Cerebral Palsy: Classification and Epidemiology

Amy Thornhill Pakula, MD[a], Kim Van Naarden Braun, PhD, CDC[b], Marshalyn Yeargin-Allsopp, MD, CDC[b,*]

KEYWORDS

• Epidemiology • Cerebral palsy • Prevalence
• Risk factors • Surveillance

HISTORY AND DEFINITION

Cerebral palsy (CP) is the most common motor disability of childhood. A recent publication from the Autism and Developmental Disability Monitoring (ADDM) CP Network sponsored by the Centers for Disease Control and Prevention (CDC) reported a prevalence of 3.3 per 1000 8-year-old children from 3 sites across the United States.[1] The history of cerebral palsy is a long one, dating back to ancient Egypt. There are at least 2 drawings of individuals from the fifth century BC with what is recognized today as spastic cerebral palsy.[2,3] An orthopedic surgeon, William John Little, who himself had an equinus deformity from early childhood secondary to poliomyelitis, is credited with the first descriptions of CP in 1843.[4] Seeking a cure for his own deformity, he was greatly influenced by the French orthopedic surgeon, Jacques Delpeche, who was interested in surgical correction of equinus deformities, and performed many tenotomies of the Achilles tendon.[5] After successful correction of his own deformity by a German orthopedic surgeon, George Stromeyer, Little improved on Stromeyer's surgical techniques and set up the Orthopaedic Institution in London. Little's interest in orthopedic deformities continued and he is regarded as a pioneer in orthopedic surgery and as the first to recognize spastic paralysis. He wrote a treatise ''On the influence of abnormal parturition, difficult labor, premature birth and asphyxia neonatorum on the mental and physical condition of the child'', which posited that these deformities of childhood were related to anoxia secondary to trauma occurring during

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

[a] Emory University, Department of Pediatrics, The Marcus Autism Center, 1920 Briarcliff Road, Atlanta, GA 30329, USA
[b] CDC, National Center on Birth Defects and Developmental Disabilities, MS E-86, 1600 Clifton Road, Atlanta, GA 30333, USA
* Corresponding author.
E-mail address: mxy1@cdc.gov (M. Yeargin-Allsopp).

Phys Med Rehabil Clin N Am 20 (2009) 425–452
doi:10.1016/j.pmr.2009.06.001 **pmr.theclinics.com**
1047-9651/09/$ – see front matter. Published by Elsevier Inc.

labor and delivery.[6] For many years, spastic diplegia was commonly referred to as Little's disease.

Sir William Osler, a British physician, is believed to have coined the term ''cerebral palsy'' in 1889; he described 151 patients affected by the disorder.[7] Sigmund Freud, a neurologist, but best known as a psychoanalyst, wrote many articles on CP, adding to the sparse body of knowledge on the subject. He also disagreed with Little on its cause, observing that children with CP had many other neurologic conditions, such as intellectual disabilities, visual impairment, and epilepsy. He therefore believed that CP might be caused by in utero abnormalities of brain development. He divided CP into 3 groups based on possible causes: (1) maternal and idiopathic congenital; (2) perinatal; and (3) postnatal, and devised a classification scheme with ''diplegia'' used to refer to all bilateral disorders of central origin.[8]

The American Academy of Cerebral Palsy (AACP) was formed in 1947.[5] Minear[9] polled the membership of the Academy in 1953 and found many different definitions of cerebral palsy. The various definitions commonly acknowledged a broad syndrome of brain damage, with predominant motor dysfunction but also psychological, epileptic, and behavioral symptoms. Transient abnormalities, neoplasms, progressive disorders, and spinal cord disorders were excluded. Despite the presence of common themes, a unified definition of CP was not presented until almost 5 years later by the Little Club, an informal group of neurologists and others formed in the United Kingdom in 1957. The Little Club developed a definition aimed to facilitate sharing knowledge and research: ''Cerebral palsy is a persisting qualitative motor disorder due to non-progressive interference with development of the brain occurring before the growth of the central nervous system is complete.'' The Little Club classification consisted of: (1) spastic (hemiplegic, double hemiplegic, and diplegic); (2) dystonic; (3) choreoathetoid; (4) mixed; (5) ataxic; and (6) atonic CP.[10] In the 1960s CP was redefined but there continued to be recognition of inconsistencies in terminology.[11]

With growing interest in public health, the Spastics Society commissioned a group to define CP for epidemiologic purposes in the 1980s. A limb-by-limb classification system, which described the functioning of each limb and the head and neck separately, built on the work in Western Australia of Fiona Stanley, was proposed by Evans.[12] This classification system also allowed the capture of information on co-occurring medical conditions such as congenital malformations and seizures. American and European CP investigators met from 1987 to 1990 and developed a common definition: ''CP is an umbrella term covering a group of non-progressive, but often changing, motor impairment syndromes secondary to lesions or anomalies of the brain arising in the early stages of development.''[13]

By 1998, there were 14 centers across Europe conducting population-based surveillance for CP; they formed a Network, the Surveillance of Cerebral Palsy in Europe (SCPE).[14] The Network used a case definition that was a reiteration of that of Mutch et al,[13] and developed and published standardized procedures for ascertaining and describing children with CP for registers.[14]

An International Workshop on Definition and Classification of CP was held in Bethesda, Maryland, July 11 to 13, 2004 because of a perceived need to revisit the definition and classification of CP.[15] The current definition, as adopted by this group, recognizes that CP is more than a motor disability and acknowledges that often other impairments accompany CP: ''Cerebral palsy describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances of

sensation, perception, cognition, communication, behavior, by epilepsy and by secondary musculoskeletal problems."[15]

The definitions of CP, including the most recent one cited,[15] have 4 core components: (1) it is a disorder of movement and posture; (2) it results from an abnormality in the brain; (3) it is acquired early in life; and (4) the condition is static at the time of recognition. However, there are still many challenges with the use of all CP definitions for epidemiologic purposes because of the lack of specificity of the definition. The criteria do not address severity of the motor disability to be included; how to assure that the brain abnormality is static; age of the acquisition of the brain lesion; or the youngest age of recognition of the condition.[16] Also, there are other conditions that do meet these stated criteria for CP that are not included.[17] Blair and Stanley have proposed that to make the term cerebral palsy more specific, especially for epidemiologic studies, CP researchers should: (1) define the lower limit of severity using a validated measure, such as the Gross Motor Function Classification System (GMFCS); (2) specify an upper age limit for post-neonatally acquired cases; (3) develop inclusion and exclusion criteria related to known chromosomal, genetic, and metabolic conditions; (4) define the age of certainty of the diagnosis beyond which one would not expect resolution or change in the diagnosis; and (5) define the minimum age of inclusion of the child in a register or surveillance system should the child die before diagnostic confirmation. Blair and Stanley also state that even if investigators do not agree on the same criteria for studies, a description of the study population according to the 5 areas as suggested would allow for comparison of results from different epidemiologic studies.[16]

CLASSIFICATION

In 1956 Minear and the Nomenclature and Classification Committee of the American Academy for Cerebral Palsy presented a set of potential classification schemes that have remained pertinent over the years.[9] This early classification system included broad clinical symptoms with categories for physiology (the nature of the motor abnormality), topography, etiology, neuroanatomic features, supplemental (associated) conditions, functional capacity (severity), and therapeutic requirements. Experts continue to address these broad categories when classifying CP.

