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Preoperative MRI findings and functional outcome after selective dorsal rhizotomy in children with bilateral spasticity

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Abstract

Purpose To identify MRI characteristics that may predict the functional effect of selective dorsal rhizotomy (SDR) in children with bilateral spastic paresis.

Methods We performed SDR in a group of 36 patients. The gross motor functioning measure-66 (GMFM-66) was applied before and after SDR. Available cerebral MRIs were retrospectively classified into three diagnostic groups: periventricular leucomalacia (PVL; $n=10$), hydrocephalus ($n=2$), and normal ($n=6$). In patients with PVL, we scored the severity of the MR abnormalities. We compared the changes in the GMFM-66 after SDR in the diagnostic groups. In patients with PVL, we correlated the severity of the MR abnormalities with the changes in the GMFM-66.

Results The mean follow-up period was 5 years and 4 months (range, 1 year and 1 month to 9 years). The best improvement in gross motor function was observed in patients with normal MRI, and the slightest improvement was observed in patients with hydrocephalus. The severity of the PVL did correlate with the GMFM-66 score before SDR but not with the functional effect of SDR.

Conclusion We conclude that with respect to gross motor skills, the improvements after SDR are good in patients with no MRI abnormalities. In the patients with hydrocephalus, the improvements after SDR were insignificant. In patients with PVL, the improvements were intermediate and did not correlate with the degree of PVL.

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Introduction

Spasticity is defined as a velocity-dependent increase in the
tonic stretch response with excessive tendon jerk reflexes
[1] and is caused by the reduction of inhibitory impulses on
lower motor neurons. Spasticity can cause pain, muscle
shortening, and orthopedic malformations, and it can
severely interfere with functional abilities and gait pattern.
Cerebral palsy (CP) is the most frequent cause of spasticity
in children. Cerebral palsy is a group of disorders of
movement and posture due to a nonprogressive lesion of
the developing brain [2]. As a consequence of this
definition, its causes are diverse.

Different treatment modalities are used to treat spasticity
in children. Selective dorsal rhizotomy (SDR) is a neuro-
surgical treatment that is mainly performed at lumbar level
in patients with bilateral spastic paresis. By incomplete
transection of the (sensory) posterior lumbosacral rootlets,
SDR reduces the excitatory input from the lower limbs that
enters the spinal cord. In children with spastic CP, SDR
leads to a more normal gait pattern [3–6], better perfor-
mance of the activities of daily life [7, 8], and improvement
in gross motor function [6–13]. Data on functional outcome
after SDR in patients with other conditions than spastic CP
are limited, though promising [14]. Detailed information
about the clinical characteristics of the selected children,
other than spasticity alone, is often lacking.

Medical history and clinical examination does not
always provide sufficient evidence to establish the diagno-
sis of the underlying disorder in patients with CP. The
Quality Standards Subcommittee of the American Academy
of Neurology and the Practice Committee of the Child
Neurology Society both advise magnetic resonance imaging
(MRI) of the brain for all CP patients [15]. In patients with
bilateral spastic CP, the most common MRI abnormality is
periventricular leucomalacia (PVL), which is characterized
by a damage of the periventricular white matter [16–19].
Gray matter lesions, early developmental abnormalities of
the central nervous system, and abnormalities of the
cerebrospinal fluid space, such as hydrocephalus, are less
commonly found [17–19], and in some children with
bilateral spastic CP no abnormalities are found with MRI
[16–19]. In patients with normal MRI findings and bilateral
spastic paresis, genetic causes or spinal cord involvement
should be considered.

The goal of this study was to identify possible relation-
ships between the MRI findings with the level of gross
motor function of the patient before SDR and the change in
functioning after SDR. For this purpose, we retrospectively
analyzed the MRIs of the patients who underwent SDR in
our clinic.

