Analysis of the correlation between three methods used in the assessment of children with cerebral palsy

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Summary

The primary aim of this study was to assess the correlations between gait analysis, magnetic resonance imaging (MRI), and Gross Motor Function Measure (GMFM) scores in children with cerebral palsy (CP). These common diagnostic tools were used to evaluate 21 children affected by CP (mean age: 6 years, range: 5-13 years; 8 females and 13 males; 5 left hemiplegics, 4 right hemiplegics, 12 diplegics). In particular, in order to compare gait analysis data with other diagnostic evaluations, the Normalcy Index (NI) was used. The results showed a good correlation between the NI and the results of MRI, and between NI and the GMFM score (r=0.76). Therefore, this investigation demonstrated that there exists a strong relationship between gait analysis and other clinical evaluation tools.

KEY WORDS: cerebral palsy, gait analysis, Gross Motor Function Measure, magnetic resonance imaging.

Introduction

Children with cerebral palsy (CP) have damage to the central nervous system (CNS), typically due to a static injury to the developing brain (1). This type of injury to the CNS commonly results in abnormal motor function, with absent or delayed onset of walking and an abnormal gait pattern. The motor impairment depends on the severity of the pathology. The patterns of brain lesions depend on the stage of brain development in which they occurred: malformations are associated with damage sustained in the first and second trimesters of pregnancy, whereas white and grey matter lesions are associated, respectively, with insults occurring early and late in the third trimester (2). Prematurity, severe oxygen shortage in the brain or trauma during labour and delivery are the most common causes of CP. One of the most frequent brain lesions in children affected by CP is periventricular leukomalacia (PVL), which is the result of hypoxic-ischemic damage to the white matter in the periventricular region where the pyramidal tracts occur. The diagnosis of CP is usually based on a multidisciplinary assessment that comprises several types of instrumental examination. Magnetic resonance imaging (MRI) gives good pictures of cerebral structures and areas and has the potential to visualize brain lesions and malformations. Using MRI it is possible to distinguish CP that originated before the end of the prenatal period from CP of postnatal origin. The Gross Motor Function Measure (GMFM) (3) is a standardized observational measure designed to evaluate changes in motor function over time or after treatment. It has been validated in children aged from 5 months to 16 years, including children with CP. Children without developmental disabilities are expected to score 100% by the age of 5 years. A trained therapist assesses 85 items related to lying and rolling (section A), sitting (section B), crawling and kneeling (section C), standing (section D) and finally walking, running and jumping (section E). The child’s ability to initiate or complete the task is scored, and both overall and goal total scores are calculated. The GMFM is widely used and is a valuable tool in assessing the functional limitations of patients (4) and in measuring functional changes after treatment of spasticity (5,6). Computerized gait analysis (GA) is a methodology that, using advanced equipment, allows the clinician to define quantitatively the gait pattern of a subject and to identify pathological deviations from a pattern of normality (7). The reliability of GA in the assessment of children affected by CP and in treatment outcome evaluation is widely documented (8-12).

Damiano and Abel (13) analyzed the relationship between GMFM scores and gait parameters, such as time and distance parameters and joint (pelvis, hip, knee and ankle) movements in the sagittal plane (and also joint moments in the sagittal plane). They found that time and distance parameters showed the highest correlations with gross motor function and generally they obtained good correlations between GMFM scores and GA data. They...
concluded that a combination of clinical GA and the GMFM provides valid indicators of motor function in CP, because GA may provide a more exact measurement of changes in walking, whereas the GMFM may prove essential in detecting clinically significant changes that affect quality of life. Like Damiano and Abel, Drouin et al. (14) carried out a study in order to determine the relationship between spatiotemporal measures of gait (velocity, cadence, stride length and cycle duration) and the GMFM and obtained significant linear relations between gait velocity and the GMFM sections related to walking and running. They found that velocity was representative of functional capacity.

Gait analysis produces a large amount of data which is difficult to interpret, and does not give a direct description of a subject’s overall ability. The Normalcy Index (NI) (15) was developed as a response to this issue. This index is derived from 16 GA parameters (3 temporal-spatial parameters: percentage of stance phase, normalized velocity, cadence; 13 kinematic parameters: mean pelvic tilt, range of pelvic tilt, mean pelvic rotation, minimum hip flexion, range of hip flexion, peak abduction in swing, mean hip rotation in stance, knee flexion at initial contact, time of peak knee flexion, range of knee flexion, peak of dorsiflexion in stance, peak of dorsiflexion in swing, mean foot progression angle) and is calculated using principal component analysis. By using this statistical method it is possible to measure, and represent in a single number, the deviation of a pathological gait pattern from a normal average profile.

The relationship between the NI and other clinical evaluation scales was investigated by Tervo et al. (16). In particular, these authors aimed to investigate correlations between the Pediatric Orthopaedic Society of North America (POSNA) Musculoskeletal Functional Health Questionnaire (a questionnaire for the investigation of upper extremity function, transfers and mobility, physical function, sports and pain), the Gillette Functional Assessment Questionnaire, the NI and energy expenditure. One of the study’s hypotheses was that the NI may be used to predict global motor functioning as measured by the POSNA. On the basis of their results, the authors asserted that the POSNA scale is a valid and useful clinical measure in the assessment of CP patients and, combined with the NI and measurement of energy expenditure, provides a more complete evaluation of a subject’s motor ability.

In two other studies (17,18), the NI was used in conjunction with other evaluation scales and diagnostic methods. The aim of these studies was not to compare the results of these various methods, but to define a multidisciplinary assessment of the functional abilities of children pre- and post-treatments.