Physiologic and Topographic Classification

CP can be divided into 2 main physiologic groups, the *pyramidal* (a term used somewhat inexactly to refer to cases in which *spasticity* is prominent) and the *extrapyramidal* types (chorea, athetosis, dystonia, ataxia). Spasticity is a clinical sign manifested by an increased resistance of a limb to externally imposed joint movement. The spastic types of cerebral palsy have neuromotor findings that are consistent and persistent; neurologic abnormalities remain during quiet periods and sleep, and do not vary much during the active state or when degrees of emotional stress or irritability are present. In contrast, extrapyramidal types of CP have marked variability in tone during relaxation and sleep, and especially during wakefulness when stressful situations arise. Rapid passive movement at a joint elicits spastic hypertonus. The classic descriptor of spasticity is the "clasp knife" resistance that is followed by a sudden "give." The comparison is made to the opening or closing of a penknife. Extrapyramidal hypertonicity, in contrast, is represented by increased tone persisting throughout slow passive flexion and extension of an extremity. It is often described as "lead pipe" rigidity. Combinations of these tone patterns in the same patient are common, creating potential difficulty in finding the proper diagnostic terminology. Extrapyramidal CP has 4-limb involvement, with upper extremities typically being

functionally more involved than the lower extremities. This situation precludes further useful topographic breakdown. Therefore, for practical purposes topographic classification is restricted to the spastic group.

To discriminate subgroups of spastic CP, classification systems often refer to the *localization* or *topography* of the abnormal motor function. *Diplegia* refers to bilateral lower extremity involvement, *hemiplegia* to unilateral upper and lower extremity involvement, *triplegia* to involvement of 3 extremities (typically both lower and one upper extremity), *double hemiplegia* to 4-extremity involvement with more severe spasticity of the upper extremities, and *quadriplegia/tetraplegia* to severe 4-extremity involvement.

There are several concerns with the physiologic and topographic schemes. The distinction between the topographic classification terms may lack sufficient reliability.[18] How much upper extremity involvement is required to distinguish diplegia from quadriplegia? How many extrapyramidal signs are required to designate mixed CP? ''Lead pipe'' rigid tone is not always easily distinguished from spasticity. Alberman[19] compared agreement on classification of CP among 6 trained clinicians and found poor reliability. Agreement on the physiologic classification of the motor dysfunction (eg, spasticity, choreoathetosis) was 40%, on the topographic classification 50%, and on severity (mild, moderate, severe) 60%. In addition to reliability concerns, the topographic and physiologic classifications do not consider functional abilities. Because brain dysfunction has diffuse manifestations in childhood, each child must be evaluated thoroughly for associated impairments in areas such as learning and cognition, vision, behavior, epilepsy, and secondary neuromuscular abnormalities. It is not possible to direct clinical assessments simply based on correlations between topography and associated dysfunctions. Finally, topographic and physiologic classifications do not aid therapy.

Etiologic Classification

Etiologic classification systems are aimed at developing prevention strategies. The association of erythroblastosis fetalis with choreoathetoid cerebral palsy served as the paradigm for this classification. However, etiologic classifications are not well developed and to date have not been successful in addressing prevention.[20,21]

The Collaborative Perinatal Project[22] helped to identify a large number of conditions that placed a child at risk for cerebral palsy. However, only a few of these conditions were found to correlate to specific motor outcome or diagnosis.[23] Most predictors were combinations of factors present prior to onset of labor, implying that CP is not caused by a single disturbance but by the interaction of many related conditions.

Some research has also focused on discerning the mechanism of the brain damage.[24] Because the brain has a limited number of ways to respond to insult, CP might result from a common pathophysiological mechanism. One hypothesis links inflammatory factors and white matter damage,[25] proposing that asphyxia, maternal infection (such as urinary tract infection), and chorioamnionitis might be related to CP through a common mechanism.

Neuropathologic Classification

In the mid-twentieth century, the idea of neuropathologic classification was proposed in an effort to reflect and highlight the inability to relate brain structure to brain function. The advent of neuroimaging has not yet significantly advanced the ability to classify CP by neuropathology. Ultrasound, magnetic resonance imaging, computed tomography, and volumetric studies have not demonstrated consistent structure or functional relationships.[21] However, as science has learned more about the developing

brain, a theory of selective vulnerability has developed. Two important associations have been described: (1) periventricular leukomalacia with prematurity, and (2) basal ganglia injury with term asphyxia. Newer and functional imaging techniques with different discriminatory abilities might contribute significantly to a neuropathologic classification of cerebral palsy in the future.[26]

Supplemental Classification and Associated Conditions

The supplemental classification describes the associated conditions or impairments found in children with CP and attempts to connect them to the physiologic and topographic classifications.[21] The idea is to identify syndromes that have a common etiology and ultimately lead to prevention. Bilirubin encephalopathy is a prototypical example of such a syndrome, and includes choreoathetoid cerebral palsy, vertical gaze palsy, dental enamel dysplasia, and sensorineural hearing loss. It has a predictable clinical course, with extensor spells during the first few months, followed by hypotonia, then choreoathetosis, and finally dystonia during adolescence. Despite a few such examples, the associations between supplemental disorders (associated impairments) and physiology or topography generally have low sensitivity and specificity.[21] Individuals with CP must each be evaluated for an array of associated conditions, including deficits in hearing, vision, cognition, and academic achievement.

Functional and Therapeutic Classifications

Minear and the Nomenclature and Classification Committee[9] originally added functional and therapeutic classifications for cerebral palsy simply to be comprehensive. The functional classification addresses the degree of severity of the condition based on limitation of activity. The therapeutic classification divides cases into 4 categories: nontreatment, modest interventions, need for a cerebral palsy treatment team, and pervasive support.

Much has changed with regard to therapeutic interventions since the 1950s. The number of interventions is significantly greater. Interventions are applied not only to the primary motor dysfunction but also to associated disorders or conditions. Service delivery systems have shifted from clinical or hospital settings to schools and the community. Therefore, older therapeutic classification systems have required adaptation. Capute and colleagues[27] interpreted CP as part of a broader syndrome of brain dysfunction, in turn suggesting that CP be part of a broader spectrum of motor dysfunction. They pointed out that in some cases, the most limiting factor is not the motor impairment, and that the treatment of CP should extend beyond the motor deficit to associated cognitive, communicative, convulsive, or behavioral conditions that affect therapeutic and functional (adaptive) success.

Interest in functional classifications has recently intensified due to a broader understanding of outcome. Newer measures of functional abilities in cerebral palsy have evolved. The World Health Organization International Classification of Functioning, Disability, and Health (ICF)[28] articulates three categories of function: impairment (the *capacity* to perform), activity limitations (the *ability* to perform), and participation restrictions (the *opportunity* to function).

Cerebral Palsy Classification for Epidemiologic Surveillance

Throughout the 1960s and 1970s, issues related to the classification of CP were largely addressed from a clinical perspective. However, in the 1980s, with rising interest in monitoring CP prevalence among populations as public health markers of rapidly changing neonatal care, significant consideration was given to classification of CP from an epidemiologic perspective. Evans' ''limb-by-limb'' classification method

looked at central motor abnormalities based on neurologic type: hypotonia, hypertonia (including stiffness, spasticity, and rigidity), dyskinesia, and ataxia.[12] This classification method included information on each limb, the head and neck, functional mobility and manual dexterity, as well as associated conditions (intellectual and sensory impairments, communication problems, seizures), neuroanatomy, and etiology (congenital and acquired malformations, genetics). Based on different methods and lack of reliability of subtype classification among centers, the SCPE (the previously mentioned European network of population-based surveys and CP registers) adopted a simple classification of 4 CP subtype groups: unilateral spastic, bilateral spastic, dyskinetic, and ataxic. The SCPE participants developed a classification tree[14] and a reference and training manual in CD format that includes video examples of the different clinical patterns of neurologic signs and motor function impairments.[29] Those useful tools have promoted a standardized way of classifying CP subtypes. Groups in other countries, including the United States (Atlanta),[30,31] Western Australia,[32] Quebec, Canada,[33] and South-east Australia,[18] have adopted similar classification systems. Data from these groups have shown similar distributions of CP subtypes.[34] However, work continues toward improving reliability of this classification system.[35] Recent advances in neuroscience and technology, as well as increasing knowledge of age-related features, have led to consideration of broader anatomic features, radiologic findings, causative factors, and timing of injury.[36,37]

