Quantitative reduction and signal hyperintensity of the peritrigonal white matter and atrophy of the calcarine cortex were present in the more severe cases. In two blind patients, an altered MR signal was detected in the lateral geniculate bodies. **CONCLUSION:** This study clearly establishes a relationship between specific MR findings and visual impairment in children with periventricular leukomalacia. The finding of hyperintensity in the lateral geniculate bodies was interpreted as an axonal reaction. MR imaging is useful for detecting potential visual impairment and for improving clinical diagnosis.

Index terms: Periventricular leukomalacia; Brain, magnetic resonance; Pediatric neuroradiology; Vision

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Periventricular leukomalacia (PVL) is a common result of cerebral injury in premature infants, second only to periventricular and intraventricular hemorrhage in frequency. It occurs in the late-second or early-third trimester of gestation, specifically within the periventricular white matter, which, owing to the immaturity of the brain and its vascular supply, is the region at highest risk when autoregulation is compromised (1-4). Lesions are most commonly posterior, close to the trigone of the lateral ventricles, and less commonly anterior, adjacent to the interventricular foramen. Corticospinal fi-

bers are typically affected; thus, the characteristic clinical presentation of PVL is cerebral palsy: a spastic diplegia in mild cases (fibers directed to the legs are the more strictly periventricular), tetraplegia in more severe cases. The magnetic resonance (MR) imaging features of PVL have already been well described: a reduction in the amount of periventricular white matter, more pronounced in posterior regions, a compensatory ventriculomegaly with irregular outline of the lateral ventricles, and abnormally increased signal intensity of the periventricular white matter on the first-echo and second-echo images of T2-weighted sequences (5-9).

Impairment of visual function is a common finding in children with PVL. Visual impairment is often due to ocular diseases, in particular to retinopathy, but cerebral visual disturbances are also common (10-12). The pathologic correlate of this problem seems to be, in most cases, damage to optic radiations, which are affected close to the trigone. After their descrip-

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tion of PVL in 1962, Banker and Larroche actually showed lesions occurring in this area (1). Neuroradiologic reports have also described this finding (8–13); however, studies of the central visual pathways in children affected by cerebral palsy have been few, regardless of gestational age (preterm and full term combined) and the type of cerebral lesion involved. Furthermore, many of these studies are based on computed tomographic (CT) or sonographic findings, while it is well recognized that MR imaging is the method of choice for studying white matter (14–16). As a consequence, unequivocal results have not been achieved.

In this study, we used MR imaging to describe the involvement of the central visual pathways in children affected by PVL, and to correlate the neuroradiologic findings with the degree of visual acuity. Our aim was to demonstrate the possible role of MR imaging in improving and in completing clinical diagnosis in this type of disorder.

Materials and Methods

We retrospectively reviewed MR images of the central visual pathways in 27 children (14 girls and 13 boys) who were born prematurely and with cerebral palsy resulting from PVL. The imaging findings were compared with the patients' degree of visual acuity.

The study population was selected from all the patients with PVL in our care on the basis of the following criteria: diagnosis of tetraplegia or diplegia according to the Hagbergs' criteria (17); gestational age at birth of less than 35 weeks; previous sonographic diagnosis of PVL during the neonatal period and by MR imaging in late infancy; and absence of significant ocular lesions. At the time of our study, the children were 16 months to 8 years old (mean age, 34 months).

Clinical evaluation was carried out by a child neuropsychiatrist, and was based on the classification established by Michaelis and Edebold-Tysk, which considers five clinical forms of tetraplegic cerebral palsy according to the topographic distribution of motor damage (18). Degree of functional impairment was categorized as light, medium, or serious, according to Glentig (19). The type of cerebral palsy was defined as spastic, dystonic, and mixed, depending on the presence of pyramidal signs, extrapyramidal signs, or both, respectively.

Cerebral visual impairment was defined as reduced sight despite normal ophthalmologic findings or findings too mild to explain the visual loss (20). Visual acuity was determined by means of Teller's Acuity Cards, a behavioral test based on a preferential looking technique, which is applicable even for young and uncooperative children (21). According to the World Health Organization's categories of sight, results equal to or above 0.1 degree of

visual acuity were considered normal, those equal to or above 0.05 were indicative of low vision, and results less than 0.05 indicated blindness (22).

