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Functional consequences of hemispherectomy

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Summary

Using the International Classification of Functioning Disability and Health (ICF) (WHO, 2001), impairments, activities and social participation are reported in 12 children (mean age at surgery 5.9 years) who were investigated before and three times over a 2-year period after hemispherectomy. Impairments were assessed (i) in terms of seizure frequency (Engel classification) and seizure severity (HASS) and (ii) with respect to muscle strength (MRC), range of motion (JAM score) and muscle tone (modified Ashworth scale). Activities were assessed in terms of gross motor functioning (GMFM) and self-care, mobility and social function (PEDI). Participation was assessed in terms of epilepsy-related restrictions and quantified by means of the Hague Restrictions in Childhood Epilepsy Scale (HARCES). Nine out of 12 children could be classified as free of seizures (Engel class I), and in the remaining three seizure frequency was Engel class III. HASS scores showed maximum improvement in 10 out of 12 children and near-maximum improvement in the two remaining children. Muscle strength and muscle tone on the side of the body contralateral to the hemispherectomy, which were already decreased preoperatively, decreased even further in the first 6 months after surgery, but returned to the presurgical baseline thereafter, except for the distal part of the arm. Range of motion was abnormal prior to operation and remained so after operation. Mean GMFM increase was 20% after 2 years (95% confidence interval 10–33); all five dimensions improved statistically significantly ($P < 0.05$). Mean PEDI increase was more than 20 scale points (95% confidence interval 10–35); again, all domains improved significantly ($P < 0.05$). In nearly all children, HARCES scores had normalized 2 years after surgery. In conclusion, decrease of seizure frequency and severity widens the scope of motor and social functioning, which overrides the effects of remaining motor impairments.

Keywords: children; hemispherectomy; limitations; motor function; ICF

Abbreviations: DI = developmental index; GMFCS = Gross Motor Function Classification Scale; GMFM = Gross Motor Function Measure; HARCES = Hague Restrictions in Childhood Epilepsy Scale; HHE = hemiplegia, hemiconvulsions, epilepsy syndrome; ICF = International Classification of Functioning, Disability and Health; IQ = full-scale intelligence quotient; JAM = Joint Alignment and Motion (scale); ROM = range of motion; PEDI = Pediatric Evaluation of Disability Inventory

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Introduction

In children with pharmacoresistant seizure disorders, epilepsy surgery reduces and even eliminates seizure activity. Until recently, the effectiveness of epilepsy surgery was measured predominantly in terms of seizure reduction. Alongside the intended seizure reduction, motor function—a valid marker of development (Beissner *et al*., 2000)—is an important presurgical consideration, as it strongly influences social participation in infancy and later childhood (Wyllie *et al*., 1998; Graveline *et al*., 2000). Change in motor functioning, addressed as a consequence of hemispherectomy, has been estimated in terms of clinical impression (Carson *et al*., 1996) or determined by the level of impairment (Beckung and Uvebrant, 1993; Beckung *et al*., 1994; Graveline *et al*., 1999). In a series of 33 hemispherectomized children, Devlin and colleagues reported that hemiplegia had not changed in the majority (22 children), had improved in five and worsened in six (Devlin *et al*., 2003). Holloway and colleagues examined hand motor function in the tasks of moving pegs, producing force and

tapping with the fingers (Holloway *et al*., 2000). They found residual motor function in children with acquired brain pathology but not in those with congenital brain pathology. To date, there has been no assessment of the course of motor impairments, limitations in activities and restrictions when participating in social life following hemispherectomy in childhood.

The International Classification of Functioning, Disability and Health (ICF) provided a useful guide for the present prospective, longitudinal study (WHO, 2001). The ICF is the generally accepted framework for classification of functional consequences of diseases or disorders (Steiner *et al*., 2002; Stucki *et al*., 2003; Wild, 2003). This taxonomy allows the classification of functions, activities and social participation and their illness-related impairments.

Whereas impairments reflect consequences of a disease at the organ level (Bilbao *et al*., 2003), limitations in activities reflect dysfunction in performance and motor activity, while restrictions refer to difficulties encountered in social participation. Assessment of daily activities and participation in social life is more comprehensive and closer to the patient's needs than assessment of impairment. Environmental and personal factors are also elaborated in the ICF but remain beyond the scope of this paper. The ICF is applicable across cultures, age groups and sexes, and allows the collection of reliable and comparable data on health outcomes (WHO, 2001).

This study addresses the questions to what degree motor impairments, motor activities and aspects of social participation exist before hemispherectomy and change thereafter.

