Official Journal of the European Paediatric Neurology Society

Original article

# Population-based study of neuroimaging findings in children with cerebral palsy

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ARTICLE INFO

*Article history:*
Received 2 March 2010
Received in revised form
30 June 2010
Accepted 1 July 2010

*Keywords:*
Cerebral palsy
Neuroimaging
Epidemiology

ABSTRACT

*Background:* Neuroimaging is currently recommended as a standard evaluation in children with cerebral palsy (CP).
*Aims:* Utilizing imaging findings from a population-based registry (REPACQ), the frequency and proportion of cerebral radiologic abnormalities in children CP over a four year birth cohort was investigated.
*Methods:* Descriptions of CT and MRI studies were extracted from the Registry dataset and classified into 10 distinct categories.
*Results:* Two hundred and thirteen children had imaging available (119 males, 94 females, mean age of 44 months [SD. ± 14 months] at Registry inscription). Eighty seven percent of participants had documented cerebral abnormalities, the most common of which were periventricular white matter injury (PVWMI) (19.2%), diffuse gray matter injury (14.6%), cerebral vascular accident (CVA) (11.7%), and cerebral malformation (11.3%). Also, 18.8% of participants had non-specific radiologic findings and 13.1% of participants had normal imaging results. Severe CP (i.e. GMFCS Level IV–V) and spastic quadriplegic CP were significantly associated with the neuroimaging findings of gray matter injury, while spastic hemiplegic CP was association with CVA, and dyskinetic and spastic diplegic CP were both associated with normal and non-specific neuroimaging findings.
*Conclusions:* Specific patterns of neuroimaging findings in children with CP were found to be associated with neurological subtype, CP severity (i.e. GMFCS Level) and other categorical variables.



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doi:10.1016/j.ejpn.2010.07.005

## 1. Introduction

Occurring in 1.5–2.5 children per 1000 live births, cerebral palsy (CP) is considered the most common cause of childhood physical disability.[1] The term CP refers to a spectrum of disorders with varied presentation, etiology, co-morbid conditions, severity, functional implications and service needs. Despite this variability, the core unifying feature of CP is an early onset motor disorder due to a non-progressive congenital or acquired cerebral lesion or abnormality.[2]

Neuroimaging may be used to uncover the cerebral lesions or abnormalities that underlie CP. In 2004, the American Academy of Neurology and the Child Neurology Society jointly published a Practice Parameter recommending routine neuroimaging of all children suspected of having CP.[3] Neuroimaging studies of individuals with CP has the potential to improve our understanding of an individual's CP, by providing insight into its pathogenesis, etiology, and timing.[4]

Though there have been studies analyzing imaging results of children with CP, few have been population-based.[5–8] Population-based studies enable analysis of the whole spectrum of cerebral palsy in a given population, reducing sampling errors and ascertainment bias, providing an accurate measure of CP across subtype and severity categories.[9] Also the potential wide range of categorical variables systematically recorded in population-based registries enables the thorough analysis of factors related to specific neuroimaging results.

Using imaging results from a population-based registry, our objective was to determine the frequency and proportion of cerebral lesions in children with CP and to analyze if any categorical variables recorded in the registry related to specific cerebral abnormalities. Such information may improve our understanding of the pathogenesis of CP which may eventually assist in the development of strategies for possible prevention.

## 2. Methods

Subjects were recruited through the Quebec Cerebral Palsy Registry (REPACQ). REPACQ is a population-based registry initially established in 1998, which became operational in 2004. It includes children born between 1999 and 2002 in 6 of the 17 geographically defined administrative health and social service regions of Quebec. Overall, this represents about half of the annual births in the province of Quebec. To receive universal, government-funded medical and rehabilitation services in Quebec, children with cerebral palsy (CP) are treated at local specialized centers responsible for specific defined geographic regions. Children with CP were identified through systematic surveys of pediatric and health care professionals and administrative data sources at these centers.

