Motor Development Toward Ambulation in Preschool Children with Myelomeningocele—A Prospective Study

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Purpose: To describe motor development toward ambulation in children with myelomeningocele. **Methods:** Forty-three children were followed prospectively from 6 months to 6 years of age. **Results:** Walking function had been achieved at the 1-year follow-up in 2 of 38 children, at the 1.5-year follow-up in 7 of 39, at the 2-year follow-up in 14 of 36, at the 3-year follow-up in 21 of 28, at the 4-year follow-up in 28 of 36, and at the 6-year follow-up in 30 of 38. At the 6-year follow-up, spasticity was present in 22 of 38 children, 42 of 43 used orthoses, and 9 children had not achieved ambulation expected with respect to muscle function. **Conclusions:** In children with myelomeningocele, walking starts in some during the first year of life and is seen increasingly more frequently until 6 years of age. Motor development before ambulation varies among children with similar muscle function. An increased incidence of spasticity is found among those not having achieved ambulation with respect to muscle function. **(Pediatr Phys Ther 2010;22:52–60)** *Key words: child, child development, myelomeningocele, neurologic ambulation disorders, prospective study*

INTRODUCTION

In persons with myelomeningocele (MMC), walking ability is primarily related to neurological level, but a large disparity has also been found in reports of ambulatory outcome across neurosegmental lesion groups.[1] Findings, however, show that ambulatory function is achieved in most children with MMC, but that some delay must be expected in most children regardless of the neurosegmental lesion.[2,3]

There is no standardized, objective developmental test to examine the gross motor skills of children with spina bifida.[4] Even children with the same motor level and need for similar orthopedic and orthotic management will have very different patterns of active movement, strength, and upright function.[5] Leg movements in the supine position when investigated at ages 1 to 6 months showed less movement activity compared with typically developing children.[6] During stepping on a treadmill infants' with MMC responsiveness was affected by lesion level but was also found to vary markedly among infants.[7]

Besides the motor paresis due to the neurological lesion, orthopedic and additional neurological factors have also been found to have a negative effect on ambulation.[8] One important factor is spasticity, which might be demonstrated due to associated central nervous system anomalies,[9] such as tethering of the spinal cord.[10] Both gait pattern and standing position were found to deviate in children with spasticity in lower limb muscles from those children with MMC without spasticity.[11] Neurological dysfunction above the cele level is common in children with spina bifida, and children with an early onset of severe functional impairment may have long persisting problems with postural control.[12] Also, symptoms of generalized muscle hypotonia unrelated to the flaccid paresis of single muscle groups were found to affect the child's activity level.[8]

Even newborns with MMC can display different muscle activity patterns, such as voluntary function down to a certain level with partial or complete loss below, and reflex

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activity or spasticity due to presence of isolated function of the spinal cord.[13] A goal of the physical therapist is to establish a preliminary motor level and monitor the patient for central nervous system deterioration, tethered cord, and hydromyelia.[5] To enable a realistic prognosis of ambulation for a child with MMC, the level of motor paresis needs to be discriminated from and complemented with an analysis of additional ambulation-related factors.[8]

To enable independent walking and standing by compensating for loss of muscle function, various types of orthoses are used.[14–16] An integrated coordination between patient and orthosis use can only be achieved with the knowledge of the principles, potentials, and limitations of orthoses.[16] The introduction of the orthosis during the first year to support weight-bearing[17] and the child's attempts to pull up into a standing position have been defined as a criterion to start a standing and gait training program.[18,19] Gradually developed tolerance to orthosic use is important, and initial experiences wearing braces while standing should be well planned to emphasize their positive aspects.[20]

A strong predictor for ambulation is involvement in a physical therapy program committed to teaching and achieving the specific goal of walking.[21] To support the child's motor development from the first year of life, a physical therapy program has been suggested that focuses on appropriate timing of the upright position with respect to lesion level and orthotic treatment based on the child's motor autonomy and motivation,[22] as well as the child's attitude toward and readiness for gait training.[5]

Because of the variation in neurological status among individuals, it is difficult to formulate criteria of typical motor development before ambulation. This might be the reason for the lack of objective tests to examine the gross motor function in children with spina bifida[19] and why motor function in children with MMC most commonly has been described in ambulatory terms. The aim of this study was to describe motor development toward ambulation during preschool years in children with MMC, with respect to muscle function and additional ambulation-related factors, in view of a current orthotic program.

