Motor function problem in pediatric TBI

Korea University Anam Hospital

Department of Physical Medicine and Rehabilitation

Bo Ryun Kim

Introduction

- Traumatic brain injury (TBI) is a leading cause of death and disability in the pediatric age group ("the silent epidemic")
- Incidence
  - The worldwide incidence of pediatric TBI ranges broadly and varies greatly by country, with most reporting a range between **12 and 489 per 100,000 children (overall rate: 235 per 100,000)**
  - Approximately 475,000 children under 14 years of age sustain a TBI yearly in US
  - More than 7,000 deaths, 60,000 hospitalizations, and 600,000 ED visits annually in US
  - After the age of 3, **male** children suffered higher rates of TBI than females
  - A bimodal age distribution : **very young children (0 ~ 5 years) and adolescents (15 ~ 20 years)** more commonly injured
  - Mild (GCS 13-15) - 70~80%, **moderate (GCS 9-12) - ~10%, severe (GCS 3-8) - ~10%**

Keenan HT et al 2006, Chen J et al 2018, Dewan MC et al 2016, Lucht ML et a

Introduction

- Age-related factors and risk
  - Mechanisms of injury vary widely by child developmental age
  - **Falls (39%)** > motor vehicle crashes (11%) > unknown causes (5%) > assault (4%)
  - **Infants: assault** > motor vehicle crashes, falls from parents' arms
  - **Toddlers : falls (stairs, furniture, playground equipment)** > motor vehicle crashes
  - **Young school-aged children : transportation-related injuries (motor vehicle, pedestrian, bike)** > falls
  - **Older school-aged children & adolescents : injuries due to automobile crashes** > unintentional sporting injuries,

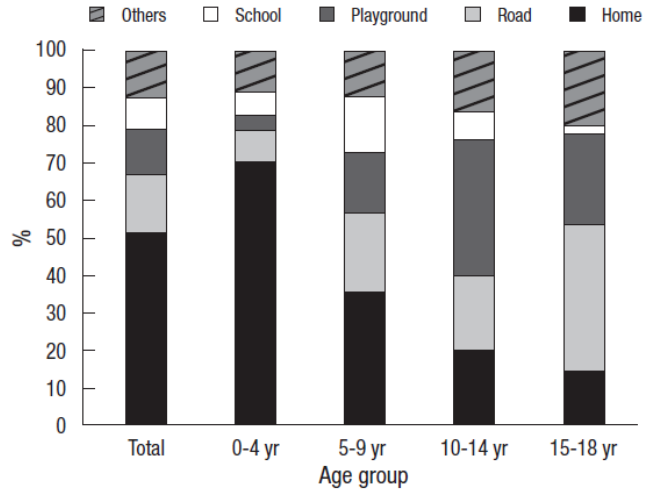


Fig. 3. Placement of head injury.

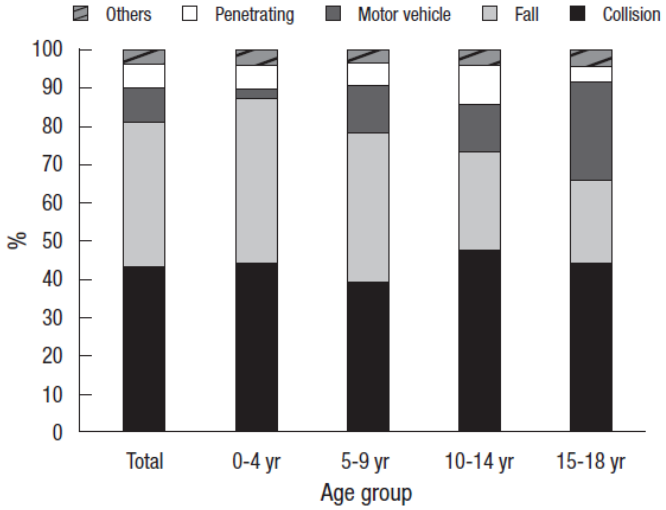


Fig. 4. Mechanism of head injury.

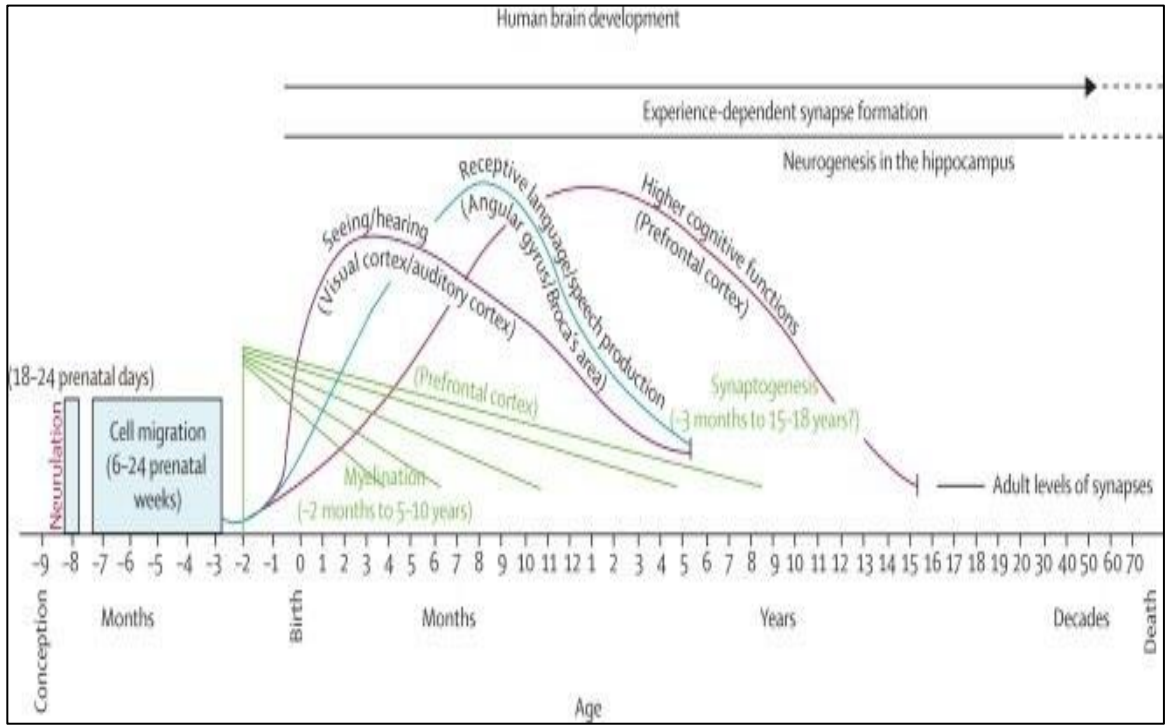
Keenan HT et al 2006, Dewan MC et al 2016, Kim HB et al

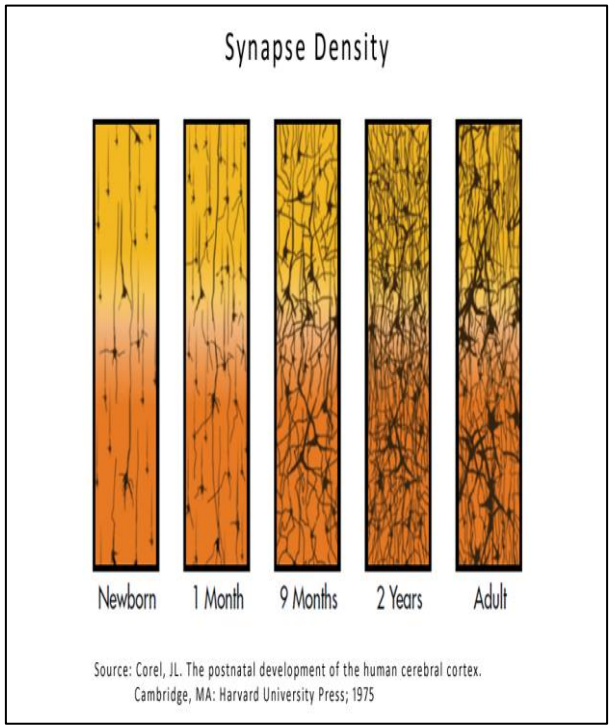
Pathophysiology

- Children have a relatively large head, weak neck musculature, higher brain water content, and lack of myelination
- Primary injury
  - Impact (contusion, usually focal gray matter injury), deceleration and rotational forces (shearing-type injury, usually diffuse white matter injury or at gray-white interfaces)
  - Forces could be more easily transmitted to deeper brain structures as a result of lack of myelination and higher brain water content
- Secondary injury
  - Complications or other events after the initial trauma
  - Hypotension, hypoxia, vasospasm, infarction, prolonged seizure activity, diffuse edema → resulting in increased intracranial pressure & decrease in cerebral perfusion pressure
- The amount of damage, rather than its location, is predictive of outcome in children of pre-school and school age

Alexander MA et al 2014, Keenan HT et al 2006, Ashton

Developing brain





- During the prolonged period from infancy to late adolescence, **brain maturation, in terms of synaptogenesis, synaptic pruning and myelination, takes place at different rates in different regions**
- **Immature (nonmyelinated) or rapidly maturing brain** regions are thought to be **more vulnerable** to the effects of brain injury, thus more at-risk of long-term impairment than those already established at the time of injury

→ The relatively high plasticity of the developing brain could actually have a negative impact on the overall outcome after diffuse TBI, especially at a very young age

Keenan HT et al 2006, Ashton R

Common motor deficits

- Although considerable attention has been given to the cognitive and behavioral consequences of the injury, **less attention has been paid to the ensuing motor deficits**
- A wide spectrum of motor deficits : variable nature of the injury + the combination of focal and diffuse damage
- Focal damage
  - Occur from a variety of causes, including gunshot wounds, other foreign-body penetrations
  - Motor deficits may vary according to brain injury loci
  - Unilateral penetrating or focal injury involving motor area→ hemiparesis
  - Long-term outcomes may be better in focal injuries versus diffuse injuries