To be included in the registry, children had to be over the age of two years and conform to the recent consensus definition of CP as a clinical diagnosis featuring a non-progressive motor impairment of early onset, that is presumably cerebral in origin, which may or may not be associated with developmental delays, cognitive disability, language impairment, epilepsy, sensory (auditory or visual) loss, orthopaedic abnormalities or behavioural difficulties.[2,10,11] A recognized motor impairment required objective changes in tone, muscle strength, posture, reflexes, and motor skills on examination for diagnosis. Diagnosis was by a pediatric neurologist in order to gain entry into the services offered by the regional rehabilitation center. Non-progressive referred to the underlying pathologic process and not apparent clinical manifestations with genetic and metabolic disorders considered for inclusion or exclusion as per Badawi et al.[12] Early onset meant signs and symptoms were evident prior to 1 year of age. By definition, children with neuromuscular disorders and myelodysplasias were excluded from the diagnosis of CP. When possible, the diagnosis of CP was confirmed at 5 years of age. It is acknowledged that this ascertainment protocol would miss those children with severe cerebral palsy who died prior to the age of 2 years and those children with CP so mild that medical or rehabilitation assessment would not be sought.

Parents or guardians of eligible children were approached for consent to participate in the registry. Through a combination of direct review of the maternal and child medical and child rehabilitation records as well as a parental (preferably maternal) directed interview, over 120 variables pertaining to each participating child were sought. Information was entered into a secure, computerized database for further analysis. Ethics approval for the Registry was provided by each participating center. Previous publications are available for further information about REPACQ implementation and methodology of data ascertainment.[13–15] Ethical approval for the Registry was obtained from the host institution (MCH-MUHC) and each pediatric rehabilitation center of recruitment.

Descriptions of any CT and MRI (1.5 Tesla) studies were extracted from the dataset and classified into one of 10 categories in all instances by a single senior neurologist (MS) blinded to the particular registry variables for each child based on the predominant radiologic finding noted. When both CT and MRI findings were available, the MRI results were given precedence. If more than one imaging study was done on a particular child, the last imaging study done was given precedence. A minority of studies had more than one imaging abnormality noted. Imaging studies were originally interpreted by university-based pediatric neuro-radiologists.The categories used were; periventricular white matter injury, cerebral malformation, cerebral vascular accident, gray matter injury, intracranial hemorrhage, infection, non-specific changes and normal. The category "gray matter injury" was further sub-divided into deep brain, superficial and diffuse gray matter injury. Table 1 summarizes the definitions utilized for these various mutually exclusive imaging categories. Imaging category assignment was by these a priori definitions as applied consistently.

Simple descriptive statistics are used throughout this paper. Possible statistical associations between categorical variables were evaluated using Pearson Chi-square or Fisher's exact tests when expected values were less than five. The threshold for statistical significance was established a priori as a p value of 0.05 or less. All statistical analysis was performed using SPSS Statistics (Version 16.0) software.

**Table 1 – Classification of abnormalities in imaging findings.**

| Classification | Description |
|---|---|
| Periventricular white matter injury | Abnormality or volume loss in the periventricular and/or deep white matter |
| Cerebral malformation | Includes cortical dysplasia, polymicrogyria, lissencephaly, pachygyria, heterotopias, schizencephaly, polymicrogyria, cerebellar hypoplasia or dysgenesis, holoprosencephaly, hydranencephaly, hydrocephalus, and agenesis of the corpus callosum |
| Cerebral vascular accident | Infarction in a specifically defined vascular territory |
| Deep brain [sub cortical] gray matter injury | Signal abnormality or volume loss in sub cortical (i.e. based ganglia and thalamus) gray matter structures |
| Superficial [cortical] gray matter injury | Signal abnormality or volume loss restricted to cortical gray matter structures typically associated with an increase in ventricular volume |
| Diffuse gray matter injury | Global/diffuse signal abnormality and/or volume loss involving the cortex/subcortex, deep gray matter, and subjacent (i.e. ventricular enlargement) white matter |
| Intracranial hemorrhage | Epidural, subdural, intracranial or intraparenchymal hemorrhage |
| Infection | Dystrophic, predominantly periventricular, calcification(s) with or without focal white matter destruction, and cerebral hypoplasia, in conjunction with a known positive serology |
| Non-specific | Other unclassifiable changes on imaging (e.g. delayed myelination, widened Vichow-Robin spaces, non-specific ventricular enlargement) |
| Normal | No abnormalities detected or noted |