Patients

Between 1996 and 2000, 12 children (nine girls, three boys), all of whom had been referred to the Dutch Collaborative Epilepsy Surgery Programme (DuCESP), underwent functional hemispherectomy. Exclusion criteria were age older than 16 years at the time of surgery, the presence of tumours, and metabolic disease. Pre- and postsurgery patient characteristics, including pathology, age at surgery, seizure outcome (frequency), Gross Motor Function Classification Scale and cognitive/developmental level [intelligence quotient/developmental index (IQ/DI)] are given in Table 1. The pathology had been ascertained both by imaging and pathological examination of the surgical specimen. In four children there was evidence of vascular pathology [three cases with congenital middle cerebral artery (MCA) infarction and one child with Sturge–Weber syndrome], in five there was evidence of acquired pathology [four cases with Rasmussen encephalitis and one child with hemiplegia, hemiconvulsions, epilepsy syndrome (HHE)], and three children exhibited developmental pathology (hemimegalencephaly). Six children underwent a right-sided and six children a left-sided hemispherectomy. Mean age at time of surgery was 5.9 years (range 0.3–11.1 years). All patients attended a rehabilitation programme at a regional rehabilitation centre after hemispherectomy. Three of them have used a splint for hand-positioning. All parents gave informed written consent and all children were followed for 2 years. The medical ethical and research committee of Wilhelmina Children's Hospital approved the study.

Methods

Patients were assessed using a standard protocol with fixed intervals: 1–3 months before surgery, and 6 months, 1 year and 2 years after surgery, at the outpatient clinic of the Wilhelmina Children's Hospital.

Epilepsy-related impairments were assessed with two measures. Surgical outcomes in terms of seizure frequency were assessed by using the modified classification of Engel and colleagues (Engel *et al*.,

Table 1 *Characteristics of patients (n = 12): demographic (sex, ages at onset and at surgery), illness (resected hemisphere, pathology/aetiology, Engel classification), cognitive level (IQ/DI) and Gross Motor Function Classification Scale*

No.	Sex	Age (years. months) at onset of epilepsy	Age (years. months) at surgery	Hemisphere resection	Pathology/ aetiology	IQ/DI		Engel classification	GMFCS	
						Before surgery	2 years after surgery		Before surgery	2 years after surgery
1	F	1.2	4.4	Right	Vas (MCA)	79	87	1	3	2
2	F	0.1	6.4	Right	Vas (MCA)	60	68	1	2	2
3	F	0.9	11.10	Left	Vas (MCA)	52	54	1	1	1
4	F	0.5	7.6	Left	Vas (SWS)	54	53	1	2	2
5	F	5.1	8.5	Right	Acq (Ras)	67	56	3	5	3
6	F	2.6	3.0	Left	Acq (Ras)	<50	55	1	2	2
7	F	7.11	11.5	Left	Acq (Ras)	67	64	3	2	2
8	M	10.3	12.1	Left	Acq (Ras)	69	77	1	3	2
9	M	0.2	3.9	Left	Acq (HHE)	<50	<50	3	4	4
10	F	0.0	0.6	Right	Devel (Hem)	54	53	1	3	3
11	F	0.0	0.3	Right	Devel (Hem)	54	55	1	4	3
12	M	0.4	1.6	Right	Devel (Hem)	<50	<50	1	4	4

F = female; M = male; Acq = acquired pathology; Devel = developmental pathology, DI = developmental index; GMFCS = Gross Motor Function Classification System; HHE = hemiplegia, hemiconvulsions, epilepsy syndrome; Hem = hemimegalencephaly; IQ = full-scale intelligence quotient; MCA = congenital middle cerebral artery infarction; Ras = Rasmussen encephalitis; SWS = Sturge-Weber syndrome; Vas = vascular pathology.

1993): class I = free of seizures or residual auras; class II = intermittent, infrequent seizures or relapse after a significant seizure-free period; class III = worthwhile improvement, i.e. more than 75% reduction in seizure frequency. The outcome of children who experience less than 75% reduction in seizure frequency is classified as Engel class IV.

Seizure severity, as perceived by the parent or caregiver, was quantified using the Hague Seizure Severity Scale (HASS), an inventory of 13 ictal and postictal problems that may have been encountered in the three previous months (Carpay, 1997). The scale is reliable in terms of test-retest stability and internal consistency (Carpay *et al*., 1997) and produces scores ranging from 13 (no epilepsy-related problems) to 52 (maximal problems).

To assess motor impairments, we selected muscle strength as an expression of the degree of paresis, and the range of motion and muscle tone.