METHODS

Participants

Of all children who were born with spina bifida between July 1993 and September 1999 and treated at the Karolinska University Hospital, those children diagnosed of MMC were followed up prospectively during the preschool years by a team consisting of a pediatrician, a neurosurgeon, an orthopedist, and a physiotherapist (PT).

Clinical visits were planned at 6 months and at 1, 1.5, 2, 3, 4, and 6 years. When the children received medical treatment between the follow-ups, the PT performed the follow-up assessment at the time of treatment, if it approximately fit the schedule for the prospective study. After each visit, a report summarizing the child's motor status and relevant orthopedic and neurological findings as well as physiotherapy recommendations for the period to the next follow-up was sent out to each child's local PT. In children without further need of treatment, the PT was asked to check the child's motor development status approximately once a month between the clinical follow-ups. Recommendations, if indicated, were given to facilitate motor development by sensorimotor stimulation, and in cases of muscle imbalance or presence of joint contractures, to perform stretching exercises. The PTs were also instructed to pay attention to the child's motor initiatives toward a vertical position. They were asked to report to the clinical team so that the children were offered orthoses appropriately timed to facilitate the upright position and to progressively assist the child to ambulate, stand, and walk. Besides parent information, the PTs were also recommended to encourage the children to accept their orthosis, by using them in motivating situations, such as playing. The local PTs, who worked with the families on a community level, obtained written information, and supervision continuously from the PT on the clinical team.

Of 47 children enrolled in the study, 4 children were excluded, 2 of whom were later revealed to have meningocele, 1 child was additionally diagnosed with juvenile idiopathic arthritis, and 1 child could not be followed for more than half a year; thus 43 children, 23 boys and 20 girls, were included, 40 of those with shunted hydrocephalus.

Ethical approval for the study was obtained from the local committee and informed consent from all participants' guardians was obtained.

Clinical Examination

All children were examined by the same PT (Å.B.) during the entire follow-up period except for 3 times when the examinations were made by the team orthopedist. The children's muscle strength was assessed by manual muscle testing on a 0 to 5 graded scale according to the guidelines of Hislop[23] and based on the assessment of the less functional limb. In infants, the assessment of muscle strength was performed through observation of spontaneous movements and with increasing age, gradually through observation of voluntary movements.

Spasticity was documented as present or absent when observed according to type, which has been described as commonly found in patients with MMC: static abnormal positioning of a joint often identified in the peroneal muscles, catch at rapid movements, resistance throughout passive range of motion, and as clonus. The findings were presented as distributed in ankle muscles and in knee/hip muscles.[8] Generalized muscle hypotonia was documented when generally decreased muscle tone was observed.[8]

The range of motion of the lower limb joints was assessed according to the recommendations of American Academy of Orthopedic Surgeons.[24] Joint contractures of the lower limb were defined at the ankle as 10° or more of fixed plantar flexion, and at the knee and hip as 20° or more from a neutral joint position. Hip extension range was measured using the Thomas test.[25] Presence of hip dislocation and orthopedic surgeries were documented from the medical records.

Muscle Function Classes

Based on the muscle strength assessment in the lower limb muscles, the children were designated into 1 of 5 muscle function classes (MFCs), with MFC I indicating the lowest neurological level of impairment with weakness of intrinsic foot muscles; MFC II and MFC III with weakness or absence, respectively, of plantar flexion, knee flexion, hip extension, and abduction activity; MFC IV with weak or no knee extension and hip adduction but good pelvic elevation activity; and MFC V indicating the highest level with no muscle activity in the lower limbs. These levels were considered critical for achieving different levels of ambulation and have been used in previous studies.[8,26] The definition of each MFC is shown in Table 1.