Methods and materials

Subjects

This study was part of the project: "Investigation of long-
term effects of SDR in children with spastic diplegia" and
was approved by the medical ethical committee of the VU
University Medical Center, Amsterdam, The Netherlands
(project number 2006/105). Informed consent was given by
the parents of all participants. The study population
consisted of all the patients who underwent SDR in our
clinic between January 1998 and December 2007. The first
nine patients have been described in a previous report [8].
The patients were selected for SDR according to the criteria
shown in Table 1. In our previous study, we only included
patients with bilateral spastic CP and documented PVL [8].
In the present study, we included patients with nonprogres-
sive spasticity due to different diagnoses. In our analysis,
we included data on patients who underwent pre- and
postoperative gross motor function measure (GMFM-66)
analysis with a follow-up period of at least 12 months and
of whom MRI was available for review.

Procedure

Selective dorsal rhizotomy was performed by the same
neurosurgeon (WVO) in all children. Dorsal roots L2-S1
were exposed and separated into different rootlets after
laminotomy L2-L5 and opening of the dura. Transection of

Table 1 Selection criteria for selective dorsal rhizotomy in the VU
University Medical Center

Criteria for selective dorsal rhizotomy

1.) Bilateral spasticity of the lower extremities interfering with
    walking performance
2.) Presence of spasticity (defined as velocity-dependent resistance to
    passive stretch) in at least six muscle groups of the lower limbs
3.) Sufficient force in the quadriceps femoris muscle (squatting at
    least seven times) and the hip extensors (kneel with extended
    hips, support for balance allowed)
4.) Absence of structural orthopedic deformities or contractures at
    hip, knee, or ankle
5.) Presence of moderate to good selective motor control in the
    lower limbs
6.) Gross motor function classification system (GMFCS) level I, II,
    or III
7.) Good support from parents and rehabilitation setting

the rootlets was performed after electro-stimulation, according to palpable muscle contraction and EMG response. At most, 50% of the rootlets were transected on one level. To prevent sexual and bladder disturbances, rootlets/fascicles showing electrical response after stimulation of the penis/the clitoris were spared. Postoperative rehabilitation included intensive physical therapy for 12 months.

Neuroimaging

The MRIs were assessed at two different points in time by two investigators—one neuropediatrician (8 years of experience in the assessment of MR neuroimaging; RJV) and one pediatrician with specialization in pediatric neuro-rehabilitation (2 years of experience in the assessment of MR neuroimaging; SG). Imaging was classified into three diagnostic groups according to the following criteria: periventricular leucomalacia (PVL; increased signal intensity of the periventricular white matter in T2 weighted imaging and/or FLAIR; other abnormalities optional); hydrocephalus (signs of ventricular dilatation and increased intracranial pressure); normal MRI (see Fig. 1a–i). In one patient, the MR abnormalities could not be classified into one of the three diagnostic groups and he was excluded from further data analysis (patient number 19, Table 2; his MRI showed delayed myelinisation and slightly enlarged ventricular size but no other white matter abnormalities and there were no signs of increased intracranial pressure). In the patients with PVL, we graded the severity of their MRI abnormalities based on the work of Cioni et al. [20]. The following items were assessed: ventricular size, evidence and extension of white matter signal intensity, evidence and extension of white matter loss, thinning of the corpus callosum, dimension (size) of subarachnoidal space, evidence and size of cysts, and presence of gray matter abnormalities. We also investigated whether white matter loss was occipitally and/or frontally present. The items were scored on a three-point scale, with a score of three indicating the most severe MRI abnormalities. The scores were summed to obtain a total score for each child (minimal score, 7 and maximal score, 21). Intra- and interobserver agreement was assessed for all items. If the two investigators did not agree, the classification and/or scoring were determined by a consensus.

Outcome measure

All patients had a detailed pre- and postoperative clinical evaluation, including spasticity assessment, range of motion of single joints, gait analysis, and the GMFM. In this study, we only report the results of the GMFM. The GMFM is a criterion-referenced observational measure that was developed to assess children with CP. The validity, reliability, and responsiveness of the GMFM have been demonstrated in a population of patients similar to the participants in the present study [21]. For our data analysis, we used the GMFM-66 version, which assesses 66 items covering five gross motor dimensions (lying and rolling/crawling and kneeling/standing and walking/running/jumping) and is elaborated to a numerical scale ranging from 0 to 100.