Alexander MA et al 2014, Kuhtz-Buschbeck JP et al 2003, Rossi C et al 1996, Abdul Rahman RA

Common motor deficits

- Diffuse damage
  - A constellation of motor impairments → difficulties with balance, coordination, and speed of response
  - Despite these impairments, a significant number of children achieve functional mobility
  - Boyer and Edwards et al reported that 79% had independent mobility (46% independent walker w/o assistive device, 27% walker with orthosis or assistive device)
  - However, disrupted balance performance and walking ability may persist after TBI in the majority of children
- Tremor
  - Mostly occur after damage to the cerebellum or its pathways
  - More pronounced proximally, increase with effort and movement

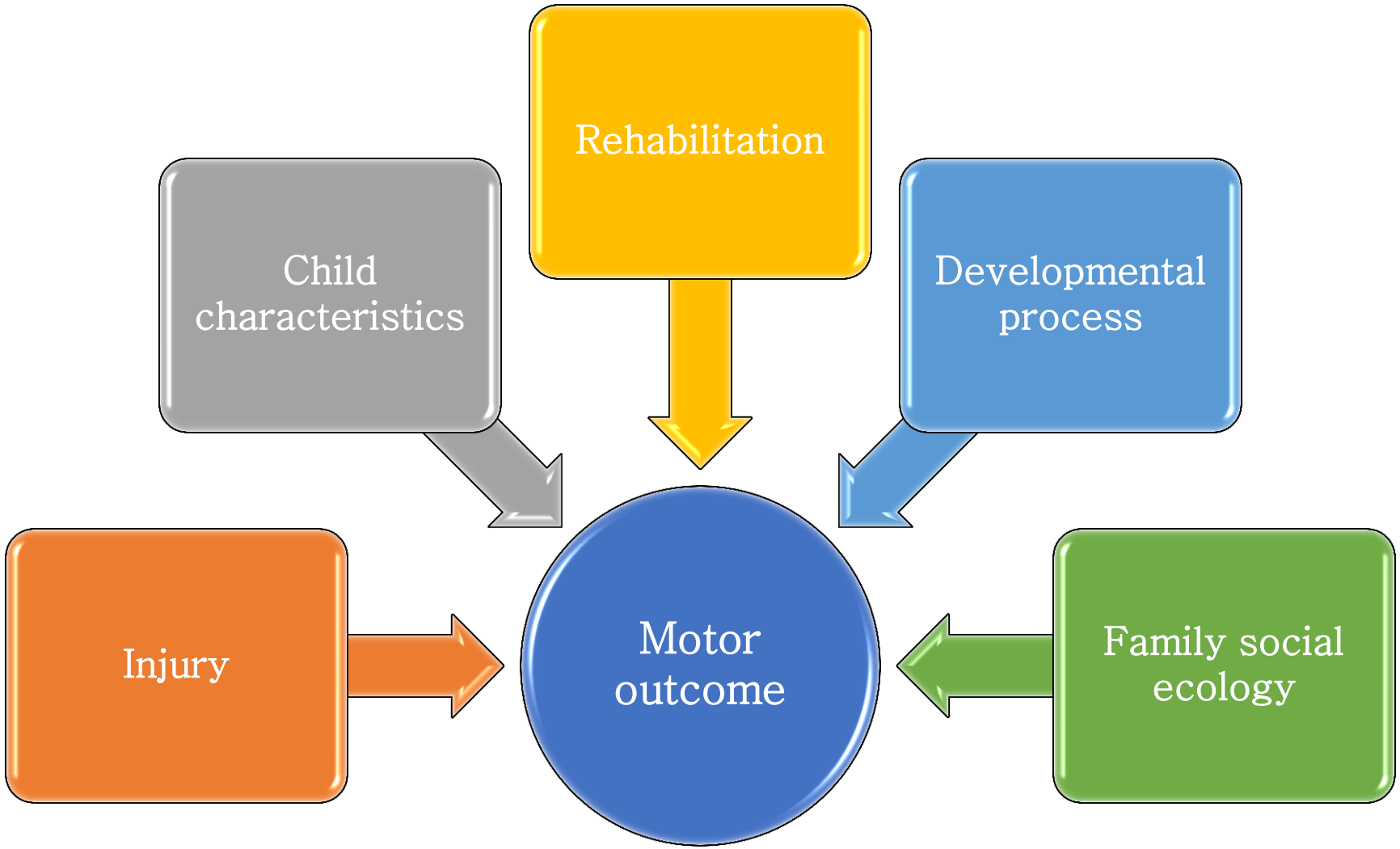
Alexander MA et al 2014, Kuhtz-Buschbeck JP et al 2003, Rossi C et al 1996, Abdul Rahman RA

Common motor deficits

- Tone abnormalities
  - Muscle tone abnormalities, including spasticity(m/c), dystonia, rigidity, is common
  - Vary depending on the time since injury, the severity of injury, the cause of injury
  - Spasticity (38%), combined spasticity and ataxia (39%) of children and adolescents 1 year after injury
  - Rigidity or dystonia : especially common in secondary injury to hypoxia or ischemia
  - Lead to long-term impairments of motor proficiency
- **Persisting impairments of upper-limb function and visuomotor control** in children after severe TBI have been noted

Alexander MA et al 2014, Kuhtz-Buschbeck JP et al 2003, Rossi C et al 1996, Abdul Rahman RA

Motor outcome



Motor outcome in very young children

TABLE 2. INJURY INFORMATION BY INJURY SEVERITY AND TYPE

Injury severity/type	*Mild TBI (N=48)* n %	*Complicated mild TBI (N=45)* n %	*Moderate TBI (N=9)* n %	*Severe TBI (N=21)* n %	*All TBI (N=123)* n %	*Orthopedic injury (N=45)* n %
Admission type						
ED/OBS only	34 (71)	7 (16)	1 (11)	0 (0)	42 (34)	31 (69)
Hospital, not PICU	13 (27)	23 (51)	0 (0)	0 (0)	36 (29)	14 (31)
PICU	1 (2)	15 (33)	8 (89)	21 (100)	45 (37)	0 (0)
Transport mode						
Ambulance	25 (52)	24 (53)	5 (56)	0 (0)	54 (44)	18 (40)
Air transport	6 (12)	11 (24)	4 (44)	21 (100)	42 (34)	0 (0)
Private vehicle	17 (35)	10 (22)	0 (0)	0 (0)	27 (22)	27 (60)
Injury mechanism						
Assault/child abuse	2 (4)	5 (11)	3 (33)	11 (52)	21 (17)	1 (2)
Fall	40 (83)	38 (84)	4 (44)	3 (14)	85 (69)	39 (87)
Motorized vehicle	3 (6)	1 (2)	0 (0)	4 (19)	8 (7)	0 (0)
Pedestrian/bicycle	0 (0)	0 (0)	2 (22)	1 (5)	3 (2)	2 (4)
Struck by or against	2 (4)	0 (0)	0 (0)	0 (0)	2 (2)	2 (4)
Other	1 (2)	1 (2)	0 (0)	2 (10)	4 (3)	1 (2)
Which extremity was fractured?						
Arm	—	—	—	—	—	22 (49)
Leg	—	—	—	—	—	22 (49)
Both	—	—	—	—	—	1 (2)
Head imaging in ED	46 (96)	45 (100)	9 (100)	21 (100)	121 (98)	—

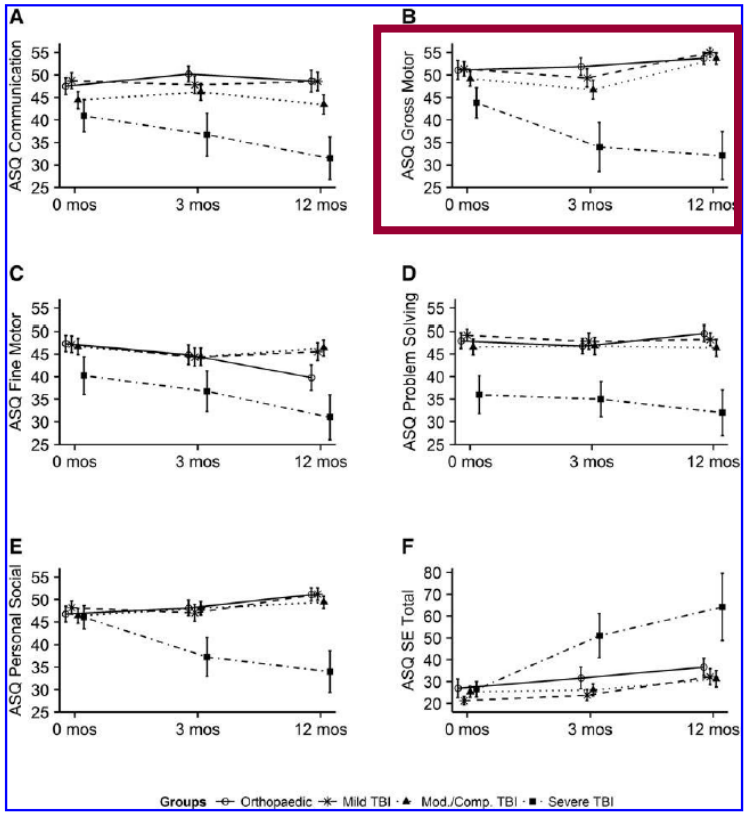


FIG. 2. Raw mean scores of ASQ:3 domains and ASQ:SE by injury severity over time with standard errors. ASQ-3, Ages & Stages-3; ASQ:SE, Ages & Stages: Social-Emotional.

- Prospective cohort study of 123 children injured before 31 months old with TBI vs 45 orthopaedic injury (OI, control)
- Mild (n = 48), complicated-mild or moderate (n = 54), and severe (n = 21) TBI groups
- Children with mild or complicated-mild/moderate TBI generally remained on developmental track
- Compared to OI, children with severe TBI tended to have a negative developmental trajectory with decrements in gross motor (-15.2; 95% CI, -21.1, -9.19) domains 12 months post-injury

Keenan HT et al 2019

Motor outcome in children

Table 1. Clinical and demographic characteristics of the total sample and the two groups divided by traumatic/nontraumatic aetiology. Description includes the symptoms associated with the primary motor disorder and the need of neurosurgery in acute.