Orthotic Program

Guidelines used in this clinical practice constituted the basis for orthoses use during the follow-up period. According to this program, the children in MFC I were generally provided with foot orthoses (FOs), in MFC II with ankle-foot orthoses (AFOs), in MFC III with knee-ankle-foot orthoses (KAFOs) with free knee joints, and the children in MFC IV and V with hip-knee-ankle-foot orthoses (HKAFOs). The orthotic guidelines also provided general aspects of timing of orthoses prescription with respect to the different MFCs. Table 1 shows the general recommendations of the orthotic program and timing of orthoses introduction. Through close cooperation of the PT with the orthotic department that provided all orthoses, attention could be given to achieve correct alignment and adequate material for each orthosis.

At the end of the 6-year follow-up, the adequacy of each child's orthosis was documented in relation to the child's muscle function and the guidelines of the orthotic program. In addition, the daily duration of orthotic use was documented by parents' information according to the following scale: 5 or more hours a day, 2 or more hours a day, less than 2 hours a day, and only during training sessions.

At the 6-year follow-up, the parents were asked whether their child used a wheelchair, manual or powered, for ambulation indoors and outdoors.

Expected Ambulatory Function

At the 6-year follow-up, each child's walking ability or ambulatory function was assessed with respect to muscle function. The criteria used were modified according to Hoffer et al[27] by defining 2 subgroups within the category of household ambulation to distinguish between those who walked indoors and those who both walked and used wheelchairs indoors.[8] Table 1 presents the expected walking ability or ambulatory function with respect to each MFC.

Motor Function

At each follow-up, the child's gross motor function was observed by the PT on the clinical team and documented in the following terms: stays in the supine position, turns to the prone from supine position, moves in the prone position (pivots, crawls, flexes hips, kneeling), sits up independently, maintains sitting position after being seated, pulls to standing, and walks with or without aid (may use orthoses). The purpose of the observation was to

TABLE 1

Muscle Function Classes Based on Muscle Strength of the Lower Limbs: Guidelines for Orthotic Program and Expected Ambulation

Muscle Function Classes	Guidelines for Orthotic Program	Expected Ambulation
I. Weakness of intrinsic foot muscles; good to normal foot plantar flexion (grade 4–5)	FO	Community ambulation; ability to keep up with peers when walking outdoors*
II. Fair or less foot plantar flexion (grade 3 or less); Fair or better knee flexion (grade 3 or more); poor to fair or better hip extension and/or hip abduction (grade 2–3 or more)	When the child initiates moving in the prone position: standing with AFO; when the child initiates steps: walking with SMO or AFO; in children with tibial torsion or knee rotation risk: walking with KAFO-F	Community ambulation; walks in the community, wheelchair use only for long distances outdoors
III. Good to normal hip flexion and knee extension (grade 4–5); fair or less knee flexion (grade 3 or less); trace of hip extension, hip abduction and below-knee muscles	When the child raises to sitting: standing with HKAFO; when the child initiates steps: walking with HKAFO; in children with stable hip joints: walking with KAFO-F; in children with hip joint instability: walking with RGO	Household ambulation; walks indoors, wheelchair only outdoors (and for long distances indoors)
IV. No knee extension activity; poor or less hip flexion (grade 2 or less); fair or good pelvic elevation	When the child raises to sitting: standing with HKAFO when the child initiates steps: walking with RGO	Household ambulation; wheelchair use both indoors and outdoors
V. No muscle activity in the lower limbs; no pelvic elevation	When the child initiates reaching with the hand in the prone position toward the vertical position: standing with SO; when the child initiates ambulation: SW	Nonfunctional ambulation or standing function

FO indicates foot orthosis; AFO, ankle-foot orthosis; SMO, supramalleolar orthosis; KAFO-F, knee-ankle-foot orthosis with free-articulating knee joint; HKAFO, hip-knee-ankle-foot orthosis; RGO, reciprocating gait orthosis; SO, thermoplastic standing orthosis; SW, Orlau swivel walker.

* According to the criteria of Pediatric Evaluation of Disability Inventory.

document the child's motor development status as the basis for planning toward achievement of the upright position and ambulation, according to the orthotic guidelines program.