As outcome parameters we used the mean of all postoperative GMFM-66 scores from 1 year after surgery. The changes after SDR were expressed as the difference between GMFM-66 score and the preoperative GMFM-66 score (Delta-GMFM-66).

Statistical analysis

For the reliability analysis of the MRI scoring, we used Kappa statistics. Agreement strengths for the Kappa values were classified according to Landis and Koch [22]. For the comparison of the outcome in patients with different MRI characteristics, we used nonparametric tests (Kruskal–Walis test for group comparison; post hoc analysis was performed using the Mann–Whitney test when the level of significance was reached). Correlations were assessed with the Spearman's rank correlation coefficient. For the statistical analysis, we used SPSS® version 14.0 for Windows. Level of significance was set at 0.05.

Results

Clinical characteristics and level of functioning

Thirty-six patients underwent SDR of whom 32 patients had a brain MRI performed before SDR, and 26 MRIs were available for review. Of the patients with available MRI, four did not have any preoperative GMFM-66 assessments. Three patients had a GMFM-66 assessment before SDR but with a follow-up period of less than 12 months. The detailed patient characteristics of the remaining 19 patients are summarized in Table 2. The mean number of GMFM assessments per patient was 4.9 (standard deviation (SD) 3.5, range 1 to 12), and the mean follow-up period was 5 years and 4 months (SD 2 years and 9 months, range 1 year and 1 month to 9 years). The mean age at the time of the operation was 6 years and 10 months (SD 1 year and 6 months, range 5 years and 9 months to 10 years and1 month). The age at the time of SDR neither correlate with the preoperative GMFM-66 (rho, 0.328; $p=0.184$) nor with the postoperative GMFM-66 scores (rho, 0.336; $p=0.173$) and the improvement after SDR (rho, -0.049; $p=0.847$). We found no difference in the Delta-GMFM-66 score between boys and girls.
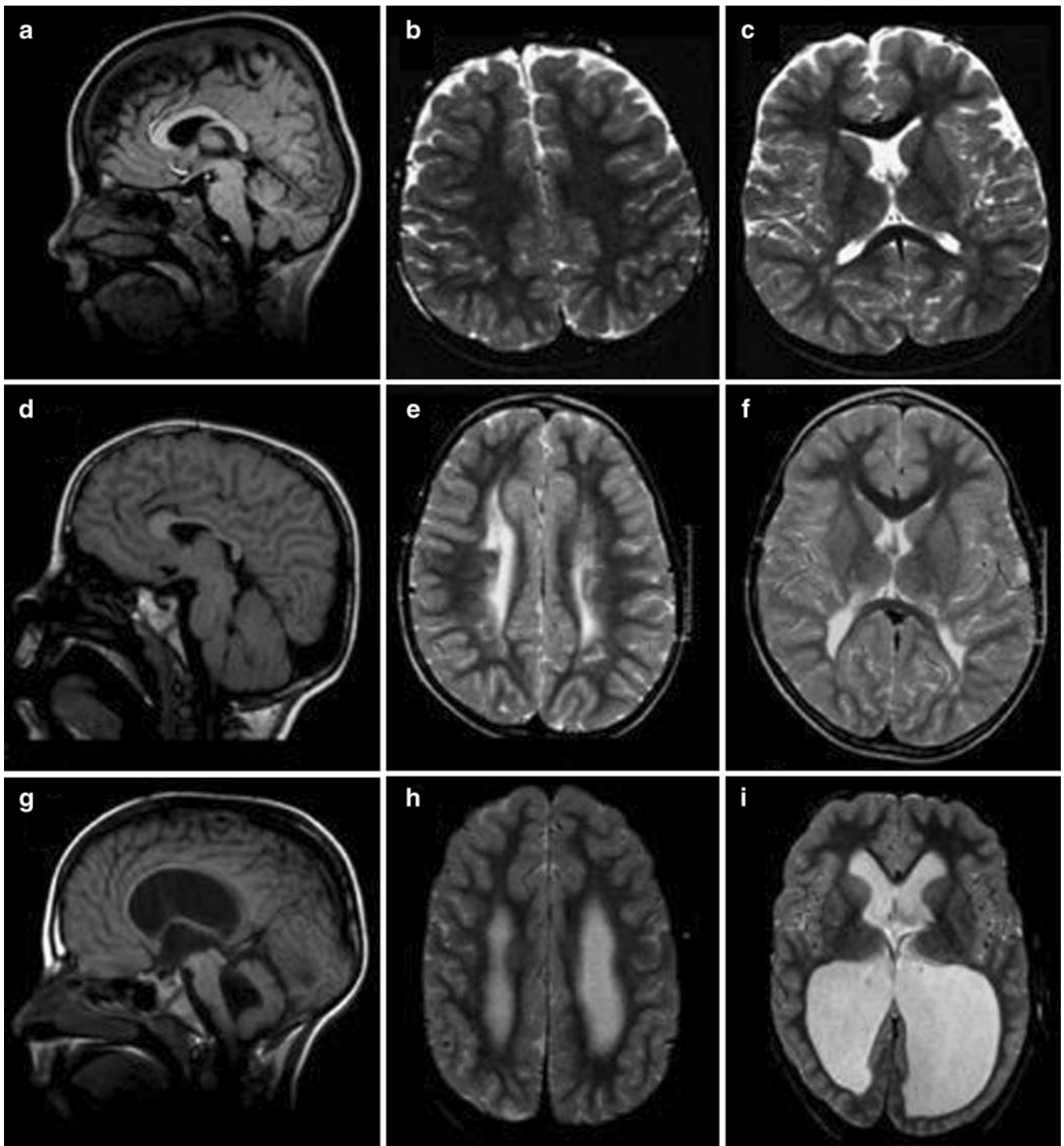
Fig. 1 a–i MR imaging of three patients with bilateral spastic paresis undergoing SDR. **a, d, g** Midsagittal T1 weighted images. **b, e, h** Transversal T2 weighted images at the level of the centrum semiovale. **g, h, i** Transversal T2 weighted imaging at the level of the basal ganglia. **a–c** MR images classified as "normal." **d–f** MR images classified as periventricular leucomalacia showing thinning of the corpus callosum involving the total body (Fig. 1a), bilaterally increased periventricular white matter signal intensity (Fig. 1e), a slight ventricular enlargement, and a loss of the occipital white matter (Fig. 1f). **g–i** MR images classified as hydrocephalus. The lateral ventricles and the third and fourth ventricles (Fig. 1i) are enlarged