	TOTAL SAMPLE (n = 496)		TRAUMATIC (n = 236)		NONTRAUMATIC (n = 260)	
	MEAN	SD	MEAN	SD	MEAN	SD
AGE AT EVENT (months)	90.7	62.0	105.7	63.8	77.2	57.1
DAYS OF COMA*	33.0	43.4	36.5	47.5	29.6	38.9
	MEDIAN	MODE	MEDIAN	MODE	MEDIAN	MODE
GCS SCORE at event	6	3	5	3	6	3
GOS SCORE at admission	3	3	3	3	3	3
GOS SCORE at discharge	3	3	4	3	3	3
DRS at admission	19	24	20	22	19	24
DRS at follow-up	6	5	5	1	8	4
	N	%	*N*	%	*N*	%
GENDER						
Male	315	63.5	165	69.9	150	57.7
Female	181	36.5	71	30.1	110	42.3
CRANIAL FRACTURE at event	105	21.2	104	44.1	0	0.0
NEUROSURGERY in acute	232	46.8	129	54.7	103	39.6
MOTOR IMPAIRMENT at admission						
Quadriparesis	261	52.6	115	48.7	146	56.2
Hemiparesis (right; left)	67; 68	13.5; 13.7	32; 37	13.6; 15.7	35; 31	13.5; 11.9
Paraparesis	6	1.2	2	0.8	4	1.5
Ataxia	39	7.9	18	7.6	21	8.1
Minimal Dysfunction	30	6.1	18	7.6	12	4.6
None	25	5.0	14	6.0	11	4.2

*Patients who remained in unresponsive wakefulness syndrome (i.e., persistent vegetative state) are omitted.

- Retrospective data from 496 patients (aged 0–18 years) with severe ABI admitted for rehabilitation during a 5 year follow-up
- Admitted for rehabilitation 59 days after the ABI event on average

Beretta E et al 2018

Motor outcome in children

Table 2. Recovery of gait and balance, and secondary motor and bone evidences in the total sample and in the traumatic/nontraumatic groups.

	TOTAL SAMPLE (n = 496)		TRAUMATIC (n = 236)		NON TRAUMATIC (n = 260)	
	MEAN	%	MEAN	%	MEAN	%
RECOVERED GAIT	349	70.4	184	78.0	165	63.5
	MEAN	SD	MEAN	SD	MEAN	SD
TIME FROM EVENT TO RECOVERY OF GAIT (months)	7.6	12.7	7.7	12.6	7.4	13.0
	N	%	*N*	%	*N*	%
BALANCE IMPAIRMENT	260	52.4	130	55.1	130	50.0
DYSTONIA	123	24.8	49	20.8	74	28.5
SECONDARY MOVEMENT DISORDERS (athetosis, myoclonus, tremor or chorea)	70	14.1	23	9.7	47	18.1
FRACTURES	38	7.7	33	14.0	5	1.9
PARAOSTEOARTHROPATHY	18	3.6	11	4.7	7	2.7
SCOLIOSIS	174	35.1	79	33.5	93	35.8
HIP DISLOCATION	35	7.1	9	3.8	26	10.0

Beretta E et al 2018

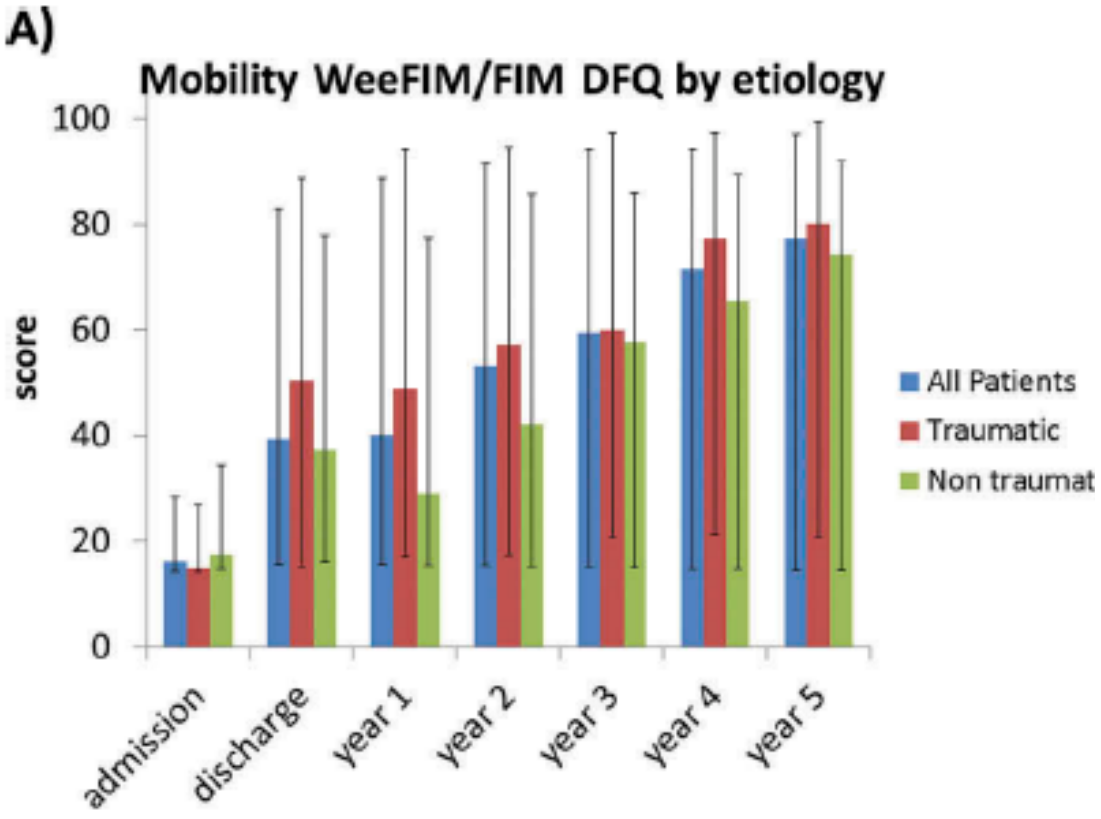
Motor outcome in children

Table 3. Incidence of spasticity, related treatments and surgery in the total sample and in the traumatic/nontraumatic groups.

	TOTAL SAMPLE (n = 496)		TRAUMATIC (n = 236)		NON TRAUMATIC (n = 260)	
	N	%	*N*	%	*N*	%
PRESENCE OF SPASTICITY	372	75.0	176	74.6	196	75.4
	TOTAL SAMPLE with spasticity (*n* = 372)		TRAUMATIC with spasticity (*n* = 176)		NON TRAUMATIC with spasticity (*n* = 196)	
	N	%	*N*	%	*N*	%
SEVERITY of spasticity						
Mild	175	47.0	89	50.6	86	43.9
Moderate	154	41.4	66	37.5	88	44.9
Severe	43	11.6	21	11.9	22	11.2
PRESENTATION of spasticity						
Localized	172	46.2	84	47.7	88	44.9
Generalized	200	53.8	92	52.3	108	55.1
Need of SURGERY	43	11.6	29	16.5	14	7.1
PHARMACOLOGICAL TREATMENT						
Multiple treatment	131	35.2	66	37.5	65	33.2
Botulinum toxin (only)	71	19.1	27	15.3	44	22.4
Baclofen (only)	21	5.7	9	5.1	12	6.1
Triesiphenidil chlorhydrate (only)	5	1.3	0	0.0	5	2.6
None	144	38.7	74	42.1	70	35.7
BACLOFEN PUMP	16	4.3	12	6.8	4	2.0
	MEAN	SD	MEAN	SD	MEAN	SD
Time from event to pump implantation (months)	13.2	12.7	9.5	7.8	24.3	19.1

Beretta E et al 2018

Motor outcome in children



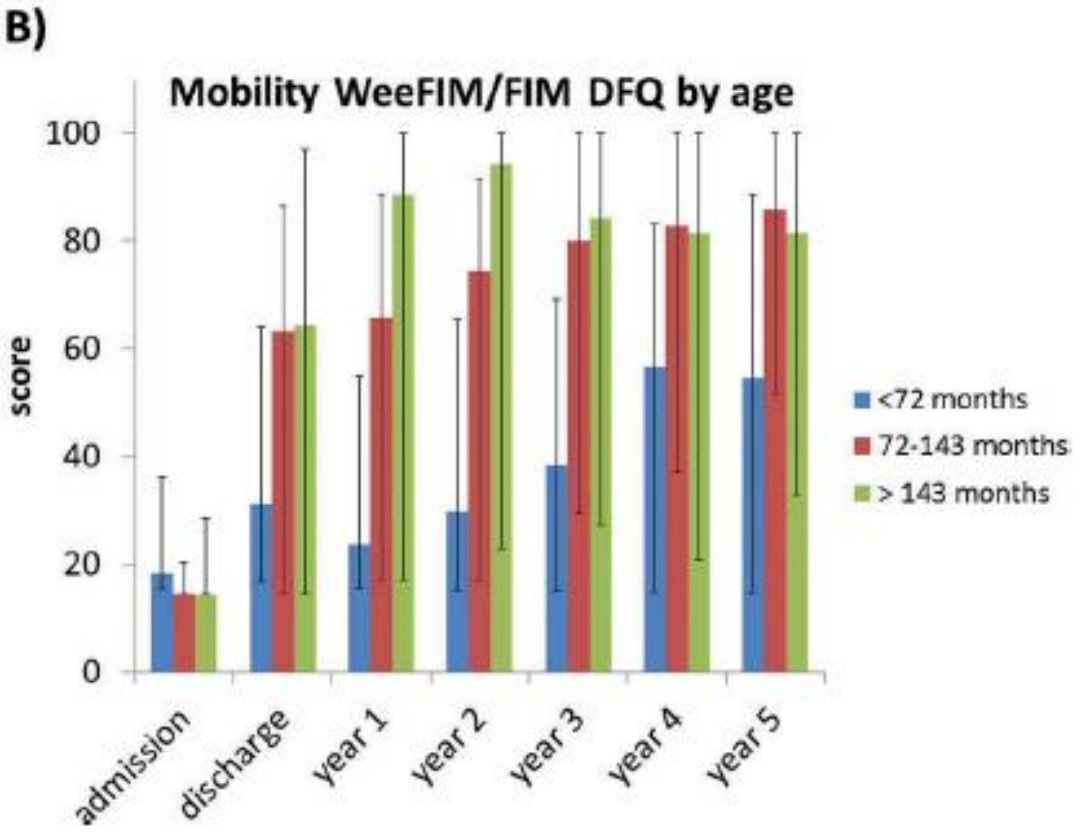


Figure 3. Time evolution of DFQ in the mobility FIM/WeeFIM domain, with respect to etiology (a) and age (b). Medians, 25% and 75% percentiles are depicted.