Statistical Analysis

Distributions of variables were calculated as means, SD, and ranges. The chi-square test was used to study the influence of spasticity, joint contractures, hip dislocation, and orthopedic surgery among the MFCs. Statistical significance was determined at $p \leq 0.05$. The statistical analyses were performed using commercially available software (SPSS, Chicago, Ill).

RESULTS

Follow-Up Assessments

In the 43 children who were included in the study, 251 assessments were performed, on an average of 5.84 occasions (range, 3–7). Thirty-six children were examined at approximately 6 months (mean = 0.58 years, SD = 0.1), 38 children at 1 year (mean = 1.1, SD = 0.2), 39 children at 1.5 years (mean = 1.7, SD = 0.2), 36 children at 2 years (mean = 2.3, SD = 0.2), 28 children at 3 years (mean 3.1, SD = 0.3), 36 children at 4 years (mean 4.3, SD = 0.3), and 38 children at 6 years (mean 6.8, SD = 0.6).

Muscle Function Classes

Of 43 children, at each child's first examination, 1 child was assigned to MFC I; 25 children to MFC II, 9 to MFC III, 1 child to MFC IV, and 7 children to MFC V.

At the 6-year follow-up, of 38 children, there was 1 child in MFC I; 16 children in MFC II, 15 in MFC III, 2 in MFC IV, and 4 children in MFC V (Table 2).

Clinical Examination

Spasticity was observed in 22 of 43 children at each child's first examination and in 22 of 38 at the 6-year follow-up, most frequently in MFC II at both examinations ($p = 0.023$ and $p = 0.037$, respectively). Distribution of spasticity in ankle and knee/hip muscles with respect to MFC is shown in Table 2. Generalized muscle hypotonia was observed in 3 children in MFC II during the entire follow-up period (Table 2).

Joint contractures in ankle and knee/hip was seen in 14 children at each child's first examination and in 21 children at the 6-year follow-up (Table 2).

During the entire follow-up period, 10 children had hip dislocation, which was congenital in 8, most frequently seen in MFC III ($p = 0.001$). Bony hip or pelvis surgery was performed in 7 children and spine surgery in 6 during the entire follow-up period, most frequently in MFC III ($p = 0.01$). Distribution of joint contractures, hip dislocation, and orthopedic surgery is shown in Table 2.

Six children had changed MFC between the first examination and the 6-year follow-up, of whom 4 from MFC II to III, 1 child from II to IV, and 1 from III to IV. Five of

TABLE 2

Distribution of the Children into Muscle Function Classes, and Distribution of Spasticity, Joint Contractures, Hip Dislocation, and Orthopedic Surgery at Each Child's First Assessment and at the 6-Year Follow-up

	Clinical Examination													
	Each Child's First Assessment (43/43)							6-year Follow-up (38/43)						
	Muscle Function Class							Muscle Function Class						
	N	I (N = 1)	II (N = 25)	III (N = 9)	IV (N = 1)	V (N = 7)	p	N	I (N = 1)	II (N = 16)	III (N = 15)	IV (N = 2)	V (N = 4)	p
Spasticity*	22	0	14	1	1	6	0.023†	22	0	11	5	2	4	0.037†
Ankle joint muscles only	15	0	8	1	1	5		9	0	6	1	1	1	
Hip and/or knee joint muscles	7	0	6	0	0	1		13	0	5	4	1	3	
Generalized hypotonia	3	0	3	0	0	0		3	0	3	0	0	0	
Joint contractures*	14	0	6	5	0	3	0.336	21	0	8	7	2	4	0.151
Ankle ≥ 10° only	13	0	6	4	0	3		10	0	5	3	1	1	
Hip/knee ≥ 20°	1	0	0	1	0	0		11	0	3	4	1	3	
Hip dislocation*	8	0	1	7	0	0	<0.001†	10‡	0	2	7	0	1	0.001†
Pelvis/hip surgery, bony‡								7‡	0	2	5	0	0	0.010†
Spine surgery‡								6‡	0	2	0	0	4	0.009†

* Unilateral or bilateral.

† Indicates statistical significance with respect to distribution among the muscle function classes.