## 3. Results

In the six administrative regions compromising the REPACQ survey, 300 children with cerebral palsy were born between the years 1999–2002. Since the total number of live births during this four year time period was roughly 144,000, the crude prevalence of cerebral palsy in this region is thus approximately 2.08 per 1000 live births. Parental or guardian consent could not be obtained for chart review and interview of 58 of these children, so the total cohort is comprised of the 242 participants. The participants included 137 males, 105 females. Age at last data ascertainment for REPACQ was a mean of 44 months (±14 months) with a range of 24–79 months. Information on a CT or MRI was available for 213 participants or 88% of the total cohort. Characteristics of the participants included the following; 27 (11.3%) were the product of twin gestation, 105 (44.1%) were preterm, 50 (22.6%) experienced moderate and 14 (6.3%) severe neonatal encephalopathy, 114 (47.1%) experienced an in-utero exposure to alcohol, tobacco or illicit drugs. Ninety-four (38.8%) had a co-existing severe co-morbidity (i.e. epilepsy, cortical visual impairment, severe auditory impairment, enteral feeding or non-verbal). The distribution of neurologic subtypes was as follows; spastic quadriplegia 84 (34.7%), spastic hemiplegia 77 (31.8%), spastic diplegia 52 (21.5%), dyskinetic 16 (6.6%), other [i.e. ataxic-hypotonia, triplegia, monoplegia] 13 (5.4%). The distribution of GMFCS levels were: I-108 (44.6%), II-23 (9.5%), III-30 (12.4%), IV-42 (17.4%), V-39 (16.1%).

When comparing 29 Registry inscribed children without neuroimaging to the 213 with neuroimaging, it is apparent that children born before 37 weeks or children from twin pregnancies were less likely to have had a CT scan or MRI performed. Children delivered by C-Section and those with a severe neonatal encephalopathy were more likely to have had neuroimaging done. Also, children with more severe CP (i.e. GMFCS Level III–V) or children with more co-morbid conditions were more likely to have had imaging. Finally, fewer children with spastic diplegia, and relatively more children with spastic quadriplegia or hemiplegia had imaging.

MRI information was available for 126 participants, while 87 only had CT scans. Of the CT or MRI done, 18.6% were performed during the first two months of life. The distribution of imaging findings from the CT and MRI (where done) are shown in Table 2. The timing of imaging studies is shown in Supplementary Fig. 1. CT scans were undertaken at a mean age of 13.0 months (13.2, range 0–66 months) with a median age of 9.0 months while MRI scans were carried out at a mean age of 14.9 months (12.3 range 0–61 months) and a median age of 13.9 months.

Less cerebral malformations were detected with CT scans than with MRI ($X^2 = 8.994$, $p < 0.05$,df = 1), though otherwise the imaging findings did not differ significantly between imaging modality utilized. The most common neuroimaging findings were: periventricular white matter injury (PVWMI) (19.2%), diffuse (cortical and sub cortical) gray matter injury (14.6%), cerebral vascular accident (CVA) (11.7%), and cerebral malformation (11.3%). Also, 18.8% of participants had non-specific imaging findings (i.e. delayed myelination, widened Virchow-Robin spaces, non-specific ventricular enlargement) and 13.1% of participants had completely normal imaging results.

The frequency of neuroimaging findings by cerebral palsy diagnostic subtype can be found in Table 3a. Children with spastic hemiplegia had a significant increase in CVA and a decrease in normal scans or non-specific results compared to other subtypes. Conversely, children with spastic diplegic CP had a decrease in CVA and an increase in normal or non-specific results. Spastic quadriplegic patients had an increase in gray matter injury collectively and dyskinetic children had an increase in normal or non-specific scan types compared to other neurologic subtypes.

The frequencies of neuroimaging findings by Gross Motor Function Classification System (GMFCS) levels are also shown in Table 3b. Children with gray matter injury were more likely