Muscle strength of the extremities was assessed proximally and distally and scored according to the criteria for manual muscle testing, using the 6-point scale (MRC range 5–0) (Medical Research Council, 1943; Hislop and Montgomery, 2002). In infancy and early childhood muscle strength can be analysed by interpretation of muscle function associated with gross and fine motor developmental milestones. Hislop and Montgomery described a brief course on the spectrum of muscle activity associated with several postures and movements. By observing the child performing a number of developmentally appropriate movements, the skilled examiner obtains the information necessary to determine a pattern of muscular strengths (Hislop and Montgomery, 2002). Because of the age of the children and the presence of muscle strengths lower than grade 4, manual muscle testing and functional testing were indicated. Despite the subjectivity of manual muscle testing, its reliability and validity are both adequate for use in clinical assessments (Hislop and Montgomery, 2002).

Strength was assessed in the following muscles: flexors and abductors of the shoulder and hip (proximal), dorsal and palmar flexors in the wrist and plantar and dorsal flexors in the ankle (distal). We measured the strength of flexors and extensors in the neck and trunk. Six strength scores were calculated by averaging the scale values per muscle group across directions of movement.

Range of motion (ROM) was measured using the Joint Alignment and Motion (JAM) scale, a five-point scale of motion decrease (0 = no decrease, 1 = 1–5%, 2 = 6–25%, 3 = 26–75%, 4 = 76–100%). Each individual joint is scored according to an estimate of the percentage of normal motion, based on the knowledge of a joint's normal ROM (Bernbeck and Dahmen, 1983). The examiner visually estimates whether a joint's ROM is normal or limited (Spiegel *et al*., 1987). Inter- and intra-reliability are reported to be high ($r = 0.91$ and $r = 0.85$ respectively) (Spiegel *et al*., 1987). In the upper extremities, range of flexion and abduction of the shoulder and of dorsal and palmar flexion of the wrist were determined. In the lower extremities, flexion, extension, abduction and adduction of the hip and plantar and dorsal flexion of the ankle were measured. Four mean JAM scores were calculated by averaging the scale values of motion decrease per joint across directions of movement.

Muscle tone was assessed using the Modified Ashworth Scale (MAS) (Bohannon and Smith, 1987), a very well known and reliable instrument consisting of a five-point scale of tone increase (0 = no resistance, 1 = slight 'catch' when limb is moved, 2 = resistance in whole range of movement, 3 = strong increase with decreased range of movement, 4 = limb rigidly in flexion or extension). Kendall's tau correlation for inter-tester reliability was 0.85 (Bohannon and Smith, 1987). Six mean scores were calculated by averaging the scale values of tone increase over movement directions (0 = normal; 1 and 2 = mild, 3 = moderate, 4 = severe impairment).

Within the activity domain (WHO, 2001) we administered three measures Gross Motor Function Classification Scale (GMFCS) (Palisano *et al*., 2000). The GMFCS for children with cerebral palsy is based on self-initiated movement, with particular emphasis on sitting (truncal control) and walking. The manual provides separate descriptions for children in the age bands of birth to second birthday, 2nd to 4th birthday, 4th to 6th birthday, 6–12 years and older. Mobility is classified into five levels, taking age band into account (for children above the age of 2 years, level I = walks without restrictions, limitations in more advanced gross motor skills; level V = self-mobility is severely limited even with the use of assistive technology) (Table 1).

The Gross Motor Function Measure (GMFM-88) is a standardized clinical observational instrument designed to evaluate change in gross motor activities in children with cerebral palsy. It assesses how much of an activity a child can accomplish, rather than how well the activity is performed (Russell *et al*., 1989, 2002). The GMFM-88 (Russell *et al*., 2002) consists of 88 items grouped into five dimensions: lying and rolling (17 items); sitting (20 items); crawling and kneeling (14 items); standing (13 items); and walking, running and jumping (24 items). The items are scored on four-point ordinal scales [0 = cannot initiate, 1 = initiates, but completes less than 10%, 2 = partially completes item (11–99%), 3 = completes item independently]. Good reliability using the intraclass correlation coefficient has been reported; the values varied from 0.87 to 0.99 (Russell *et al*., 2002). Percentage scores for each of the five GMFM dimensions and a total GMFM percentage score are calculated. Higher scores mean better performance.

The Pediatric Evaluation of Disability Inventory (PEDI) (Haley *et al*., 1992; Custers *et al*., 2002) is a structured parent's interview that assesses functional skills (capability) and caregiver assistance. It covers the domains of self-care (73 items), mobility (59 items) and social functioning (65 items). Functional skill is measured by counting the items in which the child is perceived as having mastery and competence. Caregiver assistance is measured by counting the daily functional activities in which the caregiver provides factual assistance. Although the instrument has been designed for children aged from 6 months to 7.5 years, the scaled scores offer the opportunity to estimate skills in older children whose functional abilities lag behind those expected of 7.5-year-old healthy children (Feldman *et al*., 1990; Haley *et al*., 1992; Nichols and Case-Smith, 1996; Custers *et al*., 2002). As the aim of the present study was to map individual change rather than to compare with healthy peers, we used the scaled scores rather than the age-norms. The PEDI is sensitive to changes over time. The internal consistency for PEDI scales has alpha scores ranging from 0.95 to 0.99 and a mean standard error of measurement of 0.09 (Haley *et al*., 1992; Custers *et al*., 2002).