All patients underwent a complete ophthalmologic examination to exclude subjects from the study who had a peripheral cause of visual impairment. This screening investigation eliminated one blind patient and two patients with severe visual impairment who had a serious form of retinopathy of prematurity (ROP). Children with degree I, II, or III ROP who had been cured by early cryotherapy, and those with the nonspecific finding of pale optic disk were allowed in the study, because these aberrations were considered mild enough to be insignificant.

MR imaging was done on a 0.5-T magnet and consisted of sagittal 5-mm-thick spin-echo images obtained with parameters of 520/20/2 (repetition time/echo time/excitations), axial and coronal 6-mm-thick spin echo images obtained at 2500/40–100/1, and axial 5-mm-thick T1-dependent inversion-recovery images obtained at 1500/30/2. None of the imaging examinations required anesthesia. The images were inspected for an abnormal amount of and signal intensity from periventricular white matter. The observed changes were classified as mild, moderate, or extensive, according to criteria established by Flodmark (7). Involvement of central visual pathways was scrutinized in particular, as was possible atrophy or other alterations of the occipital cortex. Assessment was made subjectively by two neuroradiologists who were blinded to the clinical condition and to the degree of visual acuity in each case. The data reported in the Table represent the average values obtained.

Results

Clinical data—including gestational age, type and degree of cerebral palsy, degree of visual acuity, and ophthalmologic findings—and MR findings of the patients are summarized in the Table. The patients are listed in order of increasing severity of their deficit of vision.

The gestational age, between 27 and 35 weeks (mean, 30.68 ± 2.52 weeks), did not influence any of the other evaluated parameters: type and degree of cerebral palsy, visual deficit, and MR alterations. Deficit of motion was variable: 16 patients had tetraplegia, 8 had diplegia, and 3 had three limbs compromised. The cerebral palsy was spastic, with the exception of 2 children who had a dystonic component to their impairment.

Ophthalmologic examinations revealed two patients with degree I ROP and two patients with degree III ROP who had all received an adequate cure by cryotherapy; three patients had a pale optic disk that was judged to be a nonspecific and insignificant finding. Squint was a frequent

Clinical features and MR, visual, and ophthalmologic findings in 27 children with PVL-induced cerebral palsy

Case	Sex	Gestational Age, wk	Cerebral Palsy			Visual Acuity	PVL	Optic Radiation Reduction	Optic Radiation Signal Alteration	Occipital Cortex Atrophy	Lateral Geniculate Corpus	Other MR Findings	Ophthalmologic Findings
			No. of Limbs Involved	Type	Degree								
1	F	35	4	Sp	Serious	Blind	Extensive	Extensive	Moderate	Severe	Altered	Callosal hypoplasia	Pale optic disk
2	F	34	4	Sp	Serious	Blind	Extensive	Extensive	Severe	Severe	...	...	Squint
3	F	33	4	Sp	Serious	Blind	Extensive	Moderate	Moderate	Severe	Altered	Microcephaly	...
4	M	30	4	Sp	Serious	MI	Moderate	Extensive	Mild	...	...	Cerebellar hypoplasia	Squint
5	M	31	4	Sp	Serious	MI	Moderate	Moderate	Moderate	Medium	...	...	Squint
6	F	30	4	Sp	Serious	MI	Moderate	Moderate	Mild	...	...	Cerebellar hypoplasia	Pale optic disk
7	M	28	4	Sp	Serious	MI	Moderate	Moderate	Moderate	...	...	Inferior vermis hypoplasia	Squint, pale optic disk
8	F	29	4	Sp	Serious	MI	Extensive	Extensive	Mild	...	...	Large interhemispheric fissure	...
9	M	34	4	Sp	Serious	MI	Moderate	Moderate	Mild	Medium	...	Inferior vermis hypoplasia	Squint
10	F	29	4	Sp	Serious	MI	Moderate	Moderate	Mild	...	...	Callosal hypoplasia	...
11	M	35	4	Sp	Medium	MI	Moderate	Moderate	Mild	...	...	...	...
12	F	30	4	Sp	Light	MI	Moderate	Mild	Mild	Medium	...	PVL, mainly parietal	Squint
13	M	31	4	Sp	Light	MI	Moderate	Moderate	Mild	...	...	...	Squint
14	M	30	4	Mx	Medium	MI	Moderate	Moderate	Mild	Medium	...	...	ROP III*
15	F	35	3	Sp	Light	MI	Moderate	Moderate	Moderate	Medium	...	Callosal hypoplasia	ROP I
16	F	31	2	Sp	Medium	LI	Moderate	Extensive	Moderate	...	...	...	ROP III*
17	F	28	2	Sp	Light	LI	Mild	Moderate	...	...	...	...	Squint
18	M	28	4	Sp	Serious	Normal	Moderate	Moderate	Mild	...	...	...	Squint
19	M	29	4	Mx	Serious	Normal	Moderate	Moderate	...	...	...	...	Squint
20	F	27	3	Sp	Light	Normal	Mild	Mild	Mild	...	...	Large interhemispheric fissure	Squint
21	M	29	3	Sp	Light	Normal	Mild	Mild	Mild	...	...	...	...
22	F	29	2	Sp	Light	Normal	Mild	Mild	Mild	...	...	...	Squint
23	M	31	2	Sp	Light	Normal	Mild	Mild	...	...	...	...	...
24	M	29	2	Sp	Medium	Normal	Mild	Mild	Mild	...	...	...	Squint
25	M	32	2	Sp	Light	Normal	Mild	Mild	Moderate	...	...	...	...
26	F	30	2	Sp	Light	Normal	Mild	Mild	...	...	...	...	Squint
27	F	31	2	Sp	Light	Normal	Mild	Mild	Mild	...	...	...	ROP I