**Table 2 – Neuroimaging findings.**

| | MRI ($n = 126$) | | CT ($n = 87$) | | Total ($n = 213$) | | Age in months at MRI scan | Age in months at CT scan |
|---|---|---|---|---|---|---|---|---|
| | *n* | % | *n* | % | *n* | % | Mean (SD) | Mean (SD) |
| Periventricular white matter injury | 28 | 22.2 | 13 | 14.9 | 41 | 19.2 | 18.7 (14.3) | 17.2 (18.6) |
| Cerebral malformation | 21 | 16.7 | 3 | 3.4 | 24 | 11.3 | 15.1 (14.9) | 15.0 (2.8) |
| Cerebral vascular accident | 11 | 8.7 | 14 | 16.1 | 25 | 11.7 | 10.4 (8.8) | 13.6 (12.1) |
| Deep brain gray matter injury | 6 | 4.8 | 3 | 3.4 | 9 | 4.2 | 15.5 (8.8) | 10.5 (12.0) |
| Superficial gray matter injury | 3 | 2.4 | 4 | 4.6 | 7 | 3.3 | 5. 0 (3.6) | 10.2 (6.0) |
| Diffuse gray matter injury | 18 | 14.3 | 13 | 14.9 | 31 | 14.6 | 10.9 (8.3) | 6.1 (6.9) |
| Intracranial hemorrhage | 2 | 1.6 | 3 | 3.4 | 5 | 2.3 | 8.4 (11.9) | 0.0 (0.0) |
| Infection | 1 | 0.8 | 2 | 2.3 | 3 | 1.4 | 11.0 (n/a) | 0.0 (0.0) |
| Non-specific | 22 | 17.5 | 18 | 20.7 | 40 | 18.8 | 17.8 (13.1) | 14.1 (13.2) |
| Normal | 14 | 11.1 | 14 | 16.1 | 28 | 13.1 | 13.8 (10.1) | 20.7 (14.2) |
| Total | 126 | 100 | 87 | 100 | 213 | 100 | 14.9 (12.3) | 13.0 (13.2) |

to have severe cerebral palsy without independent ambulation (GMFCS Level IV–V) than children with other scan results. Analysis of the number of weeks of gestation revealed that there was a significant increase in the frequency PVWMI among children born prematurely (i.e. before 37 weeks of gestation), nevertheless 37% of children with findings of PVWMI were born at term. Table 4 shows the frequency of imaging results by gestational age.

## 4. Discussion

Using the REPACQ population-based registry, a crude cerebral palsy (CP) prevalence ratio of 2.08 children per 1000 live births was found. This is near the middle of the reported range of CP prevalence (1.5–2.5 children/1000 live births) in regions comparable to Quebec.[16] This suggests that REPACQ represents a reasonably complete case ascertainment of children with CP. Also, the profiles of the neurological subtypes[17] and GMFCS levels[18] of the total registry cohort were similar to those noted in the recent literature, which suggests that the Registry represents a relatively unbiased sample of children with CP in Quebec.

This study cohort included the children from REPACQ with CT or MRI information available. Children with severe CP (GMFCS Levels IV–V [i.e. non-ambulant]), co-morbidities, and spastic quadriplegic CP or spastic hemiplegic CP were slightly over-represented, while children with spastic diplegic CP were underrepresented. It is possible that doctors and parents were more inclined to request neuroimaging information for children with severe CP or co-morbid conditions. Spastic quadriplegic and spastic hemiplegic CP are correlated with severe CP

**Table 3a – Predominant Neuroimaging findings by distribution of cerebral palsy subtype.**

| | Spastic diplegia ($n = 36$) | Spastic hemiplegia ($n = 71$) | Spastic quadriplegia ($n = 79$) | Dyskinetic (dystonic or atheoid) ($n = 15$) | Ataxic/hypotonic ($n = 9$) | Other ($n = 3$) |
|---|---|---|---|---|---|---|
| Periventricular white matter injury | 11 | 13 | 16 | 1 | 0 | 0 |
| ($n = 41$) | 30.6% | 18.3% | 20.3% | 6.7% | 0% | 0% |
| Cerebral malformation | 2 | 9 | 9 | 0 | 3 | 1 |
| ($n = 24$) | 5.6% | 12.7% | 11.4% | 0% | 33.3% | 33.3% |
| Cerebral vascular accident | 0 | 19 | 5 | 0 | 0 | 1 |
| ($n = 25$) | 0% | 26.8% | 6.3% | 0% | 0% | 33.3% |
| Deep brain gray matter injury | 0 | 1 | 5 | 2 | 1 | 0 |
| ($n = 9$) | 0% | 1.4% | 6.3% | 13.3% | 11.1% | 0% |
| Superficial gray matter injury | 1 | 1 | 4 | 0 | 0 | 1 |
| ($n = 7$) | 2.8% | 1.4% | 5.1% | 0% | 0% | 33.3% |
| Diffuse gray matter injury | 4 | 12 | 15 | 0 | 0 | 0 |
| ($n = 31$) | 11.1% | 16.9% | 19.0% | 0% | 0% | 0% |
| Intracranial hemorrhage | 0 | 2 | 2 | 1 | 0 | 0 |
| ($n = 5$) | 0% | 2.8% | 2.5% | 6.7% | 0% | 0% |
| Infection | 1 | 0 | 2 | 0 | 0 | 0 |
| ($n = 3$) | 2.8% | 0% | 2.5% | 0% | 0% | 0% |
| Non-specific | 7 | 11 | 15 | 7 | 0 | 0 |
| ($n = 40$) | 19.4% | 15.5% | 19.0% | 46.7% | 0% | 0% |
| Normal | 10 | 3 | 6 | 4 | 5 | 0 |
| ($n = 28$) | 27.8% | 4.2% | 7.6% | 26.7% | 55.6% | 0% |