The scaled scores provide estimates of the level of skill in each domain (0 = no measurable functional skill, 100 = intact functional skill, 0 = complete caregiver assistance, 100 = no caregiver assistance).

Independence refers to the ICF's participation domain. Restrictions, or difficulties when participating in social life (WHO, 2001) due to the effects of seizures, were assessed using the Hague Restrictions in Childhood Epilepsy Scale (HARCES) (Carpay, 1997), a ten-item scale that quantifies the parent's/caregiver's perception of epilepsy-related restrictions imposed on the child to avoid seizure-related injuries. The scale is based on the Liverpool Seizure Severity Scale (Scott-Lennox *et al*., 2001) and is reliable in terms of test–retest

stability and internal consistency (Carpay *et al*., 1997). Scores range from 10 (no restrictions) to 40 (maximal restrictions).

Data analysis

Descriptive statistics were calculated using SPSS software Version [11.01]. Changes in seizure severity (HASS), IQ/DI values, muscle strength, muscle tone, range of motion, and restrictions (HARCES) were analysed using non-parametric statistics (Wilcoxon signed ranks test). Data obtained before and after surgery were compared. Scores on the PEDI, GMFCS and GMFM were analysed using the Wilcoxon signed ranks test, and mean difference scores with 95% confidence interval (CI) were calculated. Analysis of variance (ANOVA) for repeated measures was also applied to analyse the scores on the GMFM and PEDI with time (before and 6, 12 and 24 months after surgery) as within-subject factor. A P value of less than 0.05 was considered statistically significant.

The non-parametric Spearman's ρ correlation was used to see whether differences in impairments between before surgery and 2 years after surgery were related to differences in activities and social participation (restriction level) assessed over the same period, and to see whether decrease in caregiver assistance and increase in functional skills were correlated (PEDI).

Results

Impairments

Seizure frequency

In all children, hemispherectomy had considerable effect in terms of seizure reduction: nine and three children were in outcome classes I and III respectively (Engel *et al*., 1993) (Table 1).

Seizure severity

The group mean score on the HASS improved from 30.52 (SD 2.9, range 27–39) before surgery to 14.8 (SD 0.8, range 13–15) 6 months after surgery ($P < 0.01$) and to 13.25 (SD 0.7, range 13–15) 2 years after surgery ($P < 0.01$). Two of the children with Engel III classification improved on the HASS to a score of 15 (almost maximally), the third one to a score of 13.

Cognition

Group-wise, mean IQ/DI changed from 58.7 (SD 9.8) before surgery to 60.3 (SD 9.7) 2 years thereafter. This difference was not statistically significant.

Muscle strength (Fig. 1A)

At the presurgical baseline, the muscle strength of the extremities on the affected side was mildly to moderately impaired. Six months after hemispherectomy, scores reflected a further postsurgical significant decrease ($P < 0.05$) in the arm and a non-significant decrease in the leg. Two years after surgery, the affected leg had recovered to presurgery strength. In the arm, strength remained very poor distally ($P < 0.05$), whereas proximal strength recovered, although this was not statistically significant. The presurgical mild impairment of strength in neck and trunk muscles did not change significantly with time. We compared muscle strength measurement scores as assessed by the child neurologist and by the paediatric physical therapist, both of whom used the MRC but were blind to each other's scoring. Results were found to be identical.

Range of motion (Fig. 1B)

Prior to surgery, all ROM scores were subnormal (range 1.4–2.2), indicating a mild (5–25%) decrease in range of motion. ROM did not change significantly during the 2 years after surgery (range 1.7–2.3).

Muscle tone (Fig. 1C)

Prior to surgery, tone was mildly increased in the proximal and distal arm and in the proximal and distal leg. Six months after surgery, tone had increased, although statistically non-significantly, both proximally and distally in the paretic arm and remained so until 1 year after surgery. At 24 months after surgery, muscle tone had increased in the distal part of the arm ($P < 0.05$). In the hemiparetic leg and in the neck and trunk no significant changes could be detected.

Activities

The GMFCS scores had improved statistically significantly 2 years after surgery compared with before surgery ($P < 0.05$) (Table 2).

