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An algorithm for identifying and classifying cerebral palsy in young children

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Abstract

Objective—To develop an algorithm based on data obtained with a reliable, standardized neurological examination, and report the prevalence of cerebral palsy (CP) subtypes (diparesis, hemiparesis, and quadripareisis) in a cohort of 2-year-old children born before 28 weeks gestation.

Study design—We compared children with CP subtypes on extent of handicap and frequency of microcephaly, cognitive impairment, and screening positive for autism.

Results—Of the 1056 children evaluated, 11.4% (120) were given an algorithm-based classification of CP. Of these children, 31% had diparesis, 17% had hemiparesis, and 52% had quadripareisis. Children with quadripareisis were 9 times more likely than children with diparesis (76% versus 8%) to be more highly impaired and 5 times more likely than children with diparesis to be microcephalic (43% versus 8%). They were more than twice as likely as children with diparesis to have an MDI score below 70 (75% versus 34%), and had the highest rate of MCHAT positivity (76%) compared with children with diparesis (30%) and children without CP (18%).

Conclusion—We developed an algorithm that classifies CP subtypes, which should permit comparison among studies. Extent of gross motor dysfunction and rates of co-morbidities are highest among children with quadripareisis and lowest among children with diparesis.

Keywords

extremely low gestational age; follow-up; developmental disorders

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Cerebral palsy (CP) is a group of non-progressive permanent disorders of movement and posture that occur following damage to the developing fetal or infant brain. It is often accompanied by other neurodevelopmental disorders ([1], [2], [3]). CP occurs in 0.2% of live births, but infants born before 28 weeks gestation have a 50-fold elevated risk when compared with infants born at term [4] with a prevalence between 6 and 26% ([5], [6], [7], [8], [9], [10], [11], [12]).

Part of the variability in prevalence may be attributable to the lack of a published operational identification or classification of CP that can be used and replicated by clinicians across settings. Indeed, because of inconsistencies in identifying forms of CP, some experts have recommended classifying CP based primarily on the degree of severity of gross motor function while minimizing or eliminating classic topography-based categorization of CP types ([13–15]). In response, we created an algorithm to more reliably identify CP and topography-based subtypes of CP that could be replicated by others. The decision tree of the algorithm we developed models the way a seasoned pediatric neurology clinician might identify and classify CP.

We sought additional confirmation that the CP subtypes identified by our algorithm were distinctive with respect to the clinical severity of dysfunction and in the frequency of associated abnormal findings. We anticipated that children with quadriplegia would be most highly affected or have greater numbers of co-morbid conditions, followed by diplegia, hemiplegia, and no CP. Specifically, we sought to determine the extent to which children with different subtypes varied in 1) their levels of dysfunction as assessed by the Gross Motor Functional Classification Scale (GMFCS), and in 2) their frequency of microcephaly, cognitive impairment, and positive screening on the Modified Checklist for Autism in Toddlers (M-CHAT) at two years adjusted age.

Methods

The ELGAN Study

The Extremely Low Gestational Age Newborns (ELGAN) study was designed to identify characteristics and exposures that increase the risk of disorders of brain structure and function (including CP) in ELGANs. During the years 2002–2004, women delivering before 28 weeks gestation at one of 14 participating institutions in 11 cities in 5 states were asked to enroll in the study. Of the 1201 survivors, 1056 (88%) underwent neurological examinations at 2 years of age and are the subject of this report. This study was approved by all involved Institutional human studies review boards, and all families consented to the study.

In order to standardize neurological examinations across all sites, a stand-alone, multimedia-training video/CD-ROM was developed [16], based on elements of a standard neurological exam ([17], [18], [19], [20]). Use of the video-CD led to a reliability of 88 to 96% when examiner findings were compared with a gold standard assessment [16]. Examiners also evaluated level of disability using the GMFCS ([21], [22], [23], [14]). Neurological examiners remained largely unaware of the child's specific medical history, other than that the infant had extremely low gestational age at birth.