‡ During the entire follow-up period.

the children exhibited spasticity in the lower limb muscles at the 6-year follow-up.

Orthoses

Orthoses use for walking or standing was documented in 42 of 43 children during the entire follow-up period. Table 3 illustrates orthosis use in MFC I to MFC V at all follow-ups.

At the 6-year follow-up, 29 of 38 children had orthoses that were adequate in relation to motor paresis of the lower limbs according to the regular orthotic program. Of the children not using adequate orthoses, 5 children were in MFC II, 3 in MFC III, and 1 child in MFC IV.

At the 6-year follow-up, 5 children used their orthoses less than 2 hours and 1 child only during training session, 9 children 2 or more hours a day, and 23 children 5 or more hours a day (17 children in MFC II and 6 in MFC III; $p = 0.005$).

Expected Ambulatory Function

Ambulatory function was analyzed in 40 children during the entire follow-up period, of whom 31 had achieved expected ambulatory function in relation to their MFC. In 3 children, for whom the follow-up duration ended at 1.5, 1.8, and 2.4 years, respectively, expected ambulatory function was not evaluated.

TABLE 3
Orthosis Use in Muscle Function Classes I to V at All Follow-Up

	Orthoses									
Follow-Up	NO	Static	FO	AFO	KAFO-F	KAFO-L	HKAFO	SW	Stand	Total No.
6-Month (5/36)										
I	1									1
II	20	2								22
III	5	3								8
IV	1									1
V	4									4
1-Year (35/38)										
I	1									1
II	2	1		7	3		2		8	23
III					1		4		4	9
IV									1	1
V								1	3	4
1.5-Year (37/39)										
I	1									1
II	1	1		6	10		3		3	24
III					3		6			9
IV								1		1
V								2	2	4
2-Year (34/36)										
I	1									1
II	1		2	3	11		1	2	1	21
III					3		5			8
IV								1		1
V								4	1	5
3-Year (27/28)										
I	1									1
II		1	3	3	9					16
III					4		1			5
IV							1			1
V								4	1	5
4-Year (35/36)										
I	1									1
II			3	5	10		2		2	22
III					5		3			8
IV								1		1
V								3	1	4
6-Year (37/38)										
I	1									1
II			2	6	5	2	1			16
III				2	8		3	1	1	15
IV						1	1			2
V							1	1	2	4

NO indicates no orthosis, FO, foot orthosis (including supramalleolar orthosis); AFO, ankle-foot orthosis; KAFO-F, knee-ankle-foot orthosis with free-articulating knee joint; KAFO-L, knee-ankle-foot orthosis with locked knee joint; HKAFO, hip-knee-ankle-foot orthosis (including reciprocating gait orthosis); SW, swivel walker; Stand, thermoplastic standing orthosis; Static, static orthosis (ankle-foot orthosis or hip abduction splint).

Of the 9 children who had not achieved expected ambulatory function, 2 children were in MFC II, 3 in MFC III, 1 child was in MFC IV, and 3 children were in MFC V. In contrast to MFC IV, children in MFC V lack pelvic elevation to support limb advancement. In MFC V, therefore, both nonfunctional ambulation and standing function were accepted as representing achievement of expected ambulation.

In the children not having achieved expected ambulatory function at the 6-year follow-up, there was an increased incidence of spasticity during the entire follow-up period compared with those who achieved expected ambulatory function (9 of 9 versus 15 of 31; $p = 0.006$), spine surgery was performed more frequently (4 of 9 versus 2 of 31; $p = 0.016$) and increased use of inadequate orthoses (5 of 7 versus 4 of 31; $p = 0.004$) was observed.

Orthoses use 5 or more hours a day was seen significantly more frequently among the children who achieved expected ambulation compared with the children who did not achieve expected ambulation (22 of 30 versus 1 of 7; $p = 0.006$). There was no difference in time usage between those who used orthoses corresponding to the regular orthotic program and those who did not ($p = 0.136$).