GMFM-88 (Fig. 2A)

Gross motor function was already limited before surgery, especially in the children with developmental pathology (hemimegalencephaly). In children 6, 7 and 10 (two children with Rasmussen encephalitis and one with hemimegalencephaly), motor function deteriorated in the first 6 months after surgery, but 12 and 24 months after surgery the percentage of completed items on the GMFM had increased, as in all other children. Overall, group mean increase after 2 years was 20% in each of the five dimensions and in the total score of the GMFM. The change between presurgical and 2-year postsurgical data was statistically significant ($P < 0.05$) in all domains of activity (Table 2).

PEDI

With respect to functional skills, a child with Rasmussen encephalitis (case 7) was the only one who, prior to surgery, scored maximally in all subscales and whose self-care worsened after surgery. All other children scored below 100 for self-care prior to the operation and increased their scores in the majority of skills after surgery. When comparing the scores of the caregiver assistance scale with those obtained before surgery, assistance had increased for four children (6, 7, 8 and 10) 6 months after surgery. In child 6 (Rasmussen encephalitis) assistance remained greater than prior to surgery, whereas child 7 recovered to maximal independence. Overall, the group mean increase in the PEDI domains for functional skills and caregiver assistance was more than 20 points on the scale scores (Fig. 2B). The change between presurgical and 2-year postsurgical data was statistically significant ($P < 0.05$) in all

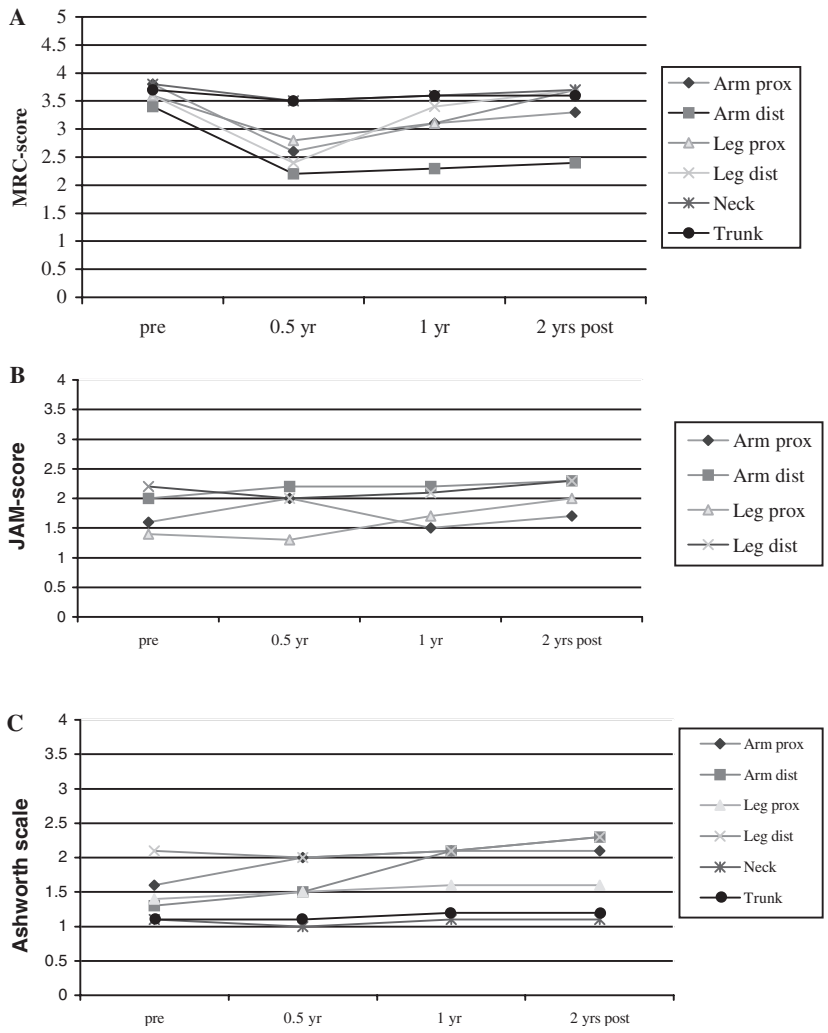

Fig. 1 Muscle strength (**A**), range of motion (**B**) and tone (**C**) of the paretic side and in the neck and trunk at presurgical baseline and 0.5, 1 and 2 years after surgery, averaged over 12 children. Muscle strength is expressed as MRC score (0–5; higher scores indicate greater muscle strength, 5 = normal). Range of motion is expressed as Joint Alignment and Motion (JAM) score (0 = normal). Tone increase is expressed as the Modified Ashworth Scale Score (0–4; higher scores mean more spasticity, 0 = normal).