The results represent columnar absolute numbers and percents.

**Table 3b – Predominant neuroimaging findings by GMFCS level.**

| | I ($n=90$) | II ($n=18$) | III ($n=28$) | IV ($n=39$) | V ($n=38$) |
|---|---|---|---|---|---|
| Periventricular white matter injury | 20 | 4 | 7 | 5 | 5 |
| ($n=41$) | 22.2% | 22.2% | 25% | 12.8% | 13.2% |
| Cerebral malformation | 9 | 3 | 1 | 5 | 6 |
| ($n=24$) | 10.0% | 16.7% | 3.6% | 12.8% | 15.8% |
| Cerebral vascular accident | 15 | 3 | 2 | 3 | 2 |
| ($n=25$) | 16.7% | 16.7% | 7.1% | 7.7% | 5.3% |
| Deep brain gray matter injury | 2 | 0 | 0 | 2 | 5 |
| ($n=9$) | 2.2% | 0% | 0% | 5.1% | 13.2% |
| Superficial gray matter injury | 1 | 0 | 2 | 2 | 2 |
| ($n=7$) | 1.1% | 0% | 7.1% | 5.1% | 5.3% |
| Diffuse gray matter injury | 13 | 1 | 5 | 4 | 8 |
| ($n=31$) | 14.4% | 5.6% | 17.9% | 10.3% | 21.1% |
| Intracranial hemorrhage | 2 | 0 | 1 | 2 | 0 |
| ($n=5$) | 2.2% | 0% | 3.6% | 5.1% | 0% |
| Infection | 0 | 1 | 0 | 1 | 1 |
| ($n=3$) | 0% | 5.6% | 0% | 2.6% | 2.6% |
| Non-specific | 15 | 4 | 5 | 12 | 4 |
| ($n=40$) | 16.7% | 22.2% | 17.9% | 30.8% | 10.5% |
| Normal | 13 | 2 | 5 | 3 | 5 |
| ($n=28$) | 14.4% | 11.1% | 17.9% | 7.7% | 13.2% |

The results represent columnar absolute numbers and percents.

(GMFCS Level IV & V),[13] which may have led to the over-representation of these populations as well. This sample bias may have resulted in a slight overestimate of the frequency of cerebral abnormalities, specifically those cerebral abnormalities associated with severe cerebral palsy (i.e. gray matter injury).

The study cohort also underrepresented children born before 37 weeks gestation and children born to twin pregnancies. A previous population-based study in Australia also found that fewer children born preterm received an MRI.[5] The authors proposed this occurred due to more premature children receiving cranial ultrasounds in their neonatal units which were thought by caregivers to be sufficient for revealing the cerebral abnormality underlying their CP.[5] The bias of our study cohort towards term-born children may have caused an under-representation of periventricular white matter injury (PVWMI), which is more common among children born prematurely.[19] However, the frequency of preterm births in our study (39%) was similar to that of the Australian cohort (34%) and comparable to the overall frequency of preterm children in REPACQ (43%).[5–8] The study includes those children who underwent a CT, MRI or both. Slightly more than a third of children underwent a CT, which was more likely, due to lesser spatial resolution, to yield a 'normal' study than MRI. This may have biased downwards the overall abnormal yield of neuroimaging in this population.