International surveillance systems are now using formalized methods to assess function in addition to impairment. The Gross Motor Function Measurement Scale (GMFMS, 88 or 66 items) was developed for clinical use, reduced to a 5-point scale for epidemiologic purposes, The Gross Motor Function Classification System (GMFCS)[38] and extended and revised in 2007. More recently, similar scales for fine motor abilities have been developed: the Manual Ability Classification System (MACS) and the Bimanual Fine Motor Function (BFMF) scales. GMFCS and MACS have been validated and are available online.[39,40] BFMF takes into account asymmetry and allows data to be extracted from medical records. Comparability of results across monitoring programs is greatly facilitated by the use of these measures. Cans and colleagues[34] compared surveillance data reported by groups in South-east Australia, Norway, Sweden, and France. In the studies reviewed, the proportion of more severely impaired children (level IV/V) on either the GMFCS or BFMF was around 25% to 35% of all CP case children. They found the dyskinetic group to have the highest variability between study sites, which not surprisingly suggests difficulties in classifying mixed types and lower frequencies of dyskinetic CP.

METHODOLOGY

Researchers have employed a variety of methods to measure the frequency of CP in the population. This frequency is measured as prevalence, which is the proportion of the number of individuals with CP among a defined population with CP at a specified period in time. In the United States, there are 5 predominant methods for obtaining prevalence data: (1) notification (reportable disease surveillance); (2) disease registries; (3) periodic population-based surveys; (4) secondary use of administrative data systems; and (5) ongoing, population-based record review.[41] Each data collection mechanism has a different primary purpose, which for most is not estimation of CP prevalence. Therefore, although all systems provide useful information, there are strengths and limitations to each as they pertain to obtaining a complete count of the number of children with CP in a defined community at a specified period in time.

Notification (Reportable Disease Surveillance)

In the United States, all states have laws that require the reporting of selected infectious diseases to the local, district, or state health department. These passive, provider-based reporting systems rely on the receipt of individual case reports from physicians, laboratories, and health care providers, and are simple and nonburdensome. Sometimes developmental disabilities such as CP are also included in such systems. One example is the Georgia Birth Defects Reporting and Information System (GBDRIS), which provides information to the Georgia Department of Human Resources on the incidence, prevalence, trends, and epidemiology of birth defects and related conditions in children from birth to age 6 years. CP is one of the conditions monitored. Because CP is often diagnosed after birth by medical providers in a variety of health care settings, it is not easily captured through a notifiable disease-reporting system such as the GBDRIS, which relies primarily on birth hospitals for case identification.

Disease Registries

Disease registries rely on the voluntary reporting of individuals with specific diseases and are usually based on service provision. Because disease registries are often clinic based, children who do not visit the participating clinics would not be counted in any prevalence estimates produced through analysis of registry data. As a result, disease registries may not be representative of a population.

Periodic Population-based Surveys

Periodic population-based surveys involve the systematic collection of information using a standardized data collection instrument administered as an in-person interview, self-completed questionnaire, or by telephone, or mail. In the United States, The Centers for Disease Control and Prevention's (CDC), The National Center for Health Statistics (NCHS), administers the National Health Interview Survey (NHIS) which includes a Disability Supplement (1994–1995) and Sample Child File (1997–2006) that provide information related to participants' experiences with children and disability. Another NCHS population-based survey that provides valuable information related to developmental disabilities is the State and Local Area Integrated Telephone Survey (SLAITS), which includes the National Survey on Children with Special Health Care Needs (2001). These surveys are conducted using a large sample size and as such are believed to be representative of national characteristics. In addition, these surveys are often more timely than other active methods of data collection. The Sample Child File, for example, is produced annually. Nevertheless, administration of population-based surveys can be labor intensive and costly. Moreover, the collection of data through parental or guardian report is subject to recall bias (that is, differences in accuracy or completeness of reporting information on risk factors and behaviors, due to disparities in recall of past events or experiences between individuals with a diagnosis compared to those without such a diagnosis) and selection bias (differences in the characteristics between individuals participating in a study and those who are not). A further limitation of these surveys that may be particularly important for a population affected by developmental disabilities is that no data are collected for individuals who live in a residential treatment facility or institution.

Secondary Use of Administrative Data

Many administrative data systems with individual-level data can be used for the public health surveillance of developmental disabilities. The most common of these

include hospital discharge data, health insurance and Medicaid billing data, and managed-care encounter data. Because these systems are not designed for public health surveillance, the accuracy and completeness of diagnostic information may be uncertain. Other administrative data systems rely on the use of existing aggregate rather than individual-level data. These passive surveillance systems examine federal-, state-, and county-level data for individuals receiving education or diagnostic and treatment services. One example in the United States is the Office of Special Education Programs (OSEP) Annual Reports to Congress on the Implementation of the Individuals with Disabilities Education Act (IDEA). This provider-based reporting mechanism relies on receipt of aggregate reports from each school district in the United States. This type of data collection method is simple, timely, and not burdensome. However, the system may underestimate the population prevalence because not all children with disabilities receive special education services through the school system. Prevalence estimates for some disabilities such as intellectual disabilities can be obtained using OSEP data because there are specific special education exceptionalities for these disabilities. However, it is not possible to describe the special education services of children with CP or measure prevalence of CP using OSEP Annual Reports for several reasons: (1) the program area in which significant numbers of children with CP are served (ie, orthopedic impairment) also includes children with other motor disorders; (2) many children with CP receive services under the other health impairment exceptionality, which is a program area for children with other medical conditions as well; (3) those with co-occurring intellectual disability (ID) are most often served through an ID exceptionality.

Ongoing, Population-based Record Review

Ongoing, population-based record review is an active surveillance system whereby information is systematically collected on individual children by standardized data collection instruments through review of existing records at administrative data sources. Programs using this method track the number of children identified with CP using multiple sources in the community that diagnose, treat, or serve children with developmental disabilities. Examples of this type of data collection include the CP surveillance programs in the United States and internationally. In the United States, the ADDM Network, funded by the Centers for Disease Control and Prevention, currently conducts surveillance of CP and other developmental disabilities in 4 communities. SCPE and the Australia Cerebral Palsy Register, which is comprised of numerous registers for CP surveillance across Australia, conduct record reviews and receive notification of CP cases from other reporting sources.

For this type of surveillance, participants do not need to be contacted as a part of data collection, so there is minimal burden on families affected by CP. Objective reliable methods for determining surveillance case definition are established, and extensive training and quality control measures are implemented to ensure adherence to data collection and case determination guidelines and reliable resultant prevalence estimates. Many of the surveillance programs that employ population-based record review do not depend solely on previously documented CP diagnoses to identify children, as descriptions of motor findings consistent with CP are also used to determine case status. Incorporating information from multiple health, education, and service providers rather than relying on only one facility or one type of facility to identify children allows for more complete coverage for case identification in a defined population. Because individual-level data are collected, the identified case series may also be used to address future research questions and may be linked to other databases such as birth certificate files and census data, providing even more information about

individuals with CP. The surveillance programs in the United States, Europe, and Australia have been ongoing for many decades, thus affording the ability to examine prevalence estimates of CP in the same population and using the same methods for classifying CP over time. The ADDM Network is strengthened by its heterogeneous population characteristics that enable examination of various racial/ethnic subgroups.