Note.—PVL indicates periventricular leukomalacia, Sp, spastic; Mx, mixed (spastic plus dystonic); MI and LI, medium and light impairment; and ROP, retinopathy of prematurity.

* ROP cured by cryotherapy.

finding (30% of patients). Cerebral visual impairment was observed in 63% of the subjects. Three children (11%) were blind, and among the 11 patients with low-grade cerebral palsy, 4 (36%) had cerebral visual impairment whereas 13 (81%) of the patients with medium/severe cerebral palsy had cerebral visual impairment.

All subjects had MR findings of PVL, which were classified into three groups according to the level (mild, moderate, extensive) of compromise: thus, 4 patients had extensive PVL, 14 had moderate PVL, and 9 had mild PVL. In all subjects a reduction in the amount of periventricular white matter was seen, which corresponded to the zone in which the optic radia-

tions run (Figs 1 and 2). In all but 4 patients (85%) a signal hyperintensity in this region was also observed. In the most severe cases, white matter was so reduced as to affect the most superficial portions and to cause a cortical atrophy in the calcarine cortex. In 2 blind patients (cases 1 and 3 in the Table) a symmetric signal hyperintensity was found in the thalami, corresponding to the lateral geniculate bodies (Fig 3). MR findings correlated with visual acuity. In particular, a relationship was detected between degree of visual acuity and reduction of the peritrigonal white matter (Fig 4) on one hand, and between degree of visual acuity and calcarine atrophy (Fig 5) on the other hand.

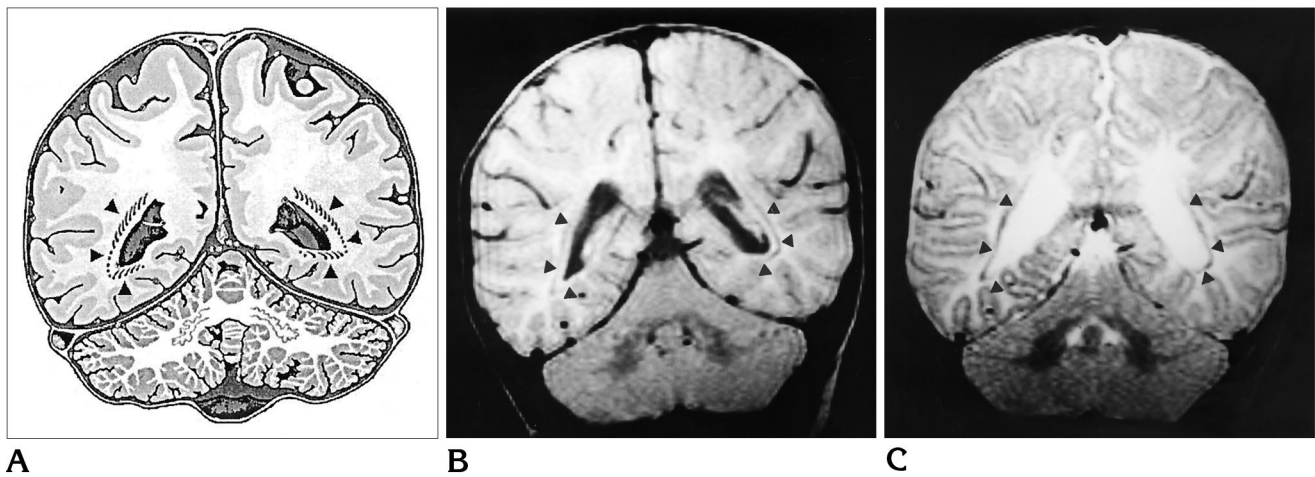


Fig 1. Normal path of the optic radiations.