Wheelchair Use at 6-Year Follow-Up

During the entire follow-up period, the use of a manual or powered wheelchair was documented in 42 children. At the 6-year follow-up, 31 of 38 children used a wheelchair of whom 11 of 16 in MFC II, 14 of 16 in MFC III, 2 of 2 in MFC IV, and 4 of 5 children in MFC V ($p = 0.063$). In 1 child, wheelchair use was unknown. Wheelchair use was more frequently seen in children who had spasticity compared with the children with no spasticity (20 versus 11, $p = 0.003$). There was no difference in wheelchair use with respect to achieved and nonachieved expected ambulation ($p = 0.175$).

Motor Function

Of 36 of 43 children, at the 6-month follow-up, 6 children laid in the supine position, 11 were able to turn to the prone position, and 12 moved in the prone position, ie, pivoted, crawled, flexed hips, or knelt. Seven children could not be assessed, which was due to a postsurgery situation in 6 and due to lack of motivation in 1.

Of 38 of 43 children, at the 6-year follow-up, 2 children sat up independently, 1 child maintained a sitting position after being seated, and 35 children walked independently with or without a walking aid, of whom 5 required human support.

The motor function at all follow-ups with respect to MFC I to V is illustrated in Table 4.

The child in MFC I moved in the prone position at the 6-month follow-up, pulled to standing at the 1-year follow-up, walked independently at the 1.5-year and at the 6-year follow-up. Among the children with MFC II, there was a large variation during the first year of life from staying in the supine position to pulling up to standing. At the 1-year and 1.5-year follow-up, pulling to standing was initiated. At the 2-year, 3-year, 4-year, and 6-year follow-ups, 10 of 21, 14 of 16, 17 of 22, and 14 of 16 children walked independently with or without a walking aid, respectively. In MFC III, the children showed a wide spectrum of motor performance until the 1.5-follow-up, at which point 8 of 9 children sat up independently or pulled up to standing. At the 2-year, 3-year, 4-year, and 6-year follow-ups, 2 of 8, 4 of 5, 8 of 8, and 12 of 15 children walked independently with or without a walking aid, respectively. The child in MFC IV turned to the prone position at the 6-month follow-up, moved in the prone position at 1-year follow-up, sat up independently at the 1.5-year follow-up, and walked at the 2-year follow-up, as well as at the 6-year follow-up. In MFC V, corresponding to thoracic motor level, there were only 7 children in total and only 4 or 5 at each follow-up. At the 2-year, 3-year, and 4-year follow-up, each child had achieved walking function, and at the 6-year follow-up, 2 children had achieved walking function. At the 6-year follow-up, 5 children, 2 of them MFC II and 3 MFC III, all of whom displayed spasticity or generalized muscle hypotonia and required human support for locomotion in an upright position.

DISCUSSION

The results of this study indicate that there is a large variation in motor development before ambulation during preschool years among children with similar muscle function. This is confirmed by other literature reporting that children with MMC must be evaluated individually, even within the same lesion level group.[5] Nevertheless, it became obvious that the more muscle function of the lower limb muscles, the earlier and more frequently the children achieved an upright position. Williams et al[3] reported age-related walking in children with spina bifida. According to their findings, 38 children with low-lumbar level, corresponding to MFC II in this study, walked at a mean age of 3 years 10 months, compared with our children of whom 1 of 23 walked at 1 year, 10 of 21 at 2 years, 14/16 at 3-years, 17/22 at 4 years, and 14/16 at 6 years. According to the same authors' findings, 9 children with mid-lumbar level, correspondingly to MFC III in this study, walked at a mean age of 5 years compared with our children of whom 2 of 8 walked at 2 years, 4 of 5 at 3 years, 8 of 8 at 4 years, and 12 of 15 at 6 years. This confirms that walking is delayed during development but occurs in most of the children. In this study, there was increased representation of spasticity among the children not having achieved expected ambulatory function compared with those with achieved ambulatory function. Because in the study of Williams et al,[3] children with spasticity were excluded when their lesion level could not be determined, further interpretations cannot be made.