Although this method provides a reasonably complete picture of the population affected by CP, there are some limitations. Because this is an active surveillance method using multiple sources, it is more labor and time intensive and costly to operate than most passive systems. For the ADDM Network, in particular, which relies solely on records, information within the system is dependent on the availability and quality of these records. Some of the records may not contain the necessary information to confirm case status because the system relies on information that has been collected for purposes other than public health surveillance. For the system in the United States, the prevalence of children with mild CP may be underestimated, because these children may not have come to the attention of service providers in early childhood and records of children in regular education, in private schools, or who are being home-schooled are not reviewed. Nevertheless, data from the ADDM Network indicate that these exceptions likely represent a very small proportion of children with CP.[31]

PREVALENCE

Prevalence is calculated as a proportion, and careful attention is necessary when measuring the numerator and choosing the corresponding population denominator. The international community of epidemiologists, who conduct surveillance of CP, grapples with many of the same methodological issues in obtaining population-based CP prevalence estimates. Issues related to obtaining an accurate numerator include the definition of inclusion and exclusion criteria for case determination, evaluation of completeness of case ascertainment, comparison of prevalence and trends, and ensuring validity. To make appropriate comparisons across surveillance systems and over time, it is imperative that the details of these issues are well understood.

There are 5 main CP inclusion and exclusion criteria areas that differ across surveillance systems. These areas include (1) the minimum age of survival, (2) hypotonia, (3) severity, (4) postneonatally acquired CP and timing of the injury, and (5) select chromosomal anomalies, genetic syndromes, metabolic diseases, and mitochondrial disorders. A survey of international surveillance systems and registers provided data on the characteristics of these programs.[42] Approximately half of the international surveillance registers do not have a minimum age of survival for inclusion as a CP case. Of those registers that do impose a minimum age criterion, there is considerable variation from 1 to 8 years of age. With respect to severity, many systems do not apply severity criteria to determine case inclusion. Of those that do, often a combination of neurologic signs, dysfunction, motor impairment by age 5 years, or Level 1 on the GMFCS is applied. Most surveillance programs do not include hypotonic CP. Data from the ADDM Network, which does include hypotonic CP cases in its monitoring efforts, found only 2.6% of cases had hypotonic CP.[31] The overwhelming majority of CP registers includes postneonatally acquired CP cases and has the ability to exclude these children for specific analyses. Of the programs that define a maximum age of cerebral damage, the age varies from 2 to 8 years. Two set of criteria currently exist detailing the specific chromosomal anomalies, genetic syndromes, and metabolic and mitochondrial disorders that constitute CP. Many of the current surveillance programs operationalize the Badawi[17] or SCPE[14] criteria.

All surveillance programs are faced with the challenge of attaining complete ascertainment of all children with CP within a specified geographic area at a specific

period in time. From the perspective of birth prevalence, one issue influencing under ascertainment is migration from the surveillance area between birth and age of identification. If it is not possible to follow the entire birth cohort to determine the CP status at the defined age, then birth prevalence will be an underestimate of the ''true prevalence'' because a proportion of CP cases migrate beyond geographic ascertainment. Another challenge for ascertainment is the type of source for data collection. Three sites in the ADDM Network, which relies on multiple source record review, do not have access to education records, rather only records from clinical and service providers. Although data from the Metropolitan Atlanta Developmental Disability Surveillance Program (MADDSP), one of the ADDM Network sites, indicate that prevalence of CP is not significantly affected by under ascertainment of CP cases identified uniquely from special education sources, prevalences reported from the other three sites is likely an underestimate. MADDSP can only review records of children receiving public education and therefore may miss children who are in private school or are being home-schooled. As previously mentioned, this is believed to be a small proportion of CP cases (because many are identified through clinical sources) but still remains a source of under ascertainment.

The same rigor that is applied when ascertaining the number of individuals with CP in a specified population must also be used to choose an appropriate denominator for calculation of prevalence. The most common denominator used to report CP prevalence is live births. Many CP registers also report prevalence using neonatal survivors as the denominator. Live birth and neonatal survivor denominator data are useful when examining etiologic questions. It can be argued that neonatal survivors are the more appropriate denominator as neonatal deaths do not have the potential to be ascertained as CP cases. Use of neonatal survivors is particularly important when examining CP prevalence by birth weight (BW) or gestational age, as infants of extremely low birth weight (ELBW, <1000g) very low birth weight (VLBW <1500g) or preterm birth (< 37 weeks gestation) have a higher neonatal mortality rate than those of greater birth weights or gestational ages. Therefore, at lower birth weights and earlier gestational ages, the effect of using these 2 different denominators can be significant. Paneth and colleagues[43] stipulate that using live births as the denominator for lower birth weight groups is the only means of obtaining a picture of the net contribution of improving survival to the population prevalence of CP. The choice of denominator is one that differs across registers, most often due to ease of availability of vital statistics data. Nevertheless, the denominator must be taken into consideration when comparing prevalence across studies. A handful of surveillance programs use children as the denominator to calculate period prevalence. These data are most informative for service provision and planning. Due to differences across CP surveillance programs with respect to the aforementioned methodological issues, it is crucial that each program assess the comparability of their own program's methods over time and account for any within-program methodological changes before examining trends. Once internal validity is established, comparison of trends across CP surveillance programs is appropriate.

Across the various surveillance programs in developed countries, estimates of CP prevalence overall using live births and neonatal survivors have been comparable, most estimates being 2.0 per 1000 (**Table 1**). Estimates using children as the denominator have been somewhat higher, ranging from 3.1 to 4.4 per 1000. Among population-based studies of CP, males have been found to have a higher prevalence of CP than females, with sex ratios ranging from 1.1:1 to 1.5:1.[31,44,45] Although there have been few studies that examined racial/ethnic differences in prevalence, a higher prevalence in black non-Hispanic children compared with white non-Hispanic children has

Table 1
Prevalence of CP per 1000 live births, neonatal survivors, or children from select epidemiologic studies, 2000 onward

				Overall Prevalence			
Reference	**Location**	**Study Population**	**Birth Cohorts[a]**	**N**	**Denominator**	**Prevalence**	**95% CI**
Colver et al, 2000[55]	North east England	4–10-year-olds	1989–1993	117	47, 691	2.5[c]	2.0, 2.9
Hagberg B et al, 2001[63]	Western Sweden	At least 4 years	1991–1994	241	113, 724	2.1[b]	1.9, 2.4
Parkes et al, 2001[51]	Northern Ireland	5-year-olds	1981–1993	784	NR	2.2[b]	2.1, 2.4
Nordmark et al, 2001[119]	Southern Sweden	5–8-year-olds	1990–1993	145	65, 514	2.2[b]	1.9, 2.6
Topp et al, 2001[52]	Eastern Denmark	At least 4 years	1987–1990	299	NR	2.4[b]	NR
SCPE, 2002[54]	11 European centres	At least 4 years	1980–1990	NR	NR	2.1[c]	2.0, 2.1
Winter et al, 2002[30]	Metropolitan Atlanta, GA, USA	0-year-olds	1986–1991	443	216, 471	2.0[c]	1.9, 2.2
Himmelmann et al, 2005[48]	Western Sweden	At least 4 years	1995–1998	170	88, 371	1.9[b]	1.7, 2.2
Sundrum et al, 2005[120]	United Kingdom	At least 2 years	1982–1997	293	105, 760	2.8[b]	NR
Bhasin et al, 2006[45]	Metropolitan Atlanta, GA, USA	8-year-olds	1992	135	43, 593	3.1[d]	2.6, 3.7
Serdarogulu et al, 2006[121]	Turkey	2–16-year-olds	1996	186	41, 861	4.4[d]	3.8, 5.1
Watson et al, 2009[122]	Western Australia	At least 5 years	1995–1999	303	126, 681	2.4[c]	2.1, 2.7
Yeargin-Allsopp et al, 2008[31]	Metropolitan Atlanta, GA, USA	8-year-olds	1994	416	114, 897	3.6[d]	3.3, 4.0
Andersen GL et al, 2008[123]	Norway	Birth–4 years	1996–1998	374	NR	2.1[b]	NR
Ameson C et al, 2009[1]	3 United States communities	8-year-olds	1996	227	68, 272	3.3[d]	2.9, 3.8

[a] Most recent birth cohort(s)/time period is reported.
[b] Live birth as denominator.
[c] Neonatal survivor as denominator.
[d] Children as denominator.
Abbreviations: CI, confidence interval; NR, not reported; Prev, prevalence.

been reported for 3 time periods in metropolitan Atlanta and overall from the 3 CDC ADDM Network sites in 2002.[31,44,46,47] Among all studies of CP, spastic subtypes have been found to be more common, with fewer percentages of the ataxic and dyskinetic subtypes.[30,31,46,48] Little is known currently about the prevalence of CP in developing countries. Whereas differences in reported prevalence may reflect accurate differences in population prevalence, variations may also reflect differences in the methodology of both the numerator and denominator. Efforts are being made to foster international communication to understand these variations and strive for comparability where possible. One of the greatest strengths of the numerous surveillance registers in existence is that they have been in operation for many decades, which affords the opportunity to examine trends in CP prevalence over time.