A, In the drawing, representing a coronal section, the optic radiations are indicated by the *arrowheads*: they appear hook-shaped, and the open part of the hook is pointing medially.

B and C, The optic radiations (*arrowheads*) are well seen in the coronal spin-echo T1-weighted (520/20) (B) and T2-weighted (3000/100) (C) sections of a normal 6-month-old infant, because at this age they are already myelinated whereas the surrounding white matter is not.

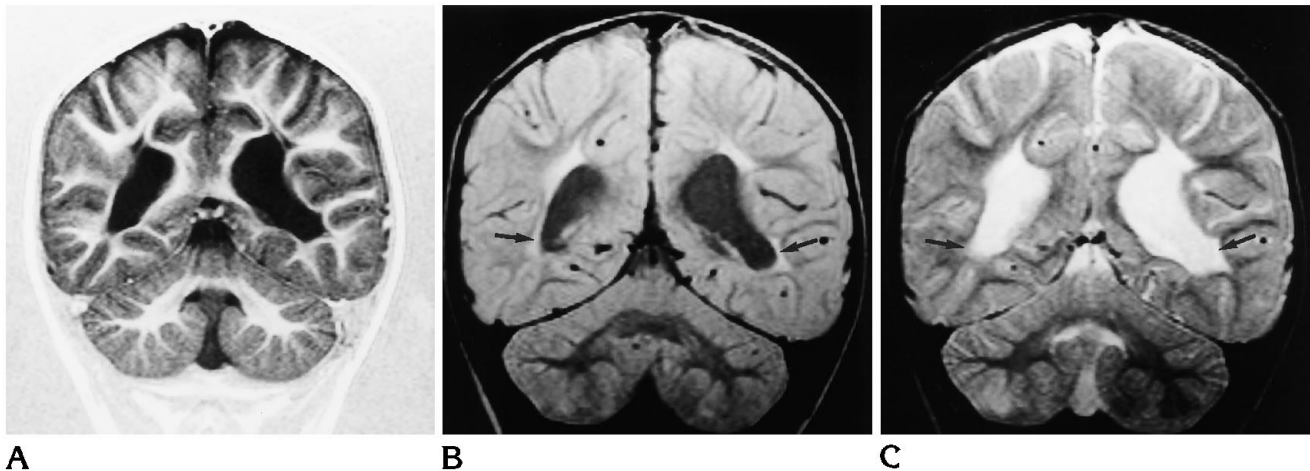


Fig 2. Case 7.

Coronal MR images obtained with inversion-recovery (1500/30) (A) spin-echo (2500/40) (B), and spin-echo (2500/100) (C) sequences show a reduction of the periventricular white matter, with compensatory ventricular enlargement. Areas of abnormal signal intensity are visible on both the first and the second echoes (*arrows*). The optic radiations are not recognizable.

Discussion

Cerebral visual impairment is a severe reduction in vision despite normal clinical ophthalmologic findings or ophthalmologic disturbances too mild to explain the visual loss. The term *cerebral visual impairment* is preferred to *blindness*, because a total loss of sight is rare, even when there is complete destruction of the striate cortex, owing to the plasticity of the central nervous system and to the presence of extrageniculostriate visual pathways (16). Among children affected by cerebral palsy, the preva-

lence of cerebral visual impairment is high, 70% in a number of examined populations; in particular, cerebral visual problems are frequent among children affected by PVL-induced palsy (11).