Beretta E et al 2018

Gait outcome

Table II. Mean (standard deviation) and ranges of clinical measures for group with TBI (hemiplegic patients after Traumatic Brain Injury) in the two sessions (S0 and S1 session) and the percentage of improved patients. GOS is the Glasgow Outcome Scale, WeeFIM is the Functional Independence Measure for Children, WeeFIMmot is the item of motor behaviour of WeeFIM, DRS is the Disability Rating Scale, GMFM is the Gross Motor Function Measure and GMFM section E is the section E of the GMFM (walking, running and jumping).

	S0		S1		
	Mean (st. dev.)	Range	Mean (st. dev.)	Range	% of improvements
GOS, 1-8	3.4 (0.6)	3–5	5.5 (1.0)*	4–7 *	100%
WeeFIM, 18-126	42.6 (17.5)	31–81	85.5 (20.2)*	55–119 *	86%
WeeFIMmot, 5-35	9.7 (6.8)	10–29	25.8 (8.0)*	22–35 *	86%
DRS, 0-29	11.6 (4.8)	5–18	6.3 (4.2)*	2–16 *	79%
GMFM, 1-100	81.9 (11.0)	65–90	91.5 (8.5)*	80–100 *	79%
GMFM section E, 1-100	66.7 (18.5)	42–89	83.3 (16.5)*	58–100 *	79%

* = p-value < 0.05, compared between S0 and S1 session.

- Fourteen children with hemiplegia after severe TBI ((range: 4–12 years) were evaluated at independent gait recovery (S0; range: 0.7–2.8 months) and 5.5 months later (S1) by clinical assessment (GOS, DRS, WeeFIM and GMFM) and 3D GA (spatio-temporal parameters, kinematics and kinetics)

Beretta E et al 2009

Gait outcome

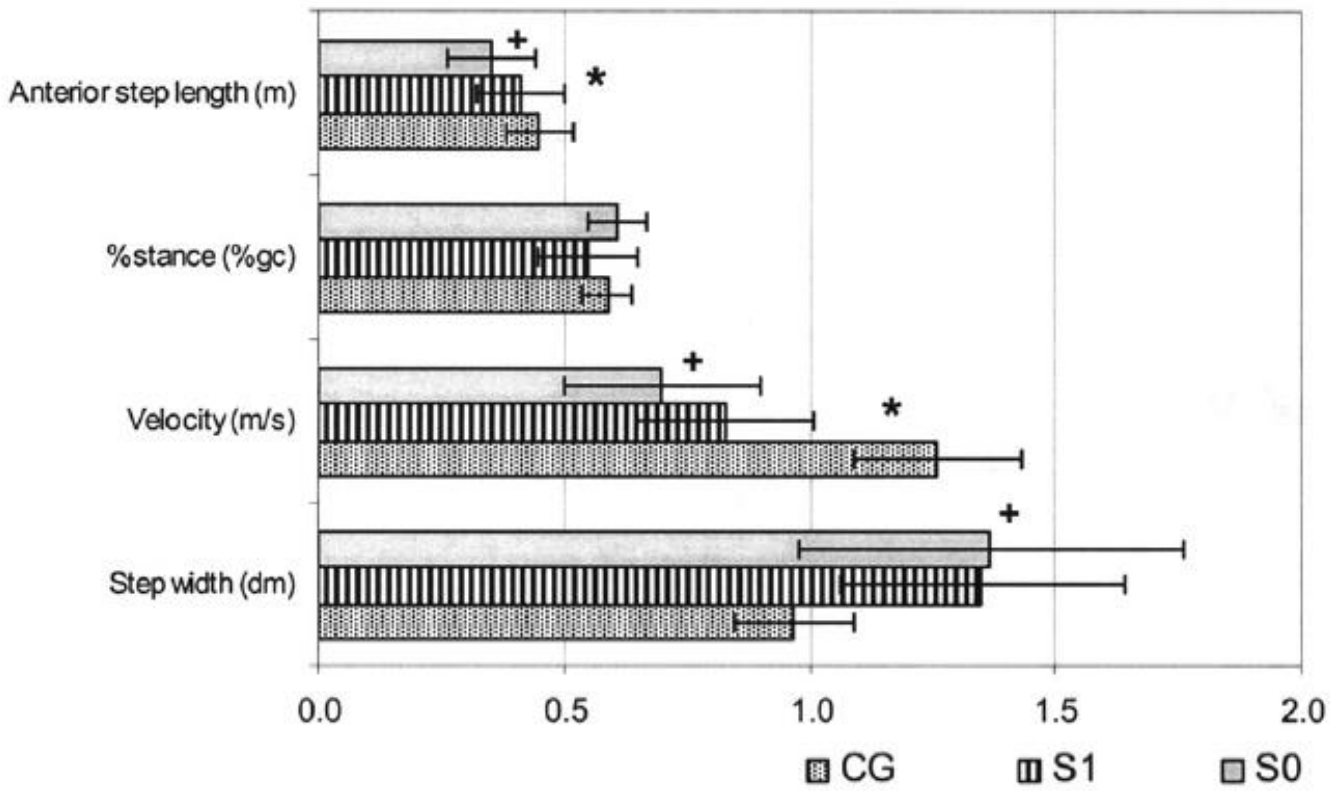


Figure 1. Mean values (standard deviation) of spatio-temporal parameters for pathological group in the two sessions (S0 and S1) and for CG were reported. (S0: first session, 1.4 months after injury; S1: second session, 5.5 months later; CG: Control Group; %gc: % of gait cycle) $^{\star} = p\text{-value} < 0.05$, compared between S0 and S1 session; $^{+} = p\text{-value} < 0.05$, compared with healthy subjects.

- Patients with TBI at first evaluation (S0) were characterized by normal duration of stance phase, shorter anterior step length, lower velocity of progression, wider step width and reduced cadence
- At S1 evaluation, velocity and step length improved

Beretta E et al 2009

Gait outcome

Table III. Mean (standard deviation) values of GA kinematic parameters for group with TBI (hemiplegic patients after to Traumatic Brain Injury) in the two sessions (S0 and S1 session) and for healthy subjects (Control Group).

	S0	S1	CG
Pelvis (°)			
ROM Pelvic Tilt	9.36 (5.04)$^{+}$	8.05 (4.42)$^{+}$	2.45 (1.67)
ROM Pelvic Obliquity	7.12 (2.95)	7.55 (2.90)	8.67 (1.23)
ROM Pelvic Rotation	14.14 (4.60)	13.36 (5.66)	12.32 (2.12)
Hip (°)			
HIC (Hip all'IC)	30.89 (8.47)$^{+}$	32.76 (8.09)$^{+}$	38.48 (7.12)
HmSt (Hip minimum in St)	−6.69 (9.15)	−5.17 (6.42)	−7.16 (5.24)
Mean Hip Rotation	8.37 (12.70)$^{+}$	14.57 (8.76)$^{\star+}$	−1.13 (4.44)
Knee (°)			
KIC (Knee all'IC)	10.56 (5.75)	11.02 (9.45)	7.59 (2.12)
KmSt (Knee minimum in St)	−4.51 (10.48)	−2.23 (9.87)	4.98 (2.58)
KMSw (Knee Maximum in Sw)	49.40 (8.78)$^{+}$	50.28 (6.54)$^{+}$	62.12 (7.68)
Ankle and Foot (°)			
AIC (Ankle all'IC)	−10.76 (6.51)$^{+}$	−3.27 (6.64)*	1.39 (4.87)
AMSt (Ankle Maximum in St)	8.54 (5.58)$^{+}$	13.12 (7.35)*	13.83 (5.12)
AmSt (Ankle minimum in St)	−13.77 (9.94)	−11.11 (8.57	−12.20 (4.19)
AMSw (Ankle Maximum in Sw)	−1.42 (7.51)$^{+}$	−0.75 (7.09)$^{+}$	5.69 (6.19)

* = p-value < 0.05, compared between S0 and S1 session.
$^{+}$ = p-value < 0.05, compared with healthy subjects.

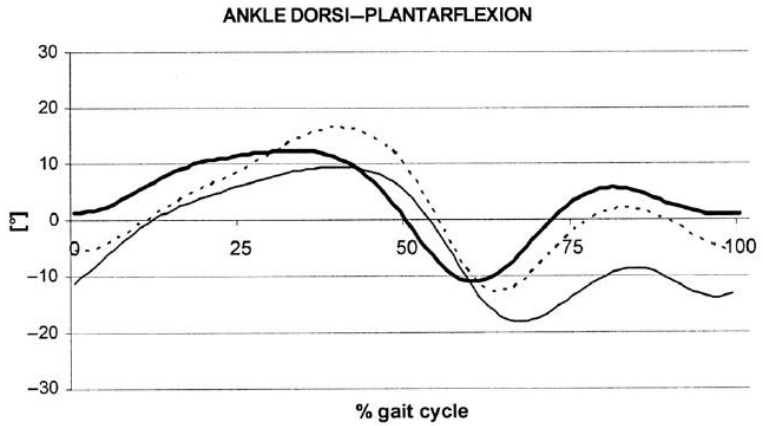


Figure 2. Ankle plantar-dorsiflexion angle plot of a trial of one patient in S0 (solid line) and in S1 session (dashed-line) and normative range of CG (thick lines) are reported (S0: first session, 1.4 months after injury; S1: second session, 5.5 months later; CG: Control Group; %gc: % of gait cycle).