Neonatal intensive care practices have experienced a dramatic evolution over the past 3 decades and these changes have had significant effects on infant mortality and morbidity. The early 1980s were marked by use of enhanced assisted ventilation; the 1990s brought the introduction and widespread use of surfactant and antenatal and postnatal steroid therapies. The American Academy of Pediatrics 2002 recommendations brought yet another practice shift, with decreased postnatal corticosteroid use and emphasis on sepsis prevention methods.[49,50] In many areas, the overall prevalence of CP has been stable over time.[30,51] In other areas, overall CP prevalence has varied. For birth years 1987 through 1998, Western Sweden found a significant decline in their total CP prevalence.[48] In Denmark, Topp and colleagues[52] also found a significant decreasing trend in overall CP birth prevalence from their 2 most recent time periods; 3.0 in 1983 through 1986 to 2.4 in 1987 through 1990. When data from the SCPE Network were harmonized, they found that an overall upward trend in the late 1970s was followed by a plateau in the 1980s and a nonsignificant downward trend toward 1990 in the overall prevalence of CP.[53,54] To the contrary, data from north-east England from 1964 through 1993 indicated a consistent upward trend from 1.7 per 1000 neonatal survivors in 1964 through 1968 to 2.5 per 1000 neonatal survivors in 1989 through 1993.[55] Nevertheless, all surveillance programs have experienced substantial prevalence changes over time within various risk factor subgroups, such as among those born with ELBW (<1000 g) and VLBW (<1500 g), or very preterm (< 32 weeks).

CAUSES AND RISK FACTORS

A plethora of research has been conducted on the causes and risk factors of CP, most of which indicates that the causal pathways may be numerous and the etiology multifactorial. Examination of risk factors is commonly categorized by the timing of their proposed occurrence: prenatal, perinatal, and postnatal. Prenatal and perinatal risk factors include ELBW and VLBW, preterm birth, neonatal encephalopathy, multiple pregnancy, assisted reproductive technology, infection and inflammation, and genetic factors. Prevention of postnatal causes holds the most promise for decreasing the prevalence of CP.

Birth Weight and Gestational Age

The inverse relationship between increased risk of CP and being born at lower birth weights or earlier gestational ages, or both, has been consistently well supported over time (**Table 2**). Population-based surveillance data indicate that the prevalence of CP among VLBW children ranges from 51 to 73 per 1000 neonatal survivors, and is lowest (1–2 per 1000 neonatal survivors) and most reflective of overall prevalence for children born at normal birth weight (NBW) (≥2500 g). Similar results, in terms of

Table 2
Prevalence of CP per 1000 live births or neonatal survivors by birth weight or gestational age from select epidemiologic studies, 2000 onward

			Birth Prevalence								
			Overall			<1500 g		1500–2499 g		≥2500 g	
Reference	Location	Birth Cohorts[a]	N	Prev	95% CI	Prev	95% CI	Prev	95% CI	Prev	95% CI
SCPE, 2002[54]	7 Centres in Europe	1980–1990[d]	3444	2.1[b]	2.0, 2.2	72.5	67.5, 77.7	11.1	10.4, 11.8	1.1	1.1, 1.2
Winter et al, 2002[30]	Metropolitan Atlanta, Georgia	1986–1991	443	2.0[b]	1.9, 2.2	59.5	50.3, 69.6	6.2	5.0, 7.7	1.1	0.9, 1.2
Himmelman et al, 2005[48]	Western Sweden	1995–1998	170	1.9[c]	1.7, 2.2	63.4	46.2, 87.2	6.7	4.4, 10.2	1.2	1.0, 1.5
Watson et al, 2009[122]	Western Australia	1995–1999	303	2.4[b]	2.1, 2.7	50.7	37.8, 63.6	8.3	6.1, 10.5	1.6	1.4, 1.9
						28–31 weeks		32–36 weeks		≥37 weeks	
SCPE, 2002[54]	7 Centres in Europe	1980–1990[d]	3444	2.1[b]	2.0, 2.2	79.5	73.3, 86.0	8.0	7.2, 8.8	1.2	1.1, 1.2
Himmelman et al, 2005[48]	Western Sweden	1995–1998	170	1.9[c]	1.7, 2.2	50.1	36.6, 68.6	6.7	4.7, 9.5	1.1	0.9, 1.4
Watson et al, 2009[122]	Western Australia	1995–1999	303	2.4[b]	2.1, 2.7	35.0	26.5, 43.5	4.9	3.4, 6.4	1.7	1.5, 1.9

[a] Most recent birth cohort(s)/time period is reported.
[b] Neonatal survivors as denominator.
[c] Live births as denominator.
[d] Birth cohorts across centers vary.
Abbreviations: CI, confidence interval; Prev, prevalence.

magnitude and differential birth weight risk, are found when examining very preterm, preterm, and term deliveries. While birth weight is more commonly used in epidemiologic analyses to evaluate trends in CP prevalence than gestational age, this is more often attributable to completeness of vital statistics data on birth weight than to implications that this is a more scientifically valid metric.

The effects of neonatal intensive care improvements over time, which differ by birth weight and gestational age, have particular implications for infants born at ELBW (<1000 g) and extremely (< 28 weeks) and very preterm birth (28 - 31 weeks). Data from Cleveland, Ohio, in the United States on the neurodevelopmental outcomes among ELBW children found that survival increased from 49% to 71% from the early 1980s through early 2000s, yet the proportion of ELBW children with CP rose from the early 1980s through 1990s from 8% to 13%, respectively, and then decreased to 5% during the period from 2000 through 2002.[50] Data from eastern Denmark found that the overall significant decline in CP prevalence through the 1980s was driven by a significant decrease among children with CP born very preterm ($\leq$31 weeks).[52] Similarly in the Province of Alberta, Canada, the steep increase in CP prevalence among extremely preterm births peaked in 1992 through 1994 at 131 per 1000 live births and fell to 19 per 1000 live births by 2001 through 2003.[56] Himmelman and colleagues[48] found that in Western Sweden the rising trend among the extremely preterm group in the 1980s stabilized in the early 1990s; this was followed by decreases in the prevalence of CP among children born very preterm, moderately preterm, and term, the latter 2 being statistically significant. Similar results in the association over time between CP and gestational age were found by the Western Australia register.[57] For both systems, in the 1990s the previously similar rates among extremely and very preterm births began to change with the CP prevalence among the extremely preterm group approximately double that of the very preterm group by the late 1990s. Demonstrating geographic differences in the effect of improved neonatal care, Doyle and colleagues[58] found that in Victoria, Australia, the prevalence of CP among ELBW children did not significantly change over 3 cross-sectional equal eras spanning 1979 through 1992, and data from Nova Scotia and North-east England showed a significant increase in prevalence among very preterm infants from 1993 through 2002 and 1970 through 1994, respectively.[59,60]

For VLBW infants (<1500 g), the SCPE Network found that from 1980 through 1996 there was a significant decrease in the prevalence of CP from 60.6 per 1000 live births to 39.5 per 1000 live births for this birth weight group. This significant decline was restricted to children born weighing 1000 through 1499 g and although the point estimates were higher, this trend held true when neonatal survivor denominator data were used.[61] In addition to the previously noted studies on ELBW and preterm birth, These data demonstrate that infants born at less than 1500 g have both a better chance of survival and of not having a severe neurologic motor impairment. The data previously discussed from Cleveland, Ohio, on ELBW infants reported consistent findings for ELBW infants born during the period 2000 through 2002.[50] These data are encouraging. Nevertheless, it is crucial to highlight the continued importance of preventing preterm delivery and VLBW.