There are no studies found that describe motor development before ambulation during preschool years in children with MMC, which might be due to the various probabilities of developing toward upright positions among children with varying degrees of muscle paresis. The criteria for assessing motor development, which were used in this study, reflect the current management philosophy of

TABLE 4
Motor Function in Muscle Function Classes I to V at All Follow-Up

Follow-up/Motor Function	N (%)	Muscle Function Classes I	II	III	IV	V
6-Month	36/43 (84)	1	22	8	1	4
Stays in supine position*	6	0	3	0	0	3
Turns prone from supine position	11	0	9	0	1	1
Moves in the prone position†	12	1	8	3	0	0
Postoperative/hip abduction splint	6	0	2	4	0	0
Noncooperative	1	0	0	1	0	0
1-Year	38/43 (88)	1	23	9	1	4
Stays in supine position*	4	0	1	2	0	1
Turns prone from supine position	8	0	5	1	1	1
Moves in the prone position†	11	0	8	1	0	2
Sits up independently	3	0	1	2	0	0
Maintains sitting position‡	2	0	1	1	0	0
Pulls to standing§	8	0	6	2	0	0
Walks independently‖	2	1	1	0	0	0
1.5-Year	39/43 (91)	1	24	9	1	4
Turns prone from supine position	1	0	1	0	0	0
Moves in the prone position†	8	0	4	1	1	2
Sits up independently	9	0	1	6	0	2
Maintains sitting position‡	1	0	1	0	0	0
Pulls to standing§	13	0	11	2	0	0
Walks with walking aid	2	0	2	0	0	0
Walks independently‖	5	1	4	0	0	0
2-Year	36/43 (84)	1	21	8	1	5
Turns prone from supine position	1	0	0	0	0	1
Moves in the prone position†	4	0	3	0	0	1
Sits up independently	8	0	3	2	1	2
Maintains sitting position‡	1	0	1	0	0	0
Pulls to standing§	7	0	3	4	0	0
Walks with walking aid	7	0	4	2	0	1
Walks independently‖	7	1	6	0	0	0
Postoperative/hip abduction splint	1	0	1	0	0	0
3-Year	28/43 (65)	1	16	5	1	5
Moves in the prone position†	2	0	0	0	0	2
Sits up independently	3	0	1	0	0	2
Pulls to standing§	2	0	1	1	0	0
Walks with walking aid	12	0	7	3	1	1
Walks independently‖	9	1	7	1	0	0
4-Year	36/43 (84)	1	22	8	1	4
Moves in the prone position†	2	0	1	0	0	1
Sits up independently	6	0	4	0	0	2
Walks with walking aid	15	0	7	6	1	1
Walks independently‖	13	1	10	2	0	0
6-Year	38/43 (88)	1	16	15	2	4
Sits up independently	2	0	0	1	0	1
Maintains sitting position‡	1	0	0	0	0	1
Walks with walking aid	13	0	2	8	1	2
Walks independently‖	17	1	12	4	0	0
Walks with human support¶	5	0	2	2	1	0

* Stays in supine position.
† Pivots, crawls, flexes hips, or kneeling.
‡ After being seated.
§ Mostly at furniture, may use orthoses.
‖ Walks without walking aid, may use orthoses.
¶ Requires human support to walk some steps, need of orthosis.

the orthopedic department and should not be regarded as an assessment of tasks in a progressive order. By documenting the motor skills, an overview of the children's motor development and a basis for assisting the child at various motor stages were obtained. The study also contributes to highlighting the importance of integrating physiotherapy and orthotic management beginning in early childhood to secure each child's potential for motor development.

Active orthotic management was provided with the goal of supporting each child's potential motor function during the entire follow-up period. For a child with a low-lumbar neurological level (MFC II), for example, who

initiated kneeling, standing in AFOs was introduced. A child with mid-lumbar level (MFC III) who sat up independently was offered a standing position with a KAFO or at the beginning with a HKAFO in a standing frame. Children with a mid-lumbar neurological lesion level, corresponding to MFC III with weak hip extensor and abductor muscles, can achieve independent ambulation with KAFOs with free knee joint, designed to vertically align the knee with the shank and foot in the frontal and transverse planes, particularly relevant in children with reduced hip abductor strength, but also when tibial torsion is present.[28] After a gait pattern has become stable, an AFO can be used. Children who require a walking aid to support body weight may also be fitted with an AFO. In recent years, a new orthosis has been introduced indicating improved gait function through use of a carbon fiber spring that is available both for KAFO and AFO models.[29]