The overall frequency of cerebral abnormalities in our cohort was similar to that found in other population-based registries. Cerebral imaging abnormalities were found in 86.9% of our participants compared to 88% in a European cohort[6] and 84% in western Sweden and Australian cohorts.[5,7] The distribution of cerebral abnormalities in our cohort was similar to that found in the Swedish and Australian cohorts except we found a lower frequency of PVWMI and an increase in non-specific images.[5,7] The distribution differed slightly from the European cohort, with a higher proportion of cerebral malformations and cerebral vascular accidents found.[6] There are variations between the classification schemes utilized for these studies, so it is difficult to determine if actual population variations exist.

**Table 4 – Predominant neuroimaging findings by preterm or term gestational age.**

| | Preterm (<37 weeks gestation) ($n=83$) | Term (≥37 weeks gestation) ($n=126$) | $p$ Value |
|---|---|---|---|
| Periventricular white matter injury | 26 | 15 | 0.001* |
| ($n=41$) | 31.3% | 11.8% | |
| Cerebral malformation | 5 | 18 | NS |
| ($n=23$) | 6.0% | 14.2% | |
| Cerebral vascular accident | 6 | 18 | NS |
| ($n=24$) | 7.2% | 14.2% | |
| Deep brain gray matter injury | 2 | 7 | NS |
| ($n=9$) | 2.4% | 5.5% | |
| Superficial gray matter injury | 5 | 2 | NS |
| ($n=7$) | 6.0% | 1.6% | |
| Diffuse gray matter injury | 10 | 21 | NS |
| ($n=31$) | 12.1% | 16.5% | |
| Intracranial hemorrhage | 1 | 4 | NS |
| ($n=5$) | 1.2% | 3.2% | |
| Infection | 1 | 2 | NS |
| ($n=3$) | 1.2% | 1.6% | |
| Non-specific | 15 | 24 | NS |
| ($n=39$) | 18.1% | 18.9% | |
| Normal | 12 | 15 | NS |
| ($n=27$) | 14.5% | 11.8% | |

The results represent columnar absolute numbers and percents.
*Significant; NS, non significant.

Normal imaging results were found for 28 (13.1%) of our participants, 13 of which were from children with the GMFCS Level I. These children may have cerebral lesions or abnormalities which are too subtle to be detected by current neuroimaging technologies. There were, however, 8 (3.8%) children with severe CP (GMFCS Level IV–V) who had normal imaging results. A similar presence of normal imaging results in severe CP patients in the Australian cohort was explained by the extremely early ages at which the imaging was performed.[5] However, since the age at the time of imaging of children with severe CP and normal imaging findings in our study ranged from 1 to 13 months (mean 4.75), age at the time of imaging alone is an insufficient explanation for this observation. Since there are metabolic disorders whose clinical presentations are very similar to CP, some of these children may have indeed undetected and undiagnosed metabolic disorders. Metabolic testing should be performed whenever a child suspected of CP has a normal imaging result.[3] The neurologic subtypes of children with normal imaging findings were similar to those found in previous studies.[5,6] Ten (28%) of the 36 children with spastic diplegic CP and 5 (56%) of the 9 children with ataxic or hypotonic CP had normal imaging results.

The frequency of periventricular white matter injury (PVWMI) found in our cohort (19.2%) was significantly lower than that found in the Swedish (32%), European (42.5%) and Australian (31%) cohorts.[5–7] It is possible that the under-representation of preterm children led to the lower proportion of children with PVWMI. However, this is likely not the complete explanation since our cohort had a larger proportion of preterm children than the Australian cohort (40% vs. 34%).[5] Another possible explanation is the inclusion of both CT scans and MRI, since CT scans are inferior to MRI scans for detecting PVWMI.[20] The Swedish cohort however also included CT scans. It may be that the combination of these two factors was sufficient to result in the reduced frequency of PVWMI found in our cohort or there could be some true variation between these populations.