Certified examiners administered and scored the mental (MDI) and motor (PDI) scales of the BSID-II. Before testing, examiners were told only the child's age. After test completion, they were told the gestational age in order to adjust the MDI and PDI for the degree of prematurity. Of the 1056 children who were identified to have CP on the basis of the algorithm, 59 were considered not testable for the MDI and 76 for the PDI. We used the Vineland Adaptive Behavioral Composite scale as a proxy for the MDI for 39 children and the Vineland Motor

Skills domain scale as a proxy for the PDI for 43 children. Caregivers of study participants completed the Modified Checklist for Autism in Toddlers (M-CHAT) screen survey [24].

Neurological Examination Instrument

The data collection form included 7 items in the upper extremities in 4 areas of motor function: motor strength (4 items), tone alteration (1 item), posture (1 item), and hand use (1 item). Two areas of function were evaluated in the lower extremities: strength (2 items) and tone (3 items). In our strength assessment, we use indirect measures of power, including the child's ability to push the chest up off the bed with the arms, support body weight on the legs, and lift and move arms and legs.

Algorithm assumptions

Assumption 1: An algorithm that simplifies options is most useful—The range of presentations of topography-based classification of diparesis, quadriparesis, and hemiparesis can include partial forms. For example, monoparesis also occurs. Rather than create a category for monoparesis, we viewed monoparesis of an upper extremity as a partial hemiparesis. Our final categorization includes the following three groups:

- quadriparesis: involvement of both lower extremities *and* involvement of one (asymmetric) or both (symmetric) upper extremities; or involvement of both upper extremities and one lower extremity (asymmetric quadriparesis);
- diparesis: involvement of both lower extremities only or only one leg;
- hemiparesis: involvement restricted to only one side of the body.

Assumption 2: Dystonia and dyskinetic forms of CP are more evident later—We did not make distinguish among qualitative forms of abnormally elevated tone (hypertonia), particularly spasticity and dystonia. Dystonia and spasticity co-occur frequently and the presence of spasticity may make identification of dystonia more difficult ([25], [26]). The distinction between the two also may be difficult because signs of dystonia may be intermittent and vary with state and level of activity. Finally, the expression of dystonia and dyskinetic forms of CP evolves over the first years of life and usually manifests more obviously later [27]

Assumption 3: The proposed algorithm's value may be limited to the very young child born extremely premature performed at 2 years corrected age—The examination we used and the proposed algorithm was tested and applied to children in the first few years of life. CP evolves in its presentation, sometimes becoming more complex in later years. For example, choreoathetosis, more often seen in infants born at term, becomes more obvious after the first years of life. Because motor findings characteristic of CP can improve or dissipate at later ages [28] [29,30], we can expect some children given a CP diagnosis at a young age, whether algorithm-based or not, to no longer be given the same diagnosis years later.

Algorithm development as an iterative process

In analyzing the CD-based neurological examination findings, a number of decisions were made sequentially (Figure).

First, components of the examination that did not specifically evaluate motor status were excluded (e.g., visual interactions, extra-ocular muscles).

Second, because the evaluation of deep tendon reflexes is less reliably assessed than other parts of the examination and probably less specific to motor impairment, an effort was made to minimize their impact on the decision tree. After considering approaches that assigned less weight to deep tendon reflexes, we decided to exclude this item from the decision tree.

Third, we required multiple, corroborating abnormal findings. Although we preferred the presence of at least 2 abnormal findings that assess different domains of the motor system (strength, tone, posture, and hand use in the upper extremities and strength and tone in the lower extremities), we accepted strongly affirming items in a single domain (3 of the 4 possible items related to strength in the upper extremities and both items related to strength in the lower extremities). Consequently minimum threshold criteria to identify CP required the presence of at least 3 abnormal items in an upper extremity, and/or at least 2 abnormal items in a lower extremity (Table I).