Children with a thoracic level lesion were introduced to the standing position with a HKAFO or a total body thermoplastic orthosis after indicating interest in achieving the vertical position when in the prone position. In contrast to supporting the child's expected ambulatory potential by paralleling the milestones of child who is healthy by starting with the use of a sitting device, followed by the use of a standing frame,[30] the focus in this clinical management was to act preventively with respect to possible muscular imbalance by introducing a standing program relative to the risk of flexion contracture development[31] and at the same time being cautious about the child's motor autonomy, which has been described previously.[22]

The choice of orthoses could not be made according to the regular program in all children when there were neurologically related impairments such as contractures, spasticity, or generalized muscle hypotonia. This is in accordance with Tappit-Emas[5] who emphasized that appropriate selection of orthoses must consider the influence of the central nervous system dysfunction on the child's ability to move and the motor level of the lower extremities. Even if all children were provided with orthoses according to the same concept and from the same orthotic department, the outcome cannot be compared with other studies due to possible variations in orthotic management.

Children with different lesion levels will progress along an individual gross motor path, and the age when the child will begin to move will vary from child to child.[4]

Determining a child's maturation and when to begin gait training has been described as an intuitive matter,[20] and the timing of the decision to put a child in the vertical position must be chosen carefully. This is the reason for the assessment of the children's attempts to reach with the hand when in the prone position toward a vertical position. This action might be interpreted as an intention to be upright and was only documented for the children with thoracic lesions.

The presence of the local PTs at the follow-up, and their involvement in setting up the treatment plan, demonstrated that they were highly involved in the children's development during the follow-up time. For organizational reasons, however, the work of each PT could not be evaluated in detail.

Szalay[30] emphasized that the level of neurological involvement can and should be determined as soon after birth as possible so that the expected ambulatory potential of the child and prediction of deformities or complications might be anticipated. In this study, the assignment of each child to a MFC was determined by assessment of muscle strength. There is a subjective element in the grading of muscle power in newborns.[32] McDonald et al[33] recommended grading of muscle power in children unable to respond to instructions with assessments relying more on observation of spontaneous posture and movements with and without applied resistance, and palpation of muscle contraction. If enough care is taken during assessment, however, it is possible during the first year of life to recognize the child's spontaneous movements and postural responses upon being passively moved. In this study, the intention was to include all children who were seen in the clinic. Although determination of the motor level might be made more difficult due to spasticity,[3] it is important to include these children, in particular as the identification of spasticity is important for the child's future development.

At the 6-month and 2-year follow-up, motor development was also influenced by orthopedic treatment for the hip and the child's postoperative situation. Hip dislocation was most frequently seen in MFC III where there is a strong muscle imbalance between hip extensors and hip flexors, as well as the highest number of bone surgeries performed. Orthopedic surgery is likely to have consequences on motor development, and thus there is the need to include the role of orthopedic management in children's motor development in future studies.

According to Begeer et al,[10] clinical symptoms of progressive neurological deterioration appeared between the ages of 6 and 14 years. Swank and Dias[2] found that deteriorated quadriceps function was the result of a late development of tethered cord in all children. In this study, 5 children had deteriorated with respect to MFC between the first examination and the 6-year follow-up and 4 of whom had spasticity in the lower limb muscles. Also, among the children who had not achieved the expected ambulatory function at the 6-year follow-up, spasticity was noted to be increased. According to Williams et al,[3] the mean age at cessation of ambulation is between 7 and 9 years for children with low- and mid-lumbar lesions. A future follow-up study may give information about the permanence of walking function in this study group.

CONCLUSIONS

In children with MMC, motor development before ambulation during the preschool years varies among children with similar muscle function. Walking function starts from the first year of life and is seen increasingly more frequently until 6 years of age. In those children who did not achieve the expected function with respect to their motor level, spasticity was increased.

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