In our study of 27 preterm children with documented PVL, only 10 (37%) had normal vision, 3 (11%) were blind, and the remaining 14 (52%) had a deficit of vision. The high frequency of cerebral visual impairment (63%) in our study population is in agreement with the published data (11). We take note of the fact that not all

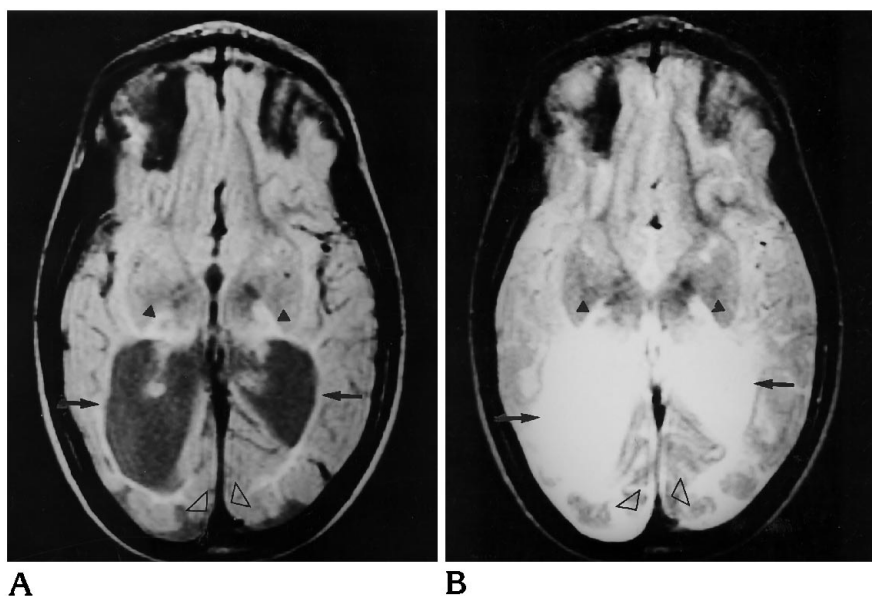


Fig 3. Case 1: Severe PVL.

Axial spin-echo MR images (2500/25) (A) and (2500/100) (B) show a marked loss and an abnormally increased signal intensity of periventricular white matter (arrows), with compensatory enlargement of the trigones of the lateral ventricles. Occipital atrophy is also evident (open arrowheads). Solid arrowheads indicate significant signal hyperintensity corresponding to the lateral geniculate bodies of the thalami.

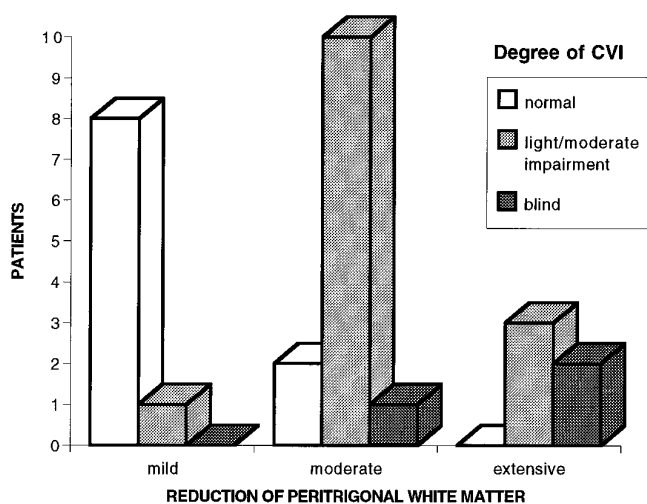


Fig 4. Relationship between a reduction in peritrigonal white matter and degree of cerebral visual impairment (CVI). A strong correlation was detected (Spearman's correlation coefficient, 0.75; $P < .0001$).

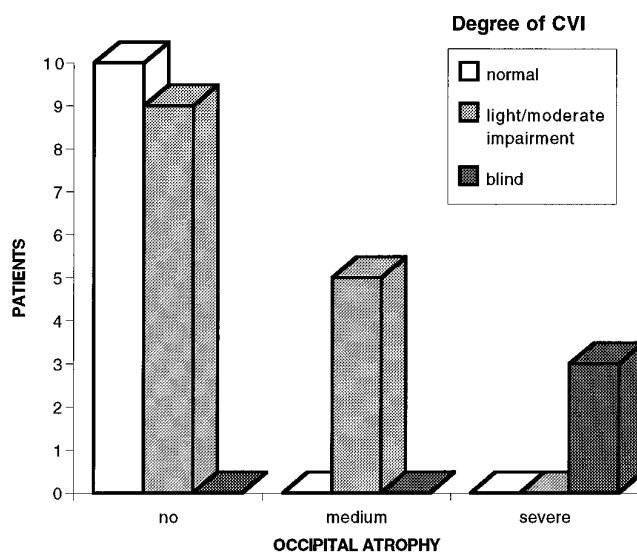


Fig 5. Relationship between severity of occipital atrophy and degree of cerebral visual impairment (CVI). A strong correlation was detected (Spearman's correlation coefficient, 0.66; $P = .0001$).

the subjects had ophtalmologic findings consistent with low visual acuity.