Table IV. Mean (standard deviation) values of GA kinetic parameters for group with TBI (hemiplegic patients after Traumatic Brain Injury) in the two sessions (S0 and S1 session) and for healthy subjects (Control Group) (St: Stance phase; Sw: Swing phase).

	S0	S1	CG
Ankle Power (W/kg)			
APmin (Ankle Power minimum)	−0.60 (0.26)	−0.61 (0.46)	−0.49 (0.26)
APMax (Ankle Power Maximum)	1.13 (0.86)$^{+}$	2.21 (1.24)$^{\star+}$	3.71 (2.19)

* = p-value < 0.05, compared between S0 and S1 session.
$^{+}$ = p-value < 0.05, compared with healthy subjects.

- In S1, an unchanged condition appeared at pelvis and hip in sagittal plane with a worsening of hip rotation which increased its internal rotation in respect of S0
- In S0, the patients generally exhibited excessive plantarflexion at initial contact and reduced ability in dorsiflexion during stance and swing phase,
- In S1, a significant improvement in the ankle position at initial contact and in terms of ability in dorsiflexion in the stance & swing phases
- In S1, the maximum of generated ankle power improved significantly, exhibiting better propulsion ability at the end of the stance phase

Beretta E et al 2009

Gross & fine motor outcome

Table I: Clinical scales and GMFM score in children after TBI[a]

Clinical Measures	*E0 examination Median (25–75 cent.)*	*E5 examination Median (25–75 cent.)*
Age at examination, years:mo	9:6 (7:4–13:3)	9:11 (7:9–13:8)
Time since injury, mo	2.8 (1.8–4.6)	7.8 (6.8–9.6)
Barthel-Index , 0–100 points	72.5 (47.5–91.2)	100 (84–100)[b]
Rappaport Disability Rating Scale, 0–29	4.5 (3–8)	2 (1–4)[b]
Glasgow Outcome Score, 1–5	4 (3–4)	4.5 (4–5)[b]
Gross Motor Function Measure, 1–100	93 (87–98)	99 (96–100)[b]

[a]Data of 20 children with brain injuries with complete follow-up periods (E0–E5); [b]$p<0.01$, significant improvements from E0 to E5 (Wilcoxon's test). E0, first examination; E5, examination 5 months later. GMFM, Gross Motor Function Measure; TBI, traumatic brain injury; cent, centile.

- Twenty-three children (range: 4–15 years) with moderate to severe TBI over five months of inpatient rehabilitation
- Brain injury had been severe (initial Glasgow Coma Scale GCS<8) in 17 children and moderate (GCS 8–10) in 6 children
- In most cases the muscle power was reduced, but active movements against gravity and slight resistance were possible
- General muscle tone was increased in three and decreased in four children
- Coordination deficits, reduced movement quality (e.g.

Kuhtz-Buschbeck JP et al 2003

Gross & fine motor outcome

Table II: Gait variables of children with brain injuries and control participants

Variables	*Children with TBI*[a]		*Control children*	
	E0 examination Median (25–75 cent.)	*E5 examination Median (25–75 cent.)*	*E0 examination Median (25–75 cent.)*	*E5 examination Median (25–75 cent.)*
Gait velocity, km/h	3.78[d] (2.58–4.2)	4.48[c] (4.03–4.93)[f]	4.91 (4.14–5.37)	4.82 (4.66–5.37)
Cadence, steps/min	102.8[d] (86.7–111.2)	113.9 (106.7–119.1)[f]	118.5 (114.6–122.1)	120.6 (113.4–125.7)
Stride length, cm	109.2[d] (84.3–126.3)	126.4[d] (113.6–144.5)[f]	130 (119.8–151.8)	137.2 (130.7–157.3)
Stride length variability, cm[b]	8.0[d] (6.1–10.4)	5.7 (4.6–7.7)[e]	4 (3.5–5.4)	4.4 (3.5–5.7)
Stride length/leg length, cm/cm	1.47[d] (1.23–1.6)	1.7 (1.63–1.76)[f]	1.78 (1.64–1.84)	1.75 (1.69–1.89)
Asymmetry index, cm/cm	0.048[c] (0.02–0.121)	0.035 (0.028–0.083)	0.014 (0.004–0.024)	0.024 (0.01–0.038)
Asymm. index variability, cm/cm[b]	0.061[d] (0.042–0.162)	0.04 (0.032–0.069)[f]	0.038 (0.025–0.048)	0.03 (0.026–0.038)
Step width, cm	10.2[c] (9.1–13.4)	9.7 (7–10.8)	8 (6.4–9.1)	8.1 (6.8–10.2)
Step width variability, cm[b]	4[c] (3.5–4.4)	3.8[c] (3.2–5.1)	3.3 (2.6–3.5)	2.9 (2.6–3.8)
Foot rotation angle, °	4.4 (0.8–10.1)	7.6 (3.1–8.3)	4.3 (1.8–7.7)	5.2 (2.8–7)

[a]Patients and controls with complete follow-up gait analysis data ($n=15$ per group). Median age at E0 was 9 years 7 months.
[b]Intra-individual variability of all steps ($n=25–35$) recorded per child.
[c]$p<0.05$, [d]$p<0.01$, significant differences between children with TBI and controls (Wilcoxon's test).
[e]$p<0.05$, [f]$p<0.01$, significant differences between first examination (E0) and examination five months later (E5; Wilcoxon's test). Cent, centile.

- Compared with healthy control children of the same age and sex, repeated gait analyses in ambulatory children with brain injury showed significant reductions of velocity, stride length, and impaired balance

Kuhtz-Buschbeck JP et al 200

Gross & fine motor outcome

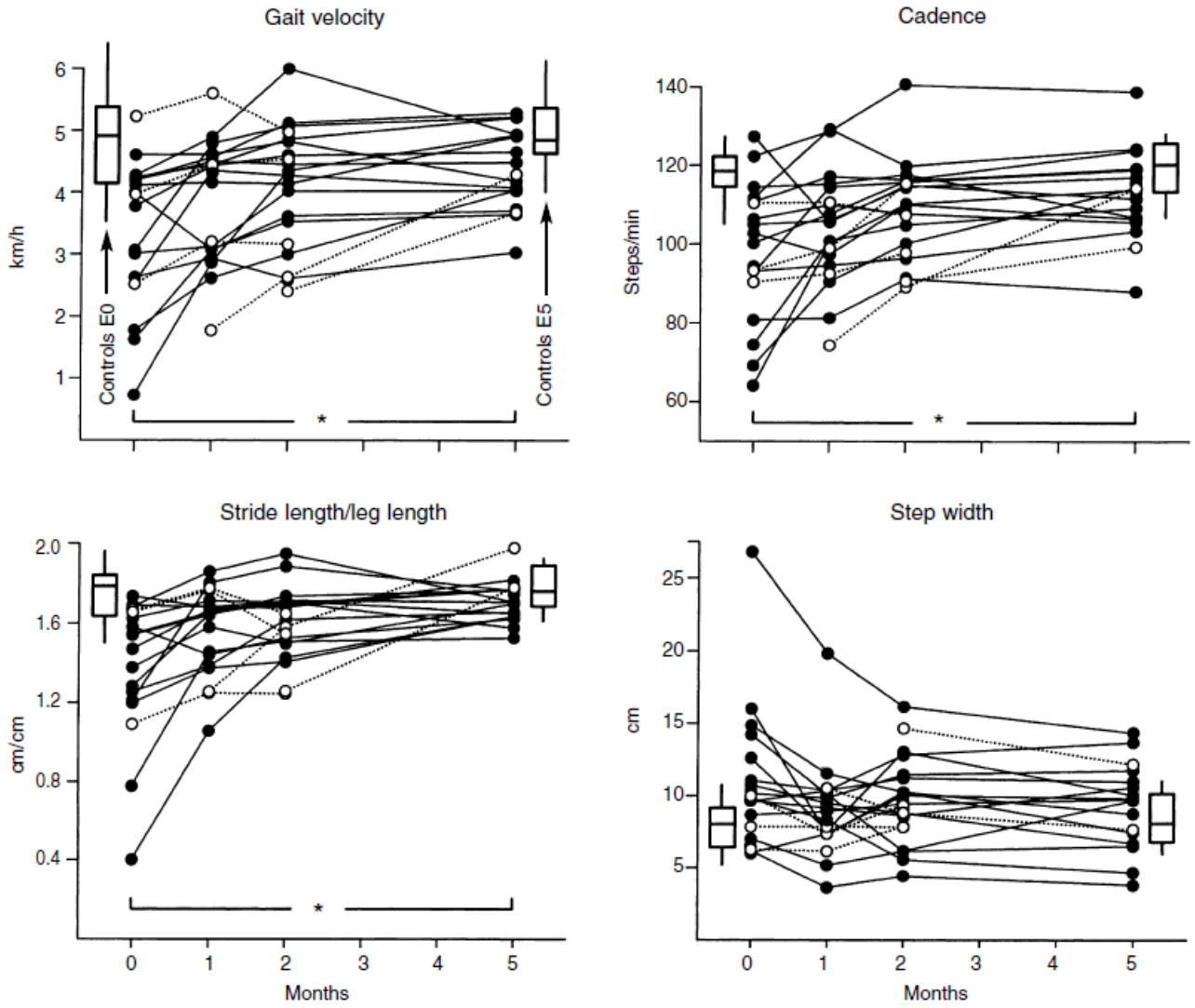


Figure 1: *Recovery of gait. Black circles show individual data (each based on 25–35 steps) of 15 children with brain injuries with complete follow-up intervals. *Significant improvements from E0 to E5 (Wilcoxon's test, $p<0.01$). Open circles with dotted lines show results of five patients with incomplete data series. Box-whisker plots indicate data of 15 matched control children, who were examined at E0 and E5. Medians, quartiles, and 10th to 90th centiles are shown.*