Whereas children born with ELBW and VLBW are clearly at greatest risk for CP, more than half of CP cases occurs among infants born at NBW, term, or near-term. Throughout the 1980s and 1990s, there was no apparent decrease in CP prevalence among term infants. Over these time frames, studies have elucidated a handful of causes for CP in term and near-term children, such as intrauterine exposure to infection and coagulation disorders, which point to the potential for prevention.[62] Post-term delivery (>41 weeks) is also a risk factor for CP, reportedly 3 times that of term birth.[16]

Small sample sizes among cohorts of children with CP born at lower birth weights make examination of the characteristics and subtypes of these children challenging. However, a handful of population-based studies have been able to investigate these issues. The decreased trend in the SCPE Network's reports of CP prevalence related to a reduction in frequency of bilateral spastic CP among infants of birth weight 1000g to 1499g, spastic CP for those with birth weight less than 1500 g was predominantly caused by periventricular lesions. Periventricular leukomalacia damages bilateral motor tracts in most cases, leading to bilateral spastic cerebral palsy, whereas periventricular hemorrhage leads to mainly unilateral motor-tract damage and unilateral spastic cerebral palsy. The prevalence data here suggest a decline mainly of periventricular leukomalacia in children of birth weight less than 1500 g. The other subtype that has been examined with respect to birth weight and gestational age is dyskinetic CP. Dyskinetic CP was found to be more common in term newborns compared with those born prematurely. Data from western Sweden found an increase in the prevalence of dyskinetic CP in term newborns from 1983 through 1998.[48,63,64]

Neonatal Encephalopathy

Badawi and colleagues[65] linked the population-based Western Australian case controlled study of a newborn encephalopathy cohort to the Western Australia Cerebral Palsy Register. These investigators compared the characteristics among children whose CP followed newborn encephalopathy with those with CP following an uncomplicated neonatal course. Intrapartum causes of CP were found to be uncommon. Among term infants, only 24% of CP case infants followed newborn encephalopathy, whereas 76% of cases had been normal during the newborn period. Following term encephalopathy, 13% of infants with moderate to severe encephalopathy developed CP. The highest rate was among those with neonatal seizures. Those with term encephalopathy and CP were more likely to have a severe, spastic quadriplegic or dyskinetic subtype, and were 4 times more likely to die during the period from diagnosis through 6 years of age.

Multiple Pregnancy

CP occurs more commonly among multiple births. In the Epipage Study, Bonellie and colleagues[66] used a Scottish register for 1984 through 1990 to examine etiologic factors and patterns of CP among multiple and singleton births. This study found twins to be 4.8 times more likely to develop CP than singletons. Being a twin was found to carry an increased risk of CP independent of prematurity and birth weight. Looking at birth weight for gestational age, twins had from 3.5 to 5.5 times higher rates of CP in all quintiles of birth weight, the greatest variance being in the lowest quintile. Death of a co-twin increased the rate of CP by a factor of 6 compared with when both twins were live-born. Twins were more likely to develop spastic quadriplegia, whereas singletons were more likely to develop dyskinetic or ataxic CP. Birth order had no effect on the rate of CP. Discordance of at least 30% was associated with a 5-fold greater risk of CP, equally distributed between the larger and smaller twin. Pregnancy complications (such as growth restriction) were not associated with CP among twins over and above the risk from preterm birth itself. The rate of CP associated with delivery preterm of a growth-restricted infant was lower than for other causes of preterm delivery, perhaps because such delivery is often by elective cesarean section avoiding the inflammatory risks of labor.

Assisted Reproduction

Reproductive technologies are emerging rapidly, as a result, their possible association with developmental outcomes is an area of wide interest. Several studies from

Denmark have provided information on such associations. Lidegaard and colleagues[67] demonstrated a statistically significant 80% increase in CP among singleton children conceived by in vitro fertilization (IVF). Pinborg and colleagues[68] compared outcomes of twins and singletons conceived by assisted reproductive technologies (ART) and naturally conceived twins. They cross-linked the national medical birth registry, the In Vitro Fertilization Register, National Patients' Register, and the Danish Psychiatric Central Register to examine outcomes of conceptions that occurred during the period 1995 through 2000. Twins conceived using ARTs had a similar risk of neurologic sequelae as naturally conceived twins and singletons conceived using ARTs.

Hvidtjorn and colleagues[69] published a population-based cohort study, that included all live-born singletons and twins born in Denmark from January 1, 1995 through December 31, 2000. Children conceived with in vitro fertilization (9,255 children) were identified through the In Vitro Fertilization Register; children conceived without in vitro fertilization (394,713 children) were identified through the Danish Medical Birth Registry. CP diagnoses were obtained from the National Register of Hospital Discharges. This group found that it was the increased proportions of preterm deliveries following IVF for twins and singletons that were associated with the increased risk of CP. The independent effect of in vitro fertilization vanished after additional adjustment for multiplicity or preterm delivery.

Infection and Inflammation

The role of infection and inflammation in the etiology of preterm birth has gained prominence in recent years.[70] It is known that preterm infants have higher rates of exposure to ascending intrauterine infection. The prevalence of positive amniotic fluid cultures and raised amniotic fluid cytokines remains high in women who have labor earlier than 34 weeks, regardless of low rates of bacterial vaginosis, chorioamnionitis, and urinary infection in pregnancy.[71] It remains unclear whether cytokines can cross the placenta and how much of the measured fetal load is of maternal origin. It has been suggested that cytokines measured in maternal or fetal compartments reflect local inflammation.[72]

Nelson and colleagues[73] examined DNA extracted from archived blood samples from very preterm infants with CP and matched controls. These investigators looked for the presence of single nucleotide polymorphisms in proteins associated with nitric oxide production, thrombosis or thromboprophylaxis, hypertension, and inflammation. Genotypic frequencies in several of the tested variants were differentially distributed in children with CP and controls. These variations in genetic coding may affect protein function/interaction, altering the balance between inflammation and suppression.

Graham and colleagues[74] performed a retrospective case-control study over a 7-year period of birth (1994–2001) of births of 23 through 34 weeks' gestation with white matter lesions and gestational age-matched controls. Severe intrapartum hypoxia/ischemia was found to be a rare association with white matter injury in this preterm group. Case infants had significantly higher rates of positive cultures of blood, cerebrospinal fluid, and tracheal fluid than control infants. Chorioamnionitis and funisitis were not associated histologically with white matter injury. These results suggest that multiple insults converge on cytokine production as a final common pathway to central nervous system injury. Some insults cause direct damage; other insults prime the immune system, making the fetal brain more vulnerable.

Several investigators have theorized a stepwise pathway of sensitization followed by injury, so that mild hypoxia may be damaging if the baby's compensatory mechanisms have been downregulated or disabled by another inflammatory insult.[75–77]

Genetics

An increasing body of evidence points to strong genetic influences on the occurrence of CP, and a multifactorial inheritance pattern is suggested. This evidence implies etiologic and genetic heterogeneity with complex interactions, and multiple environmental influences.[78] There are multiple points along a causal path for cerebral palsy that may be vulnerable to genetic variations. Single nucleotide polymorphisms and thrombophilias provide examples.