Table 2 Summary of the characteristics of the patients included in the study

Case	Gender	GA (weeks)	BW (g)	Age SDR years (mts)	Follow-up years (mts)	MRI classification	Diagnosis	GMFM-66 before SDR	GMFM-66 (mean) after SDR
1	F	30	2,000	5 (7)	8 (5)	PVL	PVL	50.85	53.29
2	F	40	2,500	5(7)	9 (0)	PVL	PVL	47.68	49.66
3	F	40	3,450	5 (8)	8 (11)	PVL	PVL	54.38	55.71
4	M	30	1,650	6 (8)	8 (11)	PVL	PVL	46.91	48.32
5	F	28	1,285	4 (11)	7 (10)	PVL	PVL	50.32	54.75
6	M	26	1,000	5 (3)	7 (10)	PVL	PVL	64.98	67.82
7	M	32	2,510	5 (1)	6 (7)	PVL	PVL	54.15	60.38
8	M	33	1,265	8 (9)	5 (1)	PVL	PVL	47.09	55.92
9	M	26	870	6 (11)	3 (11)	PVL	PVL	50.09	54.32
10	M	26	780	5 (4)	3 (0)	PVL	PVL	52.32	62.98
11	F	41	3,060	8 (4)	5 (2)	Hydrocephalus	Congenital hydrocephalus	55.62	56.35
12	M	27	1,020	10 (1)	4 (5)	Hydrocephalus	Congenital hydrocephalus	68.86	68.69
13	M	40	3,300	5 (9)	7 (2)	Normal	Unknown	65.33	67.31
14	M	34	3,155	6 (11)	3 (0)	Normal	Spinal process	76.75	85.15
15	M	38	4,280	8 (0)	2 (7)	Normal	Unknown	82.99	89.70
16	F	40	3,875	8 (10)	1 (7)	Normal	HIV-Encephalo(myelo)pathy	73.63	80.46
17	M	39	4,040	6 (7)	2 (0)	Normal	Unknown	65.98	78.38
18	M	40	3,460	6 (5)	1 (1)	Normal	Unknown	73.63	81.93
19	M	37	3,400	3 (11)	7 (1)	Not classified	Laurence moon syndrome	47.26	83.01

F female, *M* male, *GA* gestational age, *BW* birth weight, *SDR* selective dorsal rhizotomy, *GMFCS* gross motor function classification system, *GMFM* gross motor function measure, *PVL* periventricular leucomalacia, *g* gram, *mts* months

Neuroimaging

We diagnosed PVL in ten patients, hydrocephalus in two patients, and no MRI abnormalities in six patients. The classification of MRIs did not differ between the two observers. With respect to the grading of the MR abnormalities, the intrarater agreement was perfect for the frontal and occipital white matter loss, cysts, thinning of the corpus callosum, subarachnoidal space, and gray matter abnormalities (Kappa, 1.0) and almost perfect for the ventricular size (Kappa, 0.90) and the white matter signal intensities (Kappa, 0.87). The interrater agreement was considerably less than the intrarater agreement. It was perfect for the subarachnoidal space and the gray matter abnormalities (Kappa, 1.0), almost perfect for the ventricular size (Kappa, 0.90), substantial for the occipital white matter loss (Kappa, 0.74), and moderate for the frontal white matter loss (Kappa, 0.45). Kappa statistics

Table 3 Differences of gross motor outcome in with patients with different MRI classification

	Normal MRI (*n*=6)			PVL (*n*=10)			Hydrocephalus (*n*=2)			Total (*n*=18)			P value
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	
GMFM-66 before SDR	73.1[a]	6.7	65.3–83.0	51.9[a]	5.3	46.9–65.0	62.2	9.4	55.6–68.9	60.1	11.5	46.9–83.0	0.002
Mean GMFM-66 after SDR	80.5[a]	7.6	67.3–89.7	56.3[a]	5.9	48.3–67.8	62.5	8.7	56.3–68.7	65.1	13.0	48.3–89.7	0.003
Delta-GMFM-66	7.4[b]	3.4	2.0–12.4	4.4[c]	3.2	1.3–10.7	0.3[b, c]	0.6	−0.2–0.7	5.0	3.7	−0.2–12.4	0.030

MRI magnetic resonance imaging, *PVL* periventricular leucomalacia, *SD* standard deviation, *GMFM* gross motor function measure

[a] Significant difference with *p*<0.05 (Mann–Whitney test) between normal MRI and PVL

[b] Significant difference with *p*<0.05 (Mann–Whitney test) between normal MRI and Hydrocephalus