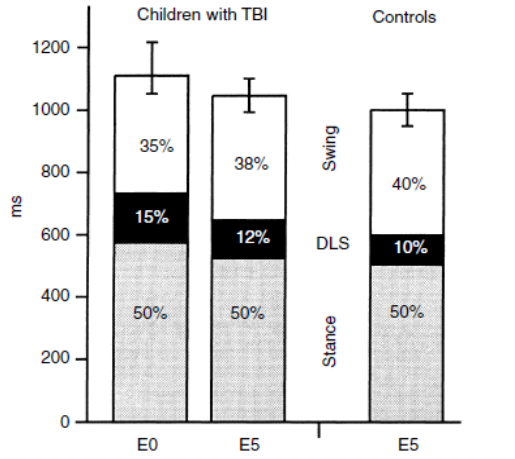


Figure 2: *Temporal gait variables. Step cycle time (bars) consists of swing (white) and stance phase (grey, black). During double limb support (DLS; black), both feet contact the ground. Intervals are given in milliseconds (y-axis) and in percent of step cycle duration. 1st and 2nd bar: medians and quartiles (whiskers) of 15 children with TBI at start (E0) and end (E5) of follow-up. 3rd bar: control children (data remained stable over time).*

- Velocity, stride length, and cadence improved significantly, whereas the decrease of the step width was non-significant
- Most changes took place during the first two months of follow-up
- The step cycle duration was longer in children with brain injuries than in controls ($p<0.05$), with a lengthened absolute and relative (percent of step cycle)

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Gross & fine motor outcome

Table III: Hand function tests of children with brain injuries and controls

Tests	*Children with TBI*[a]		*Control children*	
	E0 examination Median (25–75 cent.)	*E5 examination Median (25–75 cent.)*	*E0 examination Median (25–75 cent.)*	*E5 examination Median (25–75 cent.)*
DHFT, time in seconds				
Dominant hand	51.2[b] (42.9–77.4)	42.6[b] (36.6–53.3)[d]	31.2 (26.7–37.4)	29.5 (26.3–33.8)[c]
Non-dominant hand	61.9[b] (41.4–96.9)	43.7[b] (37.5–65.7)[d]	34.6 (30.5–39.4)	30.4 (25.8–38)[d]
Pegboard test, number of pegs				
Dominant hand	8.7[b] (5.7–9.8)	10[b] (7.7–12.8)[d]	13.8 (12.5–16.4)	15.8 (14.3–16.8)[d]
Non-dominant hand	6.7[b] (3.7–10.3)	10.1[b] (6.7–12)[d]	12.7 (11.3–14)	13.7 (13.3–16)[d]

[a]Patients and matched controls with complete follow-up data of hand function tests (dominant hand, $n=20$; non-dominant hand, $n=17$). Median age at E0 was 9 years 6 months.
[b]$p<0.01$, significant differences between children with TBI and controls (Wilcoxon's test).
[c]$p<0.05$, [d]$p<0.01$, significant differences between first (E0) and last (E5) examination (Wilcoxon's test). DHFT, Developmental Hand Function Test.

- Children with brain injuries inserted less pegs in the Purdue Pegboard test and needed more time to complete the Developmental Hand Function Test than the matched controls

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Gross & fine motor outcome

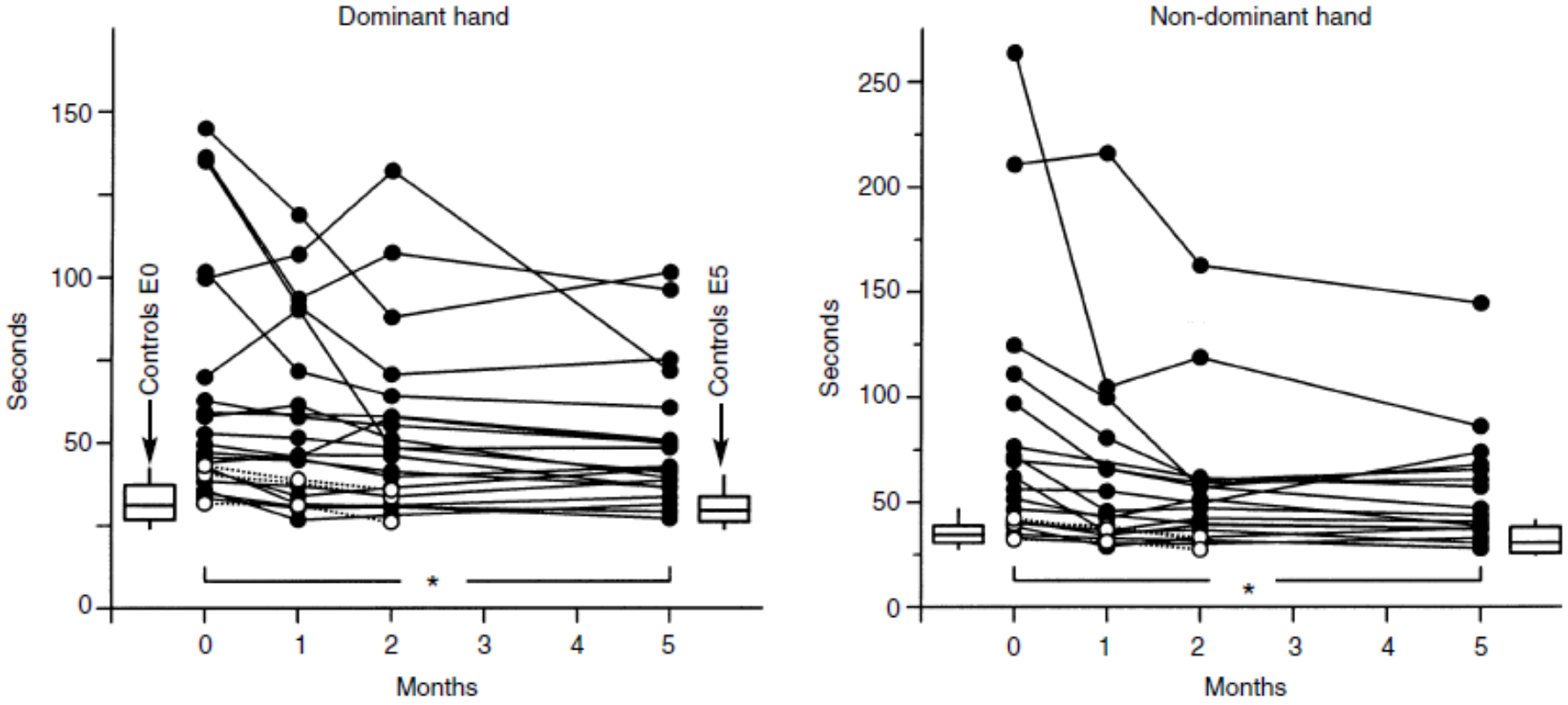

Figure 3: *Developmental Hand Function Test. Individual results of children with brain injuries with complete follow-up periods (black circles). Dominant hand (n=20 patients) and non-dominant hand (n=17). *Significant improvements (Wilcoxon's test, p<0.01). Open circles with dotted lines show data of three patients who missed last examination. Box-whisker plots indicate results of matched control children. Otherwise, as in Fig. 1.*

- Despite significant recovery, considerable deficits in fine motor performance persisted at the end of the follow-up period

→ Despite significant improvements, differences in gait velocity, stride length, and hand function of children with brain injuries and controls were still present about 8 months after TBI.

→ Hand motor skills improved less than gait

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Gait & fine motor outcome

Table 2: Gait Analysis in TBI Children and Control Subjects

Variable	Children After TBI			Control Group			Group Difference: *P* Value*
	Mean ± SD	Median	Range	Mean ± SD	Median	Range	
Gait velocity (km/h)	3.6±1.0	3.7	1.8–5.6	4.5±0.6	4.5	3.6–5.7	.002
Cadence (steps/min)	105.6±16.2	112.1	64.3–123.6	113.4±10.3	113.7	87.2–128.0	NS (.12)
Stride length (cm)	112.3±22.1	110.9	76.9–155.5	129.4±19.5	128.3	98.3–165.9	.016
Step length (cm)	56.1±10.9	55.5	38.5–77.7	65.1±9.2	64.2	50.3–82.7	.008
Variability of step length† (cm)	4.2±1.3	4.0	2.0–7.0	3.9±1.8	3.5	1.5–10.2	.08‡
Asymmetry index (cm/cm)	.04±.05	.02	.00–.16	.02±.02	.02	0.00–.07	NS (.71)
Variability of index†	.07±.03	.07	.02–.12	.04±.02	.04	.01–.09	.001
Step width (cm)	8.8±2.2	8.7	4.6–14.4	8.3±2.3	8.2	4.7–12.3	NS (.64)
Variability of step width† (cm)	3.5±1.3	3.4	1.6–6.5	3.2±0.8	3.2	2.1–4.7	NS (.43)
Foot rotation angle (deg)	7.0±4.3	5.9	−2.7 to 13.6	4.8±3.3	4.6	−0.5 to 11.5	.06‡
Clinical assessment							
Composite score of gait	15.4±6.9	19.5	4.0–21.0	21 (age-adequate performance)			

Abbreviation: NS, nonsignificant.
* Mann-Whitney *U* test, 2 sided.
† The intraindividual variability was calculated as the SD of all steps (n=25–35) recorded per subject.
‡ Step variability and foot rotation angles showed trend toward a significant difference between groups.