Single nucleotide polymorphisms in proteins are associated with the *inflammatory* process (eg, nitric oxide production, thrombosis or thromboprophylaxis, hypertension, and inflammation). Variations in the genetic coding may affect protein function or interaction, altering the balance between inflammation and suppression.[70]

The coagulation cascade is the body's response to a breach in the vascular system and is part of the body's hemostatic mechanism. The coagulation cascade normally is balanced by procoagulation and anticoagulation mechanisms. However, there are instances in which this balance is altered to favor either procoagulation or anticoagulation. Thrombophilia favors procoagulation and is an inherited or acquired condition that predisposes individuals to thromboembolism. Common inherited thrombophilias include mutations in factor V Leiden, polymorphisms in the gene for 5,10-methylenetetrahydrofolate reductase (MTHFR) associated with hyperhomocysteinemia, and mutations in the plasminogen activator inhibitor-1 (PAI-1) gene.[79–81]

Most thrombophilias require another risk factor to express the adverse phenotype. In pregnancy the overall homeostatic balance is already altered toward hypercoagulability. The presence of inflammatory cytokines (perhaps upregulated in response to infection) in conjunction with an inherited thrombophilia may provoke the development of thrombosis. Thromboses as well as inflammation have been implicated as important factors in the causal pathway of CP.[81]

A group from South Australia[80] performed a population-based, large case-control study to investigate associations between CP and hereditary thrombophilias. These investigators compared the prevalence of thrombophilic polymorphisms, common in white populations, in different types of CP cases at different gestational ages and in controls. Genomic DNA from newborn screening cards of 443 white CP case infants and 883 white control infants was tested for factor V Leiden (FVL, G1691A), prothrombin gene mutation (PGM, G20210A), and 2 single base mutations of methylenetetrahydrofolate reductase (MTHFR C677T and MTHFR A1298C). Term CP was not associated with any of these thrombophilias. FVL and PGM were not found to be associated with CP when they existed alone. MTHFR C677T (homo- or heterozygous) was associated with a significant increased risk of diplegia, especially earlier than 32 weeks. MTHFR A1298C (homozygous) was negatively associated with quadriplegia (odds ratio 0.33 [CI 0.1–0.87]). Combinations of thrombophilias had additive effects.

Genetic variations play a role in the complex interrelationship involving inflammation, coagulation, control of blood flow, and function of vascular endothelium in placenta and brain. Maternal and pregnancy conditions such as preterm birth, placental abruption, preeclampsia, and chorioamnionitis are affected. Environmental factors interact with genetic characteristics to produce risk.[82]

ASSOCIATED IMPAIRMENTS AND CONDITIONS

The defining motor impairments of CP are often accompanied by cognitive, behavioral, and sensory impairments, as well as epilepsy. Data from population-based studies have reported the proportion of children with CP with co-occurring impairments to range from 31% to 65% for intellectual disability (IQ <70), 20% to

46% for epilepsy, 2% to 6% for hearing loss, and 2% to 19% for vision impairment (**Table 3**). The 2 studies that examined speech and language deficits as associated conditions showed that 28% to 43% of children with CP have this co-occurring condition. The MADDSP in Atlanta, the only surveillance system to monitor autism spectrum disorders (ASDs) in addition to CP, found that 9% of children with CP had an ASD. The severity of the associated impairments often has a profound impact on the ability to assess impairments, management, functional attainment, and life expectancy. Therefore, differential classification of CP must be accompanied by information about not only the core but also the associated impairments.

Cognitive Impairment

More than half of individuals with CP have some type of intellectual or neuropsychological impairment; however, there is not a definitive or absolute correlation between the degree of intellectual impairment and the type or subclass of CP.[83] The severity of spastic motor impairment does correlate with the degree of cognitive deficit. Those with spastic quadriplegia have the highest risk of cognitive impairment and those with spastic hemiplegia the lowest. This finding is in contrast to dyskinetic types, wherein this relationship is not present.[84] There is also a strong association between greater intellectual impairment in children with CP and the presence of epilepsy, an abnormal electroencephalogram (EEG), or an abnormal neuroimaging study.[85]

There are clearly exceptions, and it is crucial that persons with significant physical involvement be afforded the opportunity to demonstrate their mental abilities. Children with different forms of CP may be difficult to assess because of the motor deficits, and in some forms of CP (eg, spastic diplegia) the differences between performance and verbal intelligence test scores actually increase with age.[86] Nonverbal learning impairments, with relative weaknesses in visual-spatial abilities, are common.[87,88] The proportion of children with CP and without severe associated impairment has been reported to vary from one third to one half depending on CP type and birth weight.[34] About 40% of children with hemiplegia have normal cognitive abilities, whereas most children with tetraplegia are severely cognitively impaired.[83,89] There is no association between cognitive level and location of brain damage (left or right).[90]

The impact of associated cognitive impairment must be considered when informing parents about their child's prognosis. Severe intellectual impairment, for example, has a strong influence on walking ability in children with unilateral spastic CP.[91] In addition, children with cerebral palsy and intellectual disability are more likely to experience emotional and behavioral symptoms.[92]

Speech impairment, including dysarthria and aphasia, is common and strongly associated with the type and severity of motor involvement. For example, articulation disorders and impaired speech intelligibility are present in 38% of children with CP. Language (as opposed to speech) deficits in CP correlate with intellectual limitations.[93]

Epilepsy

Odding and colleagues[83] reported that between 22% to 40% of people with cerebral palsy have epilepsy, with the prevalence varying by subtype. Epilepsy was reported in 28% to 35% of children with hemiplegic CP, 19% to 36% with tetraplegic CP, 14% with diplegic CP, 13% to 16% with ataxic CP, and 8% to 13% with dyskinetic CP. These results are consistent with those of other studies.[93] Epilepsy is most prevalent in quadriplegia (50%–94%), followed by hemiplegia and tetraplegia. Higher prevalence is also associated with more severe disability. Among those with severe cognitive impairment, 94% have epilepsy.[89] Children with CP and epilepsy tend to have a more severe epilepsy course. Studies have shown children with CP to have a higher

Table 3
Proportion of children with cerebral palsy with co-occurring developmental disabilities

Study	Study Population	Study Year(s)	Proportion of Children with CP with Co-Occurring Condition					
			Intellectual Disability	Epilepsy	Hearing Loss	Vision Impairment	Autism Spectrum Disorders	Speech and Language
Van Naarden Braun K, Doernberg N, Yeargin-Allsopp M, personal communication; 2009	8-year-olds	2006	43[a]	43	6	16	9	-
Murphy et al[44]	10-year-olds	1985–1987	65[a]	46	4	10	–	-
Watson et al[122]	Birth to 5 years	1995–1999	37[a]	32	4	2	–	-
Himmelmann et al[124]	4–8 years	1991–1998	40[a]	33	–	19	–	-
Beckung E. et al[125]	8–12 years	1991–1997	52[a]	21	2	7	–	43
Surveillance of Cerebral Palsy in Europe (SCPE)[55]	At least 4 years	1980–1990	31[b]	21	–	11	–	–
Andersen GL et al[123]	At least 4 years	1996–1998	31[a]	28	4	5	–	28
Parks J et al[51]	Birth to 5 years	1981–1993	41[a]	20	2	10	–	–

[a] IQ <70.
[b] IQ <50.

incidence of epilepsy with onset within the first year of age (47% versus 10%), history of neonatal seizures (19% versus 3%), status epilepticus (16% versus 1.7%), need for polytherapy (25% versus 3%), and treatment with second-line antiepileptic drugs (31% versus 6.7%). Generalized and partial epilepsy are predominant.[85,93]