The greatest risk for PVWMI is among children born at 23–32 weeks gestation,[19] so as expected, our study found an increase in PVWMI among children born prematurely. However, 37% of children with PVWMI in our cohort were born at term. Though this frequency is greater than that reported in the European study[6] (25%) and a 2007 review of neuroimaging in CP[4] (20%), it is similar to that found in the Swedish cohort[5] (36%) and even less than that of the Australian cohort[7] (52%). The variation in frequency of PVWMI between studies and the unexpectedly high incidences of PVWMI among children born at term in several studies indicate that further research is needed in this area. Similar to other research groups,[5,6] our study found that patients with PVWMI predominantly had spastic diplegic CP and were ambulant (GMFCS Levels I–III). However, neither of these findings reached statistical significance.

The frequency of cerebral vascular accidents (CVA) in our cohort (11.7%) was slightly higher than that found by the European cohort (7.4%) and Australian cohort (9.7%).[5,6] Similar to these studies, we found that CVA was significantly associated with a diagnosis of spastic hemiplegic CP (19/25 patients – 76%). Somewhat surprisingly however, our study also found that 5 patients with CVA had spastic quadriplegic CP, and one had spastic triplegic CP. The European cohort had only 1 patient with CVA who was diagnosed with spastic quadriplegia and in the Australian cohort all patients with CVA were diagnosed with spastic hemiplegia.[5,6] Spastic quadriplegic CP that occurs due to CVA is likely due to bilateral infracts, so it can be categorized as "bilateral spastic" hemiplegic CP. However, the reason behind the greater number of bilateral infracts in our particular cohort is unclear.

Gray matter injury was found in 22.1% of the participants in our study, of which 4.2% had deep brain (sub cortical) gray matter injury, 3.3% had superficial (cortical) gray matter injury and 14.6% had diffuse (cortical and sub cortical) gray matter injury. The frequency of diffuse gray matter injury is very similar to that found by an Australian study (14.3%), but variations in classification schemes makes direct comparisons of the frequency of the other subtypes of gray matter injury observed difficult.[5]

There was more gray matter injury amongst non-ambulant children (i.e. GMFCS Levels IV or V). Therefore gray matter injury may be an intrinsic determining factor for an eventual inability to achieve independent ambulation. Cerebral malformations were found in 11.3% of the study population which is a similar to other studies.[5–7] Findings of cerebral malformations were significantly associated with the presence of co-morbidities. This could have important clinical implications because early detection of co-morbid conditions, like vision or hearing loss, are important for improving eventual outcomes.[21]

In our study cohort, 18.8% of children had non-specific imaging results with unclassifiable cerebral abnormalities. These were distributed evenly among GMFCS Levels, but surprisingly associated with a diagnosis of dyskinetic CP. The frequency of these non-specific results was greater than other population-based registries.[5–7] This was likely partially due to the classification of imaging findings based on clinical descriptions. Additionally, our study included both CT and MRI imaging and CT scans reveal fewer cerebral abnormalities, specifically cerebral malformations and PVWMI, than MRI.[21] Consistent with this, there was a significant decrease in cerebral malformations and a trend towards more normal and non-specific results with CT compared to MRI. However, these factors alone are insufficient to entirely explain the increase in non-specific results, since the Swedish study also included CT scans and classified scans based on clinical descriptions.[8]

As mentioned previously, one limitation of this study were noted biases of the study cohort that may have led to an overrepresentation of cerebral abnormalities associated with severe CP (i.e. gray matter injury) and an under-representation of PVWMI. Additionally, sample size of this study limits the possibility of analyses to the most common of neurological subtypes. Inherent inter-observor variability in assigning a neurologic subtype is a feature of all multi-center CP studies.Finally, variations in collection methods and radiologic classification schemes limit the comparisons that can be made amongst the neuroimaging results from various population-based registries of CP.

Despite these limitations, our study showed some associations between neuroimaging findings and neurological subtype and CP severity (i.e. GMFCS Level). These observed associations may improve our understanding of the pathogenesis and etiology of CP and provide clinicians and families with information to aid in management of CP. Future efforts

should be directed towards developing an accepted unified neuroimaging classification system to aid in the analysis of neuroimaging finding from various groupings of individuals with CP.

## Conflict of interest

The authors disclose no conflicts of interest.

## Acknowledgments

Alba Rinaldi provided the necessary secretarial assistance and Anna Radzioch for her research assistance. MCH Foundation for Salary Support for MS and the RSDBE of the FRSQ and the CP Research Chair of Laval University for operational funding of REPACQ.

## Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.ejpn.2010.07.005.

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