- Twenty children (range: 6–13 years) with moderate to severe TBI were examined 1±1.2 years postinjury
- Gait velocity and step and stride lengths were significantly smaller in children after TBI than in control subjects
- The intraindividual variability of the asymmetry index was higher in the TBI children than in the control subjects, indicating a less stable symmetry of the left and right step lengths
- The step length tended to be more variable, and foot rotation angles were somewhat increased

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Gait & fine motor outcome

Table 4: Hand Movements in TBI Children and Control Subjects

Reach-to-Grasp With Dominant Hand	Children After TBI			Control Subjects			Group Difference: *P* Value*
	Mean ± SD	Median	Range	Mean ± SD	Median	Range	
Reaction time (ms)	478.2±194.5	440.0	264.0–1080.0	346.1±94.3	352.5	151.0–504.0	.005
Movement duration (ms)	789.9±205.6	744.0	540.0–1404.0	650.0±95.6	688.0	486.0–776.0	.019
Variability of movement duration† (ms)	161.6±63.1	134.5	87.0–321.0	115.4±29.2	102.5	78.0–183.0	.007
Peak hand velocity (cm/s)	83.2±19.2	83.4	49.2–132.0	96.2±15.9	91.4	70.5–122.7	.021
Straightness index (cm/cm)	1.2±0.1	1.1	1.0–1.5	1.1±0.1	1.1	1.0–1.3	NS (.76)
Maximum grip aperture (cm)	6.7±1.3	6.4	5.2–10.6	6.0±0.9	5.8	4.9–8.8	.048
Bimanual tasks and clinical assessment							
Threading large beads (s)	46.5±39.4	31.0	19.4–154.5	29.2±8.8	26.0	16.0–46.5	NS (.19)
Threading small beads (s)	100.6±82.1	73.1	22.3–300.5	47.3±24.9	37.5	21.2–95.0	.017
Score of dominant hand	11.8±3.2	12.0	4.5–15.0	15 (age-adequate performance)			
Score of nondominant hand	11.6±4.1	13.5	3.0–15.0	15 (age-adequate performance)			

* Mann-Whitney *U* test, 2-sided.
† The intraindividual variability is the SD of all trials (n=8–10) recorded per subject.

- Reaction time and movement duration were prolonged, hand velocity was reduced, and the intraindividual variability of the movement time was higher in children with TBI than control subjects
- Furthermore, the patients opened their hands wider while reaching out for the object
- The TBI children needed more time to complete a bimanual fine-motor task than did the control subjects
- Kinematic profiles (fig 3) were used to assess the coordination between reaching and shaping of the grip. Irregular patterns, indicating coordination deficits, were found in 7 TBI children

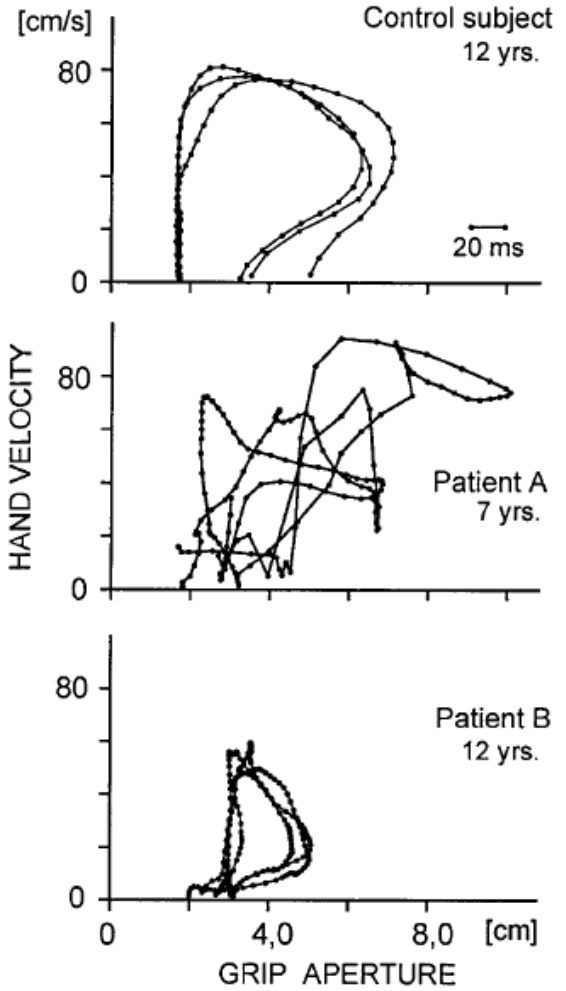

Fig 3. Kinematic profiles illustrating the coordination of reaching and grasping of a control subject and of 2 single subjects (patients A and B) after TBI. The hand velocity was plotted against the grip aperture with a sampling rate of 50Hz (20ms; dots). Three trials are superimposed for each subject. Note the disturbed coordination of patient A.

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Gross & fine motor outcome

Table 1: Characteristics of Subjects With Brain Injuries

Subject/ Sex	Injury Cause	Age at Testing (yr-mo)	Time from Injury to Testing (yr-mo)	GCS*	Duration of Coma (days)
1/M	MVA/Pedestrian	10-1	1-10	10	2
2/M	MVA/Bicycle	10-7	1-7	10(t)	15
3/M	Fall	12-9	3-8	9	1
4/M	Fall	10-2	1-4	7(t)	2
5/F	MVA/Passenger	14-8	2-3	7(t)	2
6/M	Fall	5-9	2-3	7	3
7/M	MVA/Passenger	7-9	1-6	7(t)	4
8/M	MVA/Passenger	11-10	4-1	7(t)	—
9/F	MVA/Passenger	13-2	2-8	6(t)	12
10/F	MVA/Passenger	9-3	2-4	5(t)	9
11/F	MVA/Pedestrian	8-7	1-5	5(t)	13
12/M	MVA/Pedestrian	15-0	3-9	4(t)	6
13/F	MVA/Pedestrian	8-5	3-11	3(t)	2
14/M	MVA/Bicycle	12-10	3-10	3(t)	5

Table 2: Comparison of Brain-Injured and Normal Subjects' Standard Scores on the BOTMP Gross Motor and Fine Motor Composites

	n	Mean	Median	SD	Low/High Score	*p*-value (two-tailed)
Gross Motor Composite						
Non-TBI	14	55.6	55.0	10.8	40/77	.0005
TBI	14	40.1	39.5	9.6	20/57	
Fine Motor Composite						
Non-TBI	14	56.2	55.5	8.7	45/77	NS
TBI	14	51.3	53.5	8.5	31/61	

Table 3: Comparison of the Brain-Injured and Normal Subjects' Standard Scores on the BOTMP Subtests

	Mean	Median	SD	Low/High Score	*p*-value (two-tailed)
Gross Motor Subtests					
Running Speed					
Normal	13.4	13.5	3.7	6/21	.0091*
TBI	8.6	9.0	4.6	1/17	
Balance					
Normal	15.7	15.0	7.0	6/28	.0350*
TBI	9.7	10.5	5.4	1/17	
Bilateral Coordination					
Normal	19.3	18.5	4.7	11/25	.0045†
TBI	13.4	13.5	4.0	6/20	
Strength					
Normal	18.3	19.5	3.9	13/25	.0122*
TBI	13.3	12.5	5.5	6/24	
Gross and Fine Motor Subtest					
Upper-Limb Coordination					
Normal	15.0	16.0	5.3	6/21	.0690
TBI	10.7	9.5	6.5	1/21	
Fine Motor Subtests					
Response Speed					
Normal	17.5	16.5	5.2	9/27	.9100
TBI	17.3	16.5	5.0	9/24	
Visual-Motor Control					
Normal	15.9	15.0	4.1	9/22	.6347
TBI	16.3	16.7	5.0	7/25	
Upper-Limb Speed and Dexterity					
Normal	17.4	18.5	3.9	11/23	.0012†
TBI	12.3	12.5	2.6	7/15	

* $p < .05$.
† $p < .0063$.

- Fourteen traumatically brain-injured children (5-15 years old) at least 16 months after injury
- Highly significant differences were found between groups on the Gross Motor Composite. Although no significant differences were found on the Fine Motor Composite
- On all subtests in the gross motor area, the normal group performed significantly better than the TBI group. In addition, a highly significant difference was found between the two groups on one fine motor subtest, Upper-Limb Speed and Dexterity
- This is consistent with previous research in neuropsychology, which has

Chaplin D et al 1993

Motor outcome

- Children with moderate to severe TBI have a **wide range of motor deficits**, rep orting **high incidence of spasticity, ataxia, abnormal gross and fine motor funct ion, and delayed motor milestones**
- **Delayed motor milestones appear to greater in infants and young children** than other developmental ages
- In general, **children show fewer functional deficits** (inability to walk or perform self-care) than neurologic or motor impairment, **suggesting somewhat favorab le motor recovery**
- Children show **long-lasting deficits in the areas of motor performance abilities**, especially those related to **speed and precision of performance**

Case

- M/4세 2개월
- 2016.6.6 오후 9시 30분경 3층 높이에서 떨어진 채 발견되어 119통해 응급실 내원 하였고 내원 당시 환아 의식 drowsy한 상태로 GCS 5 체크되었음
- Rt. ear bleeding 동반되었으며, brain CT상 traumatic ICH, SDH, IVH in Rt. Cerebral hemisphere and cerebellum with multiple comminuted skull fracture 소견 보여 신경외과 입원하여 craniotomy & SDH removal op 시행받았음
- 2016.6.9 bedside PT 의뢰되었음
- 2016.6.28 active PT 시행하였음
- 2016.7.5 포괄적 재활치료 위해 재활의학과 전과되었음