Sensory Impairment

The etiologies of diplegic and hemiplegic CP commonly involve pathology of the central nervous system that alters normal development of the somatosensory system.[94,95] Deficits in stereognosis and 2-point discrimination have been found in 44% to 51% of all children with cerebral palsy, with term children most severely impacted.[96] Sensory impairments are most common among those with hemiplegia, in whom 90% have significant bilateral sensory deficits. Stereognosis and proprioception are the chief modalities affected bilaterally. The degree of sensory impairment does not correlate with the degree of motor impairment.[97] Bilateral tactile deficits are common in bilateral spastic (diplegic) and unilateral spastic (hemiplegic) cerebral palsy subtypes, including those with milder motor involvement.[98]

People with cerebral palsy experience more chronic pain than the general population. Back pain is most prevalent across all types of cerebral palsy. Foot and ankle pain is most prevalent in those with diplegia, knee pain in tetraplegia, and neck and shoulder pain and headache in persons with dyskinesia. Chronic pain has been associated with low life satisfaction and deterioration of functional skills.[99–101]

Visual Impairment and Hearing Loss

Visual defects are common in children with CP. More than 70% of children with cerebral palsy have been found to have low visual acuity.[102] Although there is an increased presence of strabismus, amblyopia, nystagmus, optic atrophy, and refractive errors, central visual impairment seems to contribute significantly to the acuity problems. Children whose CP is due to periventricular leukomalacia are also more likely to have visual perceptual problems.[93] For children with cerebral palsy and a history of prematurity there is a higher prevalence of retinopathy, cortical visual impairment, and strabismus than in those with cerebral palsy without prematurity. There is no difference in refractive error between premature children with or without cerebral palsy.[103] Hearing loss is present in approximately 2% to 6% of children with CP. Significant risk factors include VLBW, kernicterus, neonatal meningitis, severe hypoxic-ischemic insults, intellectual disability, and abnormal neuroimaging.[93]

Feeding, Growth, and Endocrine Problems

Feeding problems are common in cerebral palsy.[104] During the first year of life, 57% of children with cerebral palsy have sucking problems, 38% have swallowing problems, 80% have been fed nonorally on at least one occasion, and more than 90% have clinically significant oral motor dysfunction.[105] Among children with spastic quadriplegia, one third require assisted feeding. More severe functional involvement (a GMFCS Level of IV or V) and microcephaly are associated with the need for assisted feeding.[106] (See also Pruitt and Tsai, this issue).

Linear growth is typically reduced in cerebral palsy. The California Department of Developmental Services looked at percentiles of height and weight of patients with CP over a 15-year period. This group found persons with CP to have height and weight centiles close to those of the general population for the highest functioning groups with CP, but to lag substantially for other groups. Presence of a feeding tube was associated with greater height and weight in the lowest functioning groups, with centiles for weight being 2 to 5 kg higher for those with gastrostomy tubes.[107]

Bone mineral density (BMD) is reduced in adolescents with spastic CP. Femoral osteopenia is present in 75% of all children with moderate to severe cerebral palsy, and in almost all children who cannot stand. Children with severe CP develop clinically significant osteopenia over the course of their lives. Unlike elderly adults, this is not primarily from true losses in bone mineral, but from a rate of growth in bone mineral that is diminished relative to healthy children.[108] Multiple aspects of skeletal growth and development, including skeletal maturation, are frequently altered in children with moderate to severe CP.[109] (See also Houlihan and Stevenson, this issue.)

Urogenital Problems

Children with CP gain bladder and bowel control at older ages compared with their siblings and healthy children, and also have more frequent enuresis and urinary infections.[110] Primary enuresis is present in about 25% of children and adolescents with cerebral palsy. The most important determinants are intellectual ability and tetraplegia.[111] Voiding dysfunction has been reported in more than half of children with cerebral palsy.[112] Urinary symptoms and pathologic urodynamic findings increase along with the degree of motor function impairment shown by the GMFCS. Pathologic urodynamic findings can be found in symptomatic and asymptomatic patients.[113] In one study evaluating children with cerebral palsy referred for daytime enuresis at age 10 years, 85% were found to have abnormal videourodynamics, with treatment leading to improvement.[114]

TRANSITIONING

As children with CP reach young adulthood, supportive services such as rehabilitation, special education, and specialized pediatric care often cease. Without these services, young adults with CP can experience new problems with daily activities or worsening of existing conditions, at a time when most have decreased access to services. The new social roles in young adulthood, coupled with the vulnerabilities exacerbated as a result of declining support systems, underscore the need to understand issues across the life span as children with CP grow into adulthood.

Population-based data on the consequences of CP are limited. In the 1990s, the CDC conducted one such epidemiologic study with a subset of children with CP identified through surveillance activities. This study found that 77% of young adults with CP, identified during childhood, experienced limitations in daily functioning. Also, approximately 50% of young adults with CP, without intellectual disability, hearing loss, vision loss, or epilepsy were competitively employed, compared with 16% of young adults with CP and one of these co-occurring developmental disabilities.[115,116] Data from one of the largest studies examining postsecondary education outcomes uses data from the Department of Education and categorizes children based their special education exceptionality.[117] The utility of these data for CP are limited because not all children with CP are receiving services under the same special education exceptionality. Children with CP in special education receive services under several exceptionalities, often differing by the presence of co-occurring conditions. For example, data show that 73% of children with co-occurring intellectual disability receive services under an intellectual disability exceptionality, compared with children with CP with isolated motor impairment, of whom 37%were served through other health impairment, 28% through orthopedic impairment, and 7% through an intellectual disability exceptionality.[118] Much has changed in the past decade since this work was first conducted on young adults by the CDC. It is important to evaluate the effect of current challenges as well as new and unique opportunities that have become

available for individuals with CP, to ensure that individuals with CP have a full range of life options. (See also Riehle and Rutkowski, this issue.)

SUMMARY

Although the definition of CP, the most common motor disability of childhood, has been reexamined in recent years, the core components remain unchanged: it is a disorder of movement and posture; it results from an abnormality in the brain; it is acquired early in life; and the condition is static at the time of recognition. The current definition and classification systems also recognize that the motor impairment is often accompanied by disturbances of sensation, perception, cognition, communication, behavior, epilepsy, and secondary musculoskeletal problems, all of which may significantly impact function. The diversity of clinical features enables CP to be described or classified in a variety of ways. However, challenges arise on adapting clinical classification for epidemiologic studies. For surveillances purposes, epidemiologists have developed systems aimed at improving reliability and enabling comparison of different populations. There are now several international surveillance networks that have collaborated in an effort to support international comparisons. Recent advances have been made toward incorporating measures of functioning into epidemiologic studies.

A variety of methods are used to ascertain cases and measure the prevalence of CP in the population. Surveillance systems in the United States, Europe, and Australia carry out ongoing, population-based record reviews using multiple community sources that diagnose, treat, or serve children with developmental disabilities. Systems in Europe and Australia also use other reporting methods. Incorporating information from multiple health, education, and service providers rather than relying on only one facility or one type of facility to identify children allows for more complete coverage of case identification in a defined population.

Identification of causal relationships in CP has been challenging. The causal pathways for CP are believed to be numerous and the etiology multifactorial. Risk factors are commonly categorized by the timing of their proposed occurrence: prenatal, perinatal, and postnatal. The leading prenatal and perinatal risk factors for CP are birth weight and gestational age. Other risk factors include neonatal encephalopathy, multiple pregnancy, infection and inflammation, and a variety of genetic factors. Population-based surveillance has enabled studies evaluating prevalence and risk factor relationships over time and within different risk subgroups. Population-based data on the longer-term consequences of CP are limited; it will be important in the future to use population-based methods to scrutinize the functional outcomes and consequences of CP in adults.

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