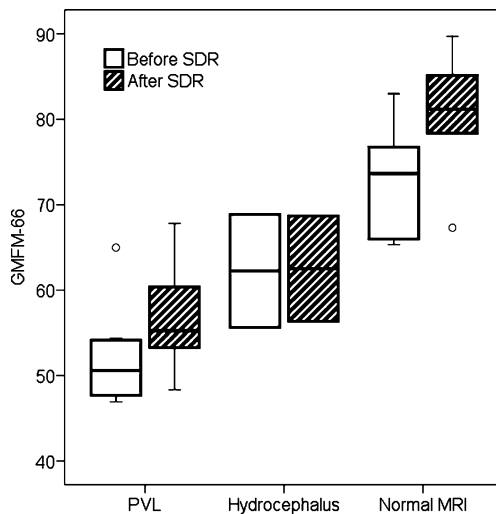[c] Significant difference with *p*<0.05 (Mann–Whitney test) between hydrocephalus and PVL

Fig. 2 *Box plots* of the preoperative GMFM-66 (*white boxes*) and the mean values of all postoperative GMFM-66 measurements (*dashed boxes*) in patients with different MRI classification. Note that the largest improvements after SDR were observed in patients with normal MRI and that the patients with hydrocephalus did not improve after SDR

could not be calculated for the white matter signal intensities, cysts, and thinning of the corpus callosum as only one of the two observers graded severe abnormalities (according grade three on the point scale). With respect to the white matter signal intensities and the thinning of the corpus callosum, the observers disagreed in 25% of the scorings, with respect to the cysts there was a disagreement in 36%.

The outcome parameters in patients with different MRI classification are summarized in Table 3 and in Fig. 2. The preoperative GMFM-66 scores were significantly higher in patients with normal MRI than in patients with PVL ($p=$ 0.001). Patients with hydrocephalus had intermediate scores and did not differ significantly from the other groups. In the follow-up measurements, the mean GMFM-66 was the highest in patients with a normal MRI (group difference, $p=$ 0.003; difference between PVL and normal, $p=0.002$). The patients with normal MRI also made the best postoperative

improvements. Almost no improvement was observed in the patients with hydrocephalus (group difference $p=0.030$; difference between PVL and hydrocephalus, $p=0.032$; difference between hydrocephalus and normal MRI, $p=$ 0.046). There was a significant group difference in age at the time of the operation ($p=0.028$). Patients with normal MRI and patients with hydrocephalus were older at the time of the operation than patients with PVL—for the patients with normal MRI this difference was significant ($p=0.044$).

The scoring of the MRI abnormalities in the patients with PVL is summarized in Table 4. Two patients with PVL did not show ventricular enlargement, and eight patients had moderate ventricular enlargement. All patients had moderate white matter signal intensity. Nine patients had moderate occipital white matter loss, and one patient had moderate frontal white matter loss. Small cysts were found in one patient, and large cysts were found in two. Four patients had no thinning of the corpus callosum, and six patients had moderate thinning of the corpus callosum. None of the patients had gray matter abnormalities or an enlargement of the subarachnoidal space. The mean total score was 10.8 (SD, 1.1; range, 8 to 12). The total score did not correlate with any of the outcome parameters. The ventricular size showed a significant correlation with the preoperative GMFM-66 score (rho, −0.696; $p=0.025$). However, none of the items in the scoring correlated with the postoperative changes of the GMFM-66.

Discussion

The aim of this study was to identify possible relationships between MR characteristics and the level of functioning before and after SDR in patients with bilateral spastic paresis. We classified the MRIs in three MRI categories: PVL, hydrocephalus, and normal MRI and compared the postoperative improvement in the GMFM in the three groups. The best results were found in the group with normal MRI, and the poorest results were found in patients with hydrocephalus. The poor outcome of patients with

Table 4 Scoring of the MR abnormalities in patients with periventricular leucomalacia ($n=10$)