In all subjects, MR studies showed lesions that directly affected the peritrigonal white matter, where optic radiations run. In all damaged areas there was a reduction in the amount of white matter, with a parallel increase in the size of the trigones; in the most severe cases, cerebral sulci were close to the ventricular walls. In all but three cases there was an alteration in the MR signal of the affected white matter, consistent with periventricular gliosis and demyelination found by pathologists in late PVL; thus, our find-

ing was of pathologic relevance, since the normal myelination of the optic radiations occurs during the third month of life (23). The characteristics of these findings are quite in agreement with published neuroradiologic data (5-9). In fact, we anticipated such MR alterations in peritrigonal white matter, since earlier pathologic studies have shown that this area is the preferential site of PVL, where lesions are always present (1, 24).

A significant finding was the direct involvement of the occipital white matter, with atrophy

of the calcarine cortex. It strongly correlated with the visual deficit, and was observed in all the blind children. Yet, a significant occipital atrophy is not an absolute requirement for the appearance of a visual deficit, since in several patients with moderate visual impairment, lesions were confined to the optic radiations. Two blind patients had signal hyperintensity of the lateral geniculate bodies, where the second neurons of the central visual pathway are located. This is an interesting finding that we have not come across before. We are inclined to exclude a direct role of PVL, since the thalami are generally not affected in this disease. A more likely explanation is that the neural cell bodies degenerate as a result of damage to the optic radiations, as in cases of axonal reactions (25–27).

The correlation between MR findings and visual impairment in children with PVL has not been clearly established so far, mainly because of a lack of a representative sample of such patients. In this study we were able to show a strong correlation between degree of visual acuity and MR alterations that were found specifically along the geniculocalcarine tracts. Thus, children with severe damage to the optic radiations were more than three times as likely to have cerebral visual impairment as were children with minor compromise; in fact, none of the children with major MR alterations had normal vision. Our data confirm the results of Eken et al (14) that were based on sonographic evaluation; that is, that a clear relationship exists between MR abnormalities and deficit of vision in patients with severe PVL, although minor MR alterations may not produce a significant loss in visual acuity.

Not all investigators agree on this association. Many articles report no obvious relationship between visual impairment and neuroradiologic findings (5, 6, 15). Moreover, Crawford and Hobbs, in a study also based on a presumed lack of correlation between degree of visual acuity and abnormal radiologic and pathologic findings, proposed a new model for the onset of spasticity in PVL, and hypothesized a dying-back neuropathy of the pyramidal fibers caused by selective damage to the corticospinal neurons, perhaps induced by deficiency of an unidentified specific trophic factor (28). We are convinced that the lack of correlation in all these studies stems mainly from the difficulty in diagnosing a central visual deficit in children

who are too young or too mentally compromised to be cooperative. Indeed, an impairment of vision may easily elude discovery if not specifically searched for, and careful examination is needed to highlight significant abnormalities. It is noteworthy that in some of the children we studied the impairment of vision was overlooked until a specific test was used. This test, known as the Teller Acuity Cards test, is based on preferential looking techniques, which can be evoked even in very young patients, and allows a quantitative assessment of visual function (21). Numerous studies have demonstrated the soundness of the test, which proved effective in our subjects (21, 29–31).

In an MR study of 18 preterm patients with spastic diplegia, Koeda and Takeshita (10) detected cerebral lesions in all subjects and demonstrated a correlation between the volume of the peritrigonal white matter of the parietal and occipital lobes, estimated by morphologic measurements, and visuoperceptual impairment. We have shown that the same result is attainable with a descriptive analysis.

It is known that in patients with cerebral palsy, visual impairment may hamper recovery from an associated motor deficit. Therefore, any technique that may contribute to a correct clinical evaluation is worth considering. Our data show that there is a direct correspondence between MR alterations in the path of optic radiations and significant functional deficit. We believe that an evaluation of MR findings in such cases should not merely confirm the clinical diagnosis of PVL but instead should specifically consider the affected central nervous fibers. This is particularly important for visual pathways, since damage to the pyramidal fibers causes diplegia or tetraplegia that can easily be diagnosed at an early age; and a lesion in the geniculocalcarine tract provokes a deficit that may escape correct clinical diagnosis and cause further serious damage to the young patient.

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