Table 2 *Recovery in Gross Motor Function Classification Scale (GMFCS) and Gross Motor Function Measure (GMFM) of 12 children*

	Before surgery	After surgery[1,2]		
		6 months	12 months	24 months
GMFCS	Median 3.0	Median 3.0	Median 3.0	Median 2.0*
GMFM	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Lying, rolling	58.27 (33.5)	72.01 (27.6)**	76.27 (22.1)**	82.73 (18.6)**
Sitting	49.82 (38.9)	59.73 (36.8)*	73.18 (25.2)**	80.45 (18.4)**
Crawling, kneeling	40.01 (33.3)	36.09 (32.1)	48.36 (40.3)	59.00 (41.3)*
Standing	38.71 (37.0)	38.82 (37.4)	51.91 (38.9)*	55.91 (40.6)*
Walking, running, jumping	37.90 (33.0)	35.11 (33.0)	44.36 (38.6)	51.91 (42.8)*
Total score	43.55 (37.2)	49.80 (31.6)	58.80 (31.9)*	65.38 (31.9)*

Median ratings on GMFCS and mean ratings on GMFM before and 6, 12 and 24 months after surgery, averaged for each subscale and compared with presurgical scores. [1]Wilcoxon signed ranks test for GMFCS; [2]ANOVA (repeated measures) for GMFM: statistically significant difference (*$P < 0.05$; **$P < 0.01$) relative to presurgical scores.

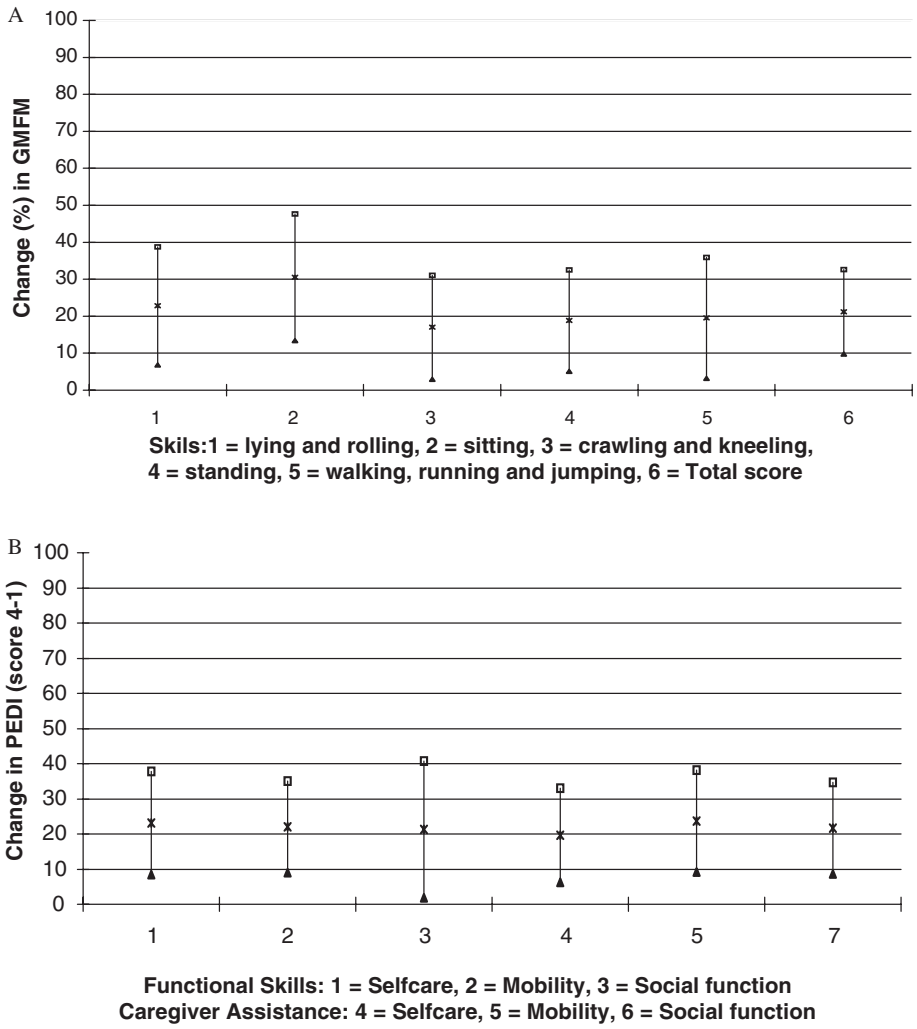

Fig. 2 Improvement, averaged over 12 children in GMFM (**A**) and PEDI (**B**) over time (2 years after surgery) [mean (*x*) and 95% CI (demarcated by line ending in triangle and square)].

domains of functional skill as well as of caregiver assistance (Table 3).