Fourth, building on these 2- and 3-item requirements for minimal characterization of CP, we classified quadriplegia, hemiparesis, and diparesis on the basis of the quadrants of the body involved (Table II, Figure). Once the threshold for presence of an abnormality was attained, we did not ascertain further gradations of severity by neurological examination findings. All subjects were classified using a computerized version of the algorithm program.

Data analysis

We used the GMFCS to assess the extent of gross motor impairment. For the purposes of the current study, children with a score of less than 1 were classified as not impaired, those with a score of 1 as mildly impaired, and those with a score of 2 to 5 as more highly impaired. The head circumference, measured as part of the 2-year neurological examination, was assigned a Z-score based on standards established by the Centers for Disease Control ([31]). Children with Z-scores of -2 or below were deemed microcephalic. On the BSID-II, a score of <70 for either the MDI or PDI defined delay. Children were categorized on the M-CHAT screen as positive if they scored positive in 2 of 6 “critical” items or 3 of the 23 total items ([32] [24]).

Results

CP Algorithm

Of the 1056 children evaluated at 2 years of age, 11.4% (120/1056) satisfied the algorithm’s identification criteria for CP. Fifty-two percent had quadriplegia, 31% had diparesis, and 17% had hemiparesis (Table II).

According to the algorithm, 9 individuals had motor deficits that conformed to a pattern most often seen in diparesis or quadriplegia (leg $\geq$ arm), but the abnormalities occurred uniquely on one side, more typical of hemiparesis, but did not demonstrate the characteristic hemiparetic pattern of arm weakness greater than leg weakness. We found that the extent of motor limitations and prevalence of co-morbid dysfunctions were nearly identical whether the pattern of weakness was arm $>$ leg or leg $\geq$ arm (data not shown). As a result, we combined into a single group all individuals who had involvement of arm and leg or of arm alone.

Severity and co-morbidities of CP (Table III)

More than three quarters of all children with quadriplegia were given a GMFCS of 2 or greater (high functional impairment). In contrast, only 8% of those with diparesis were so classified, and an additional 27% had milder functional impairment. Only 19 children were classified as having hemiparesis. Two of them had high functional impairment and 1 had a milder impairment. Two percent (20/934) of children who were not identified to have CP had functional motor impairment, and only 3 were more highly affected.

Seventy-two percent of children with quadriplegia had BSID-II MDI subscale score below 70 in contrast to 34% of children with diplegia and 58% of children with hemiplegia. The PDI scores, which are more an assessment of motor function than the MDI, tended to be even lower. Thus, 93% of children with quadriplegia and more than half of children with diplegia and children with hemiplegia had a PDI score less than 70. Only four percent of children with quadriplegia had both a PDI and an MDI score of 70 or more in contrast to 32% of children with diplegia, 38% of children with hemiplegia, and 66% of children not identified to have CP (data not shown).

Fully 42% of the 62 children with quadriplegia were microcephalic in contrast to 21% of children with hemiplegia and 8% of those with diplegia or no CP. Motor impairment was associated with being screened as positive on the M-CHAT. The highest rate of M-CHAT positivity was in children with quadriplegia (76%), with lower rates in children with hemiplegia (44%), and children with diplegia (30%). In contrast, 18% of children without CP were M-CHAT positive.

Discussion

Using the algorithm developed for this study, we identified CP in 11% of the ELGAN study cohort. This overall CP rate is within range of reported CP rates among extremely low gestational age infants ([6], [7,33–48], [49], [50]). In the cohorts most comparable to the ELGAN children, the Victorian Collaborative Infant Study Group and the northwest North Carolina cohort, the frequency of CP was 11–13% ([8], [9] [51]).

In this cohort, 52% of the CP population had quadriplegia, 31% had diplegia, and 17% had hemiplegia. Algorithm-based quadriplegia prevalence is somewhat higher and diplegia prevalence is modestly lower than others have reported based on clinical diagnoses ([52], [44], [45], [46], [47], [48]). The differences in distribution of topography-based patterns of CP might be a consequence of unstable rates expected with small numbers of children with CP ([45,46], [47], [48]), use of birth weight rather than gestational age, inclusion criteria ([45], [47,48]), or differences in identification criteria. A lack of operational classification for CP makes studies of antecedents and therapies difficult to replicate, and limits reasonable comparisons with reported or future studies [53].