Case

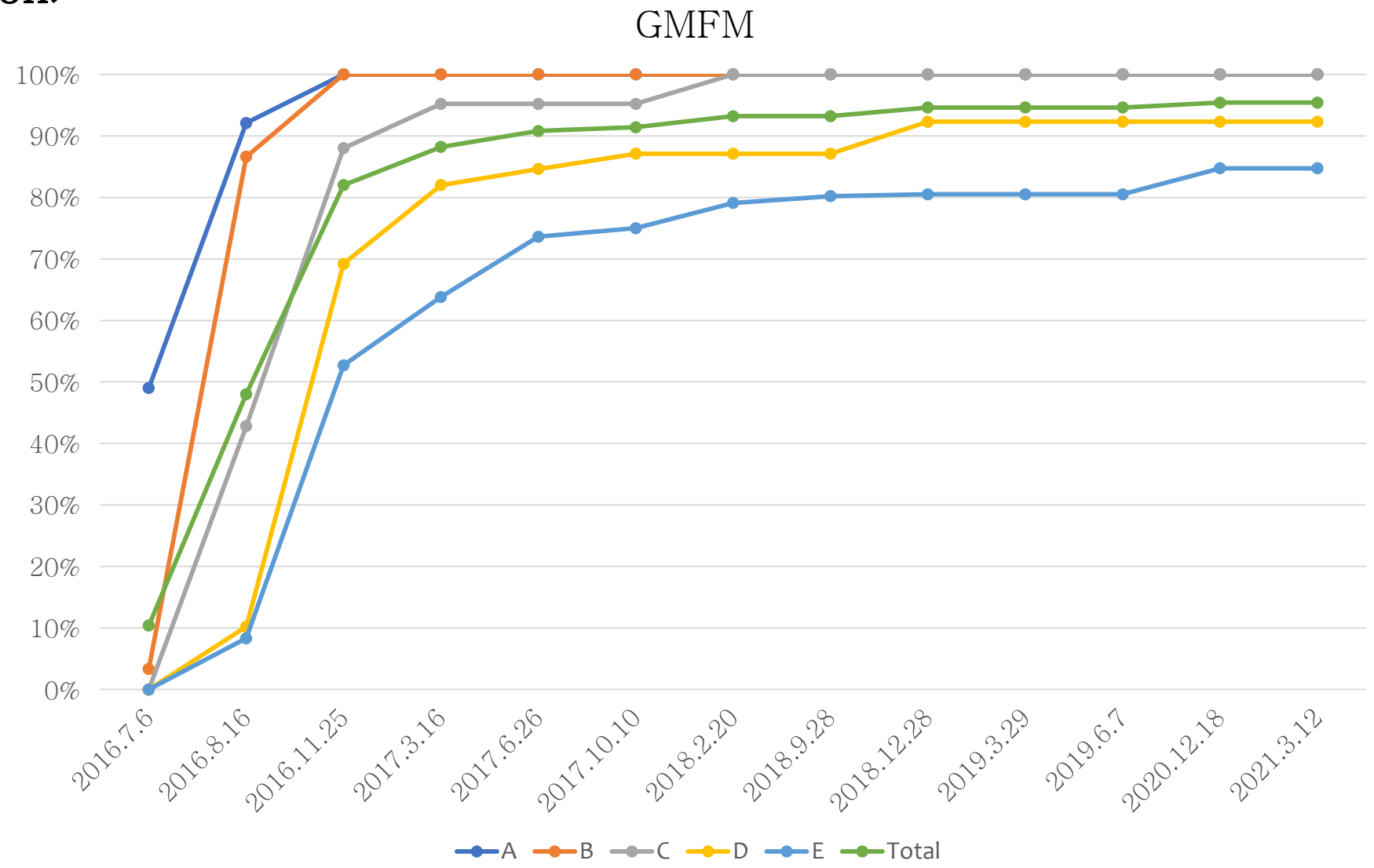
- P/Ex>
  - M/S : drowsy
  - Obey command (-)
  - MMT: Rt upper & lower extremities generally F grade 이상
    Lt upper & lower extremities generally P grade
  - Sensory: pain response (+)
  - Tone: normotonous on all extremities
  - DTR : BJ(++/++) TJ(++/++) KJ(++/+++) AJ(++/+++)
  - Functional level
    - Side rolling : (+/+)
    - Come to sit : maximal assist
    - Sitting balance : static & dynamic poor
    - Sit to stand : total dependent
    - Standing balance : static & dynamic poor
    - Gait : total dependent
  - ADL: total dependent

Case

- Progress>
  - 2016.7~ 2018.2 본원 재활의학과 입원 재활치료 시행하였음
  - 입원기간 동안,
    - 좌측 상지 근력은 G grade, 하지 근력은 F+ ~ G grade 정도로 호전되었으며, Lt. ankle MAS 1 소견 관찰되었음
    - Gross motor: self gait 가능한 상태로 호전되었으나 Lt hemiparesis & ataxia로 인해 gait velocity 저하, step length 저하, step width 증가, step length 와 step width의 variability 증가 소견 보여 보행장애 및 균형능력 저하 소견 지속적으로 관찰되었음
    - Fine motor: Lt. hemiparesis & dysmetria, Lt homonymous hemianopsia로 인해 과제 수행시 visuomotor coordination, speed, dexterity 저하 소견이 지속적으로 관찰되었음
  - 2018. 2 환아는 퇴원 후 통원 재활치료 (PT, OT, ST) 지속하면서 초등학교 병설 유치원 통합반 입학하였음
  - 2019.3 환아는 통원 재활치료 지속하면서 일반 초등학교 통합반 입학하였음

Case

- Evaluation>



Case

- Evaluation>

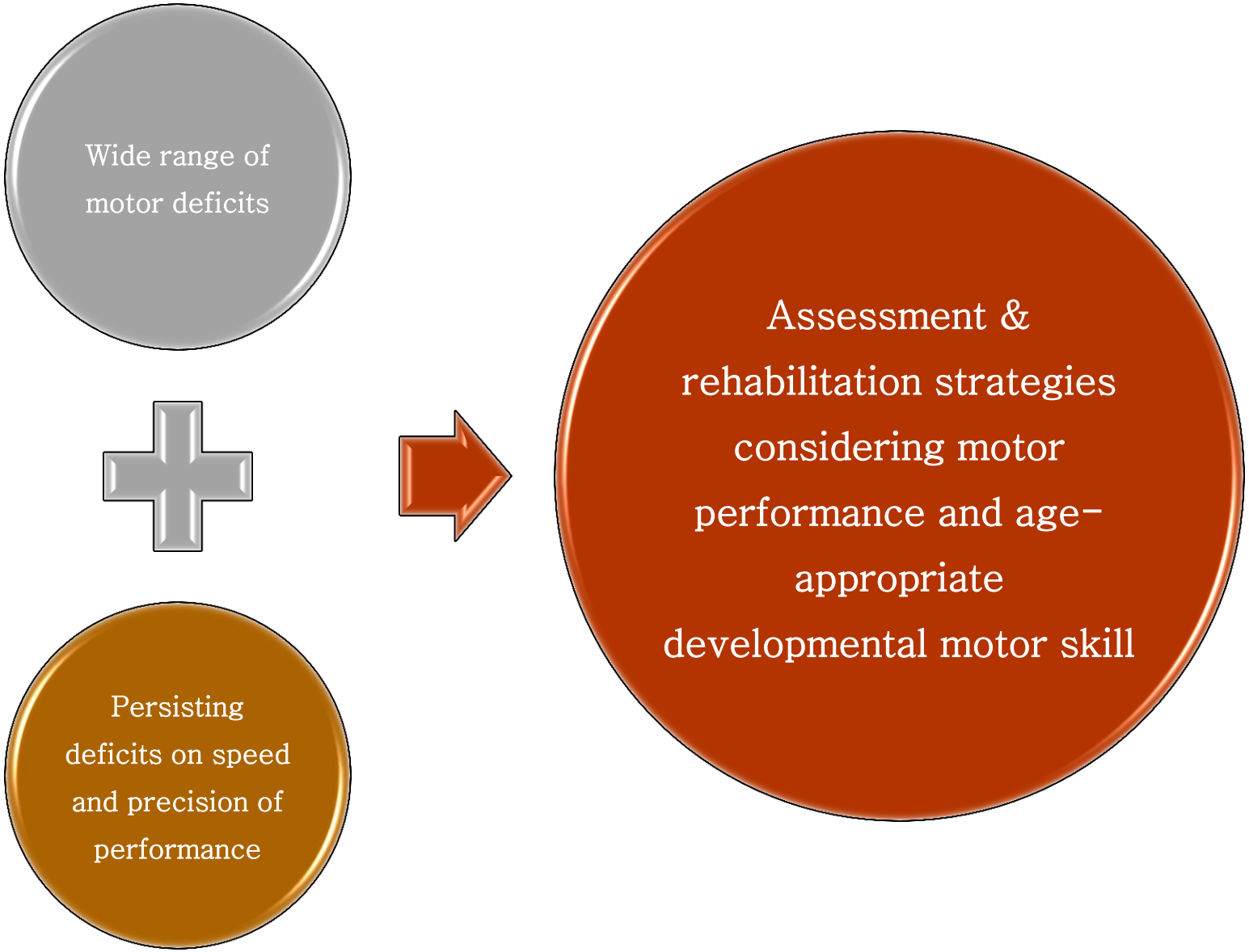
  - Bayley scale III – developmental age

2016.10.24 (5mo post-injury)	2017.1.26 (8mo post-injury)
Cognitive 40-42 months	Cognitive 40-42 months
Language - Receptive >42 months - Expressive 35 months	Language - Receptive >42 months - Expressive 40-42 months
Motor - Fine motor Lt. 24 months/ Rt. 37-39 months (양측 수행능력을 따로 평가하였음) - Gross motor 14 months	Motor - Fine motor >42 months (양측 수행능력을 따로 평가하지 않았음) - Gross motor 18 months

  - 9-hole pegboard test

2016.7.6 (1mo post-injury)	2016.8.31 (3mo post-injury)	2017.9.29 (16mo post-injury)	2018.2.23 (21mo post-injury)
Dominant Rt. NT	Dominant Rt. NT	Dominant Rt. 48초 27	Dominant Rt. 57초 71
Non-dominant Lt. NT	Non-dominant Lt. NT	Non-dominant Lt. 4분 41초 63	Non-dominant Lt. 2분 45초 20

Summary


Wide range of motor deficits
Persisting deficits on speed and precision of performance
Assessment & rehabilitation strategies considering motor performance and age-appropriate developmental motor skill

경청해 주셔서 감사합니다.