Participation

Restrictions with respect to epilepsy

The mean score on the HARCES decreased significantly from 30.8 (SD 3.6, range 25–33) prior to surgery to 13.5 (SD 3.1, range 10–20) 6 months after surgery ($P < 0.01$) and to 13.1 (SD 0.3, range 10–15) 2 years after surgery ($P < 0.01$).

Relationships between measures

With respect to the change between scores obtained 2 years after surgery to those obtained before the operation, no significant association was found between impairments (muscle tone, range of motion, muscle strength) and activities (GMFM) or functional skills (PEDI). For PEDI, however, there was a statistically significant correlation between a decrease in caregiver assistance and an increase in functional skills: subscales self-care (r between 0.77 and 0.83, $P < 0.05$) and social functioning (r between 0.79 and 0.86, $P < 0.01$).

Time of onset of epilepsy was not statistically significantly associated with functional outcome 2 years after surgery.

Discussion

To our knowledge, this is the first report of the outcome of hemispherectomy in children that not only deals with seizures and motor impairments but also focuses on changes in activities and social participation. Regarding the effects of hemispherectomy on seizure frequency, this study is in agreement with previous favourable reports (Vining *et al*., 1997; Wyllie *et al*., 1998; Holthausen and Strobl, 1999; Chen *et al*., 2002; Devlin *et al*., 2003). In the 2-year period following hemispherectomy, nine out of 12 children had no seizures at all and the remaining three children had a reduction in seizure frequency of more than 75%.

Table 3 *Recovery in functional skills and caregiver assistance (PEDI) of 12 children*

	Before surgery: mean (SD)	After surgery: mean (SD)[1]		
		6 months	12 months	24 months
Functional skills				
Selfcare	48.53 (30.1)	57.83 (17.9)	62.97 (18.2)*	72.00 (21.1)**
Mobility	50.69 (35.6)	57.41 (35.7)	67.26 (26.1)**	73.84 (25.3)**
Social function	50.38 (33.4)	58.30 (32.2)*	70.26 (25.5)**	74.82 (23.5)**
Caregiver assistance				
Selfcare	43.63 (32.2)	48.03 (29.9)	59.77 (22.2)**	65.06 (21.0)**
Mobility	50.52 (36.1)	57.43 (31.1)*	65.91 (22.9)**	73.67 (20.5)**
Social function	52.19 (34.7)	55.10 (35.7)	64.66 (27.6)*	73.08 (21.1)**

Mean ratings before and 6, 12 and 24 months after surgery averaged for each subscale and compared with presurgical scores. [1]Anova for repeated measures: statistically significant difference (*$P < 0.05$; **$P < 0.01$) relative to presurgical scores.

The primary goal of epilepsy surgery is to relieve the patient of his/her epilepsy. Negative effects on function, however, make one unwilling to carry out such a drastic intervention as hemispherectomy. Based on the International Classification of Functioning Disability and Health (WHO, 2001), we present data on impairments in muscle tone, range of motion and muscle strength as well as on activities and social participation in 12 children.

At the presurgical baseline, all children had impairments. Muscle strength, range of motion and muscle tone of the arm and leg were mildly to moderately impaired on the affected side.

The different course between the arm and the leg is remarkable. Proximally and distally in the contralateral arm, an increase in muscle tone was present when measured 6 months after hemispherectomy, and assessments after 1 and 2 years showed a further increase. The increase affected the hand in particular, while muscle tone in the contralateral leg remained unchanged when measured 12 and 24 months after surgery. This increase in tone coincided with a significant decrease in muscle strength 6 months after hemispherectomy and later on in the distal part of the arm, while strength in the muscles of the proximal part of arm and leg returned to preoperative values. The difference in course and degree of impairment between the upper and lower limbs can be explained by several hypotheses. The upper limb, particularly the hand, has become specialized to perform skilled hand movements and is more under the control of the corticospinal pathways than the leg, while the locomotor task of the lower limbs is more under the control of the spinal neuronal circuits (Duysens and Van de Crommert, 1998; Dietz *et al*., 2002; Dietz, 2003). This could be a reason why the arm is more impaired than the leg after hemispherectomy. Dietz (2003) and others (Barbeau and Fung, 2001; Taub *et al*., 2002) suggest that the lumbosacral spinal cord contributes to the ability to walk in animals and humans. There is some indirect evidence that locomotion depends upon neuronal circuits (networks of interneurons) within the spinal cord which are thought to be a type of central pattern generator (Dietz, 2003). Another explanation may be the following: preservation of the ability to ambulate may be due to contributions of subcortical regions of the nervous system. Several structures in the nervous system other than the cortex are known to support coordinated movement; these include the cerebellum and the mesencephalic locomotor region of the brain stem (Wieser *et al*., 1999), structures which are preserved after hemispherectomy. Thirdly, intact ipsilateral cortical pathways could be responsible for preserved locomotion. Wieser and colleagues described the transfer of motor control of the left leg to the ipsilateral primary motor cortex in a patient with a right-sided surgical resection. He reasoned that both motor areas have the latent capacity to control motoricity bilaterally and that the ipsilateral capacity is brought into function only after removal of the opposite hemisphere (Wieser *et al*., 1999). This line of reasoning does not, however, account for the fact that, apparently, transfer of motor control of the arm is less successful than that of the leg.