	Normal	Moderate	Severe
Ventricular size	2 (20%)	8 (80%)	0 (0%)
White matter signal intensity	0 (0%)	10 (100%)	0 (0%)
White matter loss	1 (10%)	9 (90%)	0 (0%)
Thinning of the corpus callosum	4 (40%)	6 (60%)	0 (0%)
Cysts	7 (70%)	1 (10%)	2 (20%)
Gray matter abnormality	10 (100%)	0 (0%)	0 (0%)
Enlargement of the subarachnoidal space	10 (100%)	0 (0%)	0 (0%)
	Mean	SD	Range
Total Score	10.8	1.1	8–12

hydrocephalus could be a consequence of persistently elevated intracranial pressure, which can be observed in the absence of characteristic symptoms in children with CP [23]. In the present study, both patients with hydrocephalus (patient 11 and patient 12) underwent surgical correction. Patient 11 had a ventriculo peritoneal shunt placed early during childhood. Patient 12 was diagnosed with hydrocephalus a few months before SDR, and he underwent third ventriculostomy. Unfortunately, there was no follow-up imaging available for either of these patients, and although neither of them showed any clinical evidence of elevated intracranial pressure, it cannot be ruled out definitively. Previous studies found greater postoperative improvements after SDR in children with less motor impairment [7, 13]. In contrast, in the three randomized controlled trials comparing functional outcome after SDR, the poorest results were found in the study which included children with the best preoperative gross motor skills [9, 10]. In the present study, the patients with normal MRI had much better preoperative gross motor skills than the patients with PVL and hydrocephalus. We found no correlation between the preoperative GMFM score and its improvement postoperatively. McLaughlin et al. found an inverse correlation between the age at the time of the operation and the postoperative changes in the GMFM [9]. This could be explained as a consequence of faster spontaneous motor development in early childhood. However, in our study, not only the children with hydrocephalus (who showed the poorest outcome), but also the children with normal MRI (who showed the best outcome) were older than the patients with PVL when SDR was performed. There was no correlation between the age at the time of SDR and outcome.

In the patients with PVL, we graded the severity of the MR abnormalities and correlated them with the gross motor abilities. For this purpose, we used a grading scale that has previously been used to describe MR abnormalities in patients with spastic CP [20, 24]. We performed a reliability analysis of the various items included in this grading scale. The agreement between investigators was substantially worse than in the Cioni et al. study in which two experienced raters scored the MRIs [20]. In the present study, the interobserver reliability was notably poor for the assessment of the cysts. Several explanations should be considered: it was difficult to detect cysts in an area with extensive gliosis, there is a difference between the level of experience with brain MRI in the two investigators (2 years vs 8 years). Only the amount of ventricular enlargement correlated with the preoperative gross motor abilities. Correlations between ventricular size and gross motor abilities have been described previously in patients with spastic CP [25]. In contrast to the findings of previous studies [20, 24, 26], we did not find a correlation between

gross motor skills and the total MRI score/the thinning of the corpus callosum. However, the present study was limited to ambulatory patients with GMFCS levels I to III, and patients with more severe motor handicaps where more severe brain abnormalities could be expected on MRI have not been studied. No correlations were found between the severity of the brain anomalies and the outcome after SDR.

The outcome assessment in the present study consisted in the GMFM-66 which—according to the International Classification of Functioning, Disability, and Healths (ICF) [27]—assesses the domain of activity. However, the other two domains of the ICF—body structure and participation— have not been evaluated. One other limitation of the present study was the small sample size. Unfortunately, we did not have access to all MRI scans and not all patients had a preoperative GMFM assessment. We could only include data on a small number of patients in our analysis. Notably, the group with hydrocephalus was small and comprised only two patients. Therefore, the association between the type of brain lesion and the outcome after SDR needs to be proved in future studies with larger study samples, including the other ICF domains—body structure and participation.

Conclusion

We found significant differences in the post-operative changes in the GMFM-66 in patients with different brain MRI abnormalities. The largest postoperative improvement was observed in patients with normal MRI, and the poorest outcome was observed in patients with hydrocephalus. In patients with PVL, we could not detect any relation between MRI abnormalities and the postoperative improvement in of gross motor function after SDR. We conclude that MRI of the brain can provide additional information for the selection of patients for SDR. However, the degree of PVL does not provide information about the degree of improvement in gross motor function after SDR.

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