We created an algorithm that classifies CP subtypes. Our proposal offers reasonably objective criteria for identifying and classifying CP. Previous attempts to enhance diagnostic reliability of CP in young children born at extremely low gestational age have focused on severity measures, such as the GMFCS ([21], [22], [23], [14]), or distinguishing disabling from non-disabling CP [54]. In contrast to earlier definitions of CP, the definition proposed by the 2004 International Workshop on Definition and Classification of Cerebral Palsy includes an explicit criterion for the lower limit of abnormality that must be exceeded in order to diagnose CP, i.e., "activity limitation". However, the authors of that definition did not specify an operational approach to the decision as to whether activity restriction is present. For this purpose, several recent clinical trials have included measurements of the GMFCS, as was used in the current study. In attempting to study antecedents of CP, the full range of severity ought to be identified as even individuals with CP who have minimal functional motor disability are at increased risk of substantial neurodevelopmental morbidity [46].

The Surveillance of Cerebral Palsy in Europe project [55] and the Neonatal Research Network developed decision trees similar to that described here. Both studies identify increased tone or reflexes, but diagnoses were not based on specified objective or reproducible criteria. The Neonatal Research Network enhances reliability, for example, by use of hands-on workshops ([56], [57], [52]) using a CP diagnosis "based on the writing of Amiel Tison" [58]. Other

investigators have tried to improve uniformity of CP diagnosis using video [59] or having more precise definitions of spasticity [60], but neither effort resulted in operational, replicable criteria.

Individuals with quadriplegia are distinguished from individuals with hemiparesis and diparesis in relation to both the severity of dysfunction and the likelihood of having co-morbid conditions. Children with quadriplegia were more than 9 times more likely than children with diparesis to be classified on the GMFCS as having high degree of impairment. In addition, children with quadriplegia were twice as likely as children with diparesis to have an MDI score lower than 70.

Microcephaly was 5 times more likely to occur in children with quadriplegia (43% versus 8%) and twice more likely to occur in children with hemiparesis than in children with diparesis or no CP. Because head circumference percentile measure is a function of brain tissue volume, those with quadriplegia or hemiparesis can be assumed to have substantially less brain tissue than the other children. Notably, children with diparesis have a rate of microcephaly that is not distinguishable from children without CP; yet, the 8% microcephaly prevalence in both groups is still nearly triple the rate of children born at term.

We also found that children with hemiparesis have higher degree of gross motor dysfunction and co-morbidity rates intermediate between rates of children with quadriplegia and diparesis. This pattern of quadriplegia > hemiparesis > diparesis was seen consistently and somewhat different from our expectation that those with hemiparesis would be least affected. Excluding the 9 individuals whose hemiparesis involved the leg as much or more than the arm and the 2 individuals who had a double hemiparesis (hemiparesis with arm more affected than leg on both sides of the body) did not alter these findings.

Some challenge the existence of CP subtypes categorized by topography because of vagueness in identifying each type [25]. The impairment classification system for CP offered in the 2005 concept/consensus paper, which was re-presented in 2007, recommended simplifying topographic description of CP by removing the term spastic diparesis (and quadriplegia) from the CP lexicon ([1], [3]), preferring a simple descriptive statement of either 2 or 4 extremity involvement. We, on the other hand, have found support for maintaining a topographic-based system of CP categorization ([61]).