Holthausen and colleagues concluded that patients who are ambulatory prior to hemispherectomy remain so thereafter, whether the pathology was acquired or not (Holthausen *et al*., 1997; Holthausen and Stobl, 1999). The present study, although on a small number of patients, corroborates and qualifies this conclusion. Children 1–8 (Table 1) walked before and after the hemispherectomy. These children suffered 'vascular pathology' and Rasmussen encephalitis. Children 10 and 11 were too young at the time of surgery to be ambulant; they did not start to walk during the 2-year follow-up. Children 9 and 12 were mentally very retarded; they did not walk either before or after surgery. Patient 5 was completely immobile (GMFCS level 5) as a result of her continuous partial seizures in combination with her hemiplegia. After surgery she had an occasional seizure, but mobility improved to level 3 of the GMFCS, she could walk indoors and outdoors on a level surface with an assistive mobility device. At least as important as impairments and their course is the issue of change in daily activities after hemispherectomy. A gold standard reflecting 'true' change usually not being available for outcome studies, an increase of more than 10 scale points is considered to reflect a clinically relevant change (Iyer *et al*., 2003). The smallest change in PEDI scores during inpatient rehabilitation that

was considered to be associated with a minimal but clinically important difference by physical therapists and other clinicians ranged from 6 to 15 points (mean = 11.5, SD = 2.8) for all PEDI scales (Iyer *et al*., 2003). Hence, the increase of 20 points on the PEDI scales may be taken to indicate a significant improvement in daily activities. The change in caregivers' assistance over time underscores this deduction, as the children need less assistance with self-care, mobility and social functioning.

The change on the HARCES shows indeed that freedom to participate in social life has come within reach of the children since the seizures (largely) stopped.

On balance, impairments remain after hemispherectomy. But apart from a slight deterioration in the first postoperative months they improve to at least the presurgical level, except for muscle strength and muscle tone in the distal part of the arm. Failure to recover strength and tone does not, however, lead to further functional drawback. Impairments are only remotely associated with functional outcome, as is underscored by the weak correlations that we found between the two. Neither the improvement in activities nor the positive changes in social participation can be understood from change in motor impairments. It is the relief from seizures that widens the scope of action for the children.

This study does not allow a detailed analysis of determinants of outcome, due to the small number of children and their heterogeneity in age, pathology and level of cognitive functioning. Differences in postsurgical outcome between children with congenital and those with acquired cerebral damage have previously been observed in the domains of general cognitive abilities and seizure freedom (Devlin *et al*., 2003), and in the domain of hand motor function (Holloway *et al*., 2000). We did not assess hand motor function with specific tests, because focus was directed to gross motor function and overall functional skills and the degree of independence of the children. However, in terms of activities, outcome was poorer in the children with developmental pathology (children 10, 11 and 12) than in those with Rasmussen encephalitis and vascular pathology. The fact that these three patients were younger than the children in both other groups renders final statements about aetiological effects doubtful, but the finding indicates the need for larger studies. Secondly, it has been suggested that children with better cognitive development prior to hemispherectomy improve more in motor function after surgery than children with weaker cognitive abilities (Devlin *et al*., 2003; Maehara *et al*., 2002). In our study, three children (children 1, 2 and 8) improved both in IQ/DI and in functional skills, but a significant relationship between level of presurgical intelligence and improvement in daily activities could not be found. It is obvious that these issues require further study in a larger group of patients with a longer period of follow-up. Thirdly, the time of onset of epilepsy was not associated with functional outcome.

One might expect that the outcome of impairments in right-handed children with a right-sided hemispherectomy would be better than in right-handed children with a left-sided hemispherectomy because in the former children the dominant hemisphere was preserved. Verification of this expectation requires a larger number of children.

The present study emphasizes that outcome has to be defined more extensively than in terms of seizure reduction, as discussed in a recent ILAE Commission report (Wieser *et al*., 2001).

Future research on the outcome of hemispherectomy should be structured according to the framework of the WHO-ICF classification, which enables one to evaluate not only impairments but also, and perhaps more importantly, activities and social participation.

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