The neuropathology underlying hemiparesis may differ from that underlying diparesis or quadriplegia in those born at extremely low gestational age. For example, symmetrical white matter injury close to the ventricle (leg fibers of the pyramidal systems are closest to the ventricles) is likely to be associated with diparesis, and involvement of broader areas of white matter, including areas further from the ventricle subserving arms, is likely to be associated with quadriplegia ([62], [63], [64]). As a result, children with diparesis have brain lesions that are less likely to be located in white matter association areas that may impair cognition and they have lower rates of microcephaly. In contrast, hemiparesis, with arm more involved than leg, often reflects focal injury/middle cerebral artery distribution stroke-like events, more often sparing fibers closest to the ventricle that control legs ([65], [66], [67]). Hemiparesis, which involves the leg comparably or more than the arm, is associated with periventricular hemorrhagic infarction [68]. Hence, the risk factors and antecedents of the different types of CP may vary based on differences in pathophysiology that are associated with these cerebral lesions.

In children born at term, M-CHAT positivity is an indicator of elevated risk of autism. A number of the M-CHAT questionnaire items are influenced by motor dysfunction. Consequently, we cannot distinguish an increased risk of autism from a positive screen based

mainly on motor dysfunctions in CP groups. Fully 18% of infants without CP also screen positive, an observation that warrants further study.

Extremely premature children in our study who do not have CP also had substantial rates of neurodevelopmental dysfunction as measured by the BSID-II. They also had a higher than expected rate of microcephaly, although less notably than in those with CP. This is consistent with the high rate of neurodevelopmental dysfunction reported with extreme prematurity, even in the absence of CP ([46]), or apparent structural damage on cranial ultrasound studies ([69]).

We have applied the term cerebral palsy to children in this cohort that we deemed to have motor impairment without the benefit of an expert clinician to validate the presence or absence of cerebral palsy. We created our algorithm to assist researchers who study CP to have some measure of comparability of CP phenotypes. We believe that from a population perspective, we have identified the vast majority who have CP and excluded from the diagnosis almost all who do not have the diagnosis at 2 years. We do not advise that our algorithm be used clinically. Because the algorithm targeted young children, we did not seek to evaluate certain CP forms, such as choreoathetosis, which often do not manifest until a later age.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure.

CP classification flow sheet. The algorithm begins by identifying laterality and number of features seen in the lower extremities (column 1). Then based on laterality and extent of findings in the upper extremities (column 2), a CP diagnosis is rendered (column 3).

Final classification of CP types based on topography of upper and lower extremity neurologic exam abnormalities. Each child is counted only once for the highest number of neurologic exam abnormalities for either right or left extremity.

Table 1

Number of abnormalities on the neurologic examination							
Upper Extremity (UE)		Lower Extremity (LE)					
		0	1	2	3	4	5
0	No CP	Diparesis					
1							
2							
3							
4	Hemiparesis	Quadriparesis; if bilateral Hemiparesis; if unilateral					
5							
6							
7							

Table 2
Prevalence of CP classified according to the pattern of extremity involvement (Q plot) in 1056 ELGANs. X indicates involvement of each extremity and o indicates no involvement. The symbols in the top row are right and left upper extremity and the symbols in the bottom row are right and left lower extremity.

CP classification	Q plot				N
	oo	oo	***		
None	oo	oo			936
Diparesis	oo	oo			37
	XX	Xo			
Hemiparesis*	Xo	Xo			19
	oo	Xo			
Quadriparesis**	XX	Xo	XX	Xo	64
	XX	XX	Xo	oo	

* Includes 2 double hemiparesis and 9 quadri-hemiparesis

** Includes 1 opposite UE-LE diparesis + hemiparesis

*** Mirror image patterns are combined

Table 3

The percent of children classified by their cerebral palsy classification who had the abnormality on the left. These are column percents.

	CP classification			
	Quadripareisis	Diparesis	Hemiparesis	None
GMFCS* > 2	76	8	11	0.3
MDI** < 70	72	34	58	22
PDI** < 70	93	62	63	25
M-CHAT positive†	76	30	44	18
Microcephaly‡	42	8	21	8
Maximum N	64	37	19	936

* Gross Motor Function Classification System

** Bayley Scales of Infant Development, Mental Development Index & Psychomotor Development Index

† Modified Checklist for Autism in Toddlers

‡ Head circumference more than 2 SD below the mean for age