The aim of the current study was to analyze the correlations between MRI, GMFM scores and GA data, represented here by the NI. It was hypothesized that a more severe neurological condition corresponds to a more severe functional limitation. Since the score on section E of the GMFM is directly related to walking ability, a specific correlation between NI and this section was sought.

Materials and methods

Twenty-one children affected by CP (mean age: 6 years, range: 5-13 years; 8 females and 13 males; 5 left hemiplegics, 4 right hemiplegics, 12 diplegics) were analyzed using an interdisciplinary clinical functional assessment that included MRI, the GMFM and GA. Eleven of these subjects (all diplegics) were premature, while the other 10 (9 hemiplegics, 1 diplegic) had been born at full term. None of these subjects had undergone previous surgery. A group of 10 healthy children (mean age: 9 years, range: 6-15 years) served as a control group and also underwent GA. MRI and administration of the GMFM were carried out at the Department of Child Neurology and Psychiatry, IRCCS “C. Mondino Institute of Neurology” Foundation in Pavia, Italy. A single radiologist analyzed the patients’ MRI scans and defined five subject categories: severe periventricular leukomalacia (PVLs), moderate PVL (PVLmo), mild PVL (PVLmi), focal anoxia (FA) and basal ganglia lesion (BGL). A positive MRI scan was one of the criteria for the inclusion of patients in this study. For the clinical functional assessment, each child was evaluated by a child neurologist, and a single physiotherapist scored the patients according to the GMFM.

For the acquisition of gait data, all the subjects underwent GA at the “Luigi Divieti” Movement Analysis Laboratory at the Department of Bioengineering, Polytechnic of Milan, Italy. The laboratory was equipped with an opto-electronic system (ELITE 2002, BTS, Italy) for motion analysis with 8 infrared cameras working at a sampling rate of 100 Hz and with a force platform (AMTI, MA, USA) for the acquisition of the ground reaction forces. Twenty passive markers were placed on the subject’s body according to the Davis protocol (19) and during the data acquisition session the subjects were asked to walk barefoot at their normal walking speed along the walkway. Subjects began walking from a point which allowed them to place one foot on the force plate without any modification of cadence or stride length. For each subject (pathological and healthy) 10 trials were collected in order to verify the repeatability of the GA data. Then, the GA data were reduced on the basis of Euler angles and Euler’s equations of motion (19). In each subject, the two most representative trials for each leg were selected. The values of the 16 kinematic parameters for calculation of the NI were extracted from the reduced data. The NI values for both healthy and pathological subjects were then calculated. The mean NI value (left and right) was calculated for each subject in order to characterize the subject’s gait ability in a single number. Then the mean NI for each of the above-defined MRI categories was calculated.

Statistical analysis was performed using the non parametric Mann-Whitney test (p value<0.05) in order to test the efficacy of the NI in distinguishing the patient subgroups, and correlation analysis (r) was carried out in order to analyze the relationship between the NI and GMFM scores.

It is important to note that the limited number of subjects was due to the restrictive inclusion criteria that were adopted: absence of previous surgical treatment, independent walking ability, the same neurologist for MRI classification, positive MRI, the same clinician for GMFM assessment and the same technician for gait data acquisition. These requirements were needed in order to limit possible inter-operator differences.
Results

On the basis of the MRI findings, PVLs was found in 3 patients, PVLmo in 4, PVLmi in 4, FA in 9, and BGL in one (Fig. 1). In particular, all the hemiplegic subjects were in the FA group; instead, of the diplegic subjects, 11 had PVL of varying severity, and one had BGL. On the basis of this categorization, the analyzed group was found to be representative of the CP population: 92% of the diplegics were affected by PVL, which is the most frequent third-trimester brain lesion in CP children (3). All the hemiplegics were affected by focal anoxia, which normally occurs in full-term babies and causes less motor limitation than PVL.

Calculating the mean NI value for all the subjects with diplegia (NIdiplegics=272.5±176) and hemiplegia (NHemiplegics=104±29.8), the results of the current study corresponded with the findings of previous studies (1,20) and demonstrated the efficacy of the NI in the classification of these subjects on the basis of their gait impairment (p<0.05). In particular, in the group of hemiplegics, a statistically significant difference (p=0.05) emerged between the NI values of the involved limbs (NInvolved limbs=122.35±37.5) and of the uninvolved limbs (NUninvolved limbs=83.8±39).

Figure 1 - Distribution of patients according to MRI findings.
Abbreviations: PVLs=severe periventricular leukomalacia; PVLmo=moderate periventricular leukomalacia; PVLmi=mild periventricular leukomalacia; FA=focal anoxia; BGL=basal ganglia lesion.

Figure 2 shows the NI values (means and standard deviations) of the subjects classified by MRI findings. It is worth reiterating that the NI represents the amount by which a patient's gait deviates from a normal pattern. Hence, the higher the NI value, the more affected the patient is.

From the graph in Figure 2, the correlation between the MRI classification and the NI emerges quite clearly. Despite the small number of subjects included in this study, it is nevertheless possible to observe that a trend does exist. Lower NI values correlated with the less severe cerebral lesions, such as FA, whereas higher NI values were found in the subjects with PVLs. The subjects with the lowest NI values (FA in the graph) were all hemiplegic. Eleven diplegic subjects had PVL of varying severity. Several types of brain injury can cause diplegia: some of these are less severe (i.e. PVLmi) and the impact on functional ability is small, whereas others are more severe and lead to greater impairment of gait pattern and functional abilities. Statistical analysis (p<0.05) confirmed that the NI is able to distinguish between subjects with different cerebral lesions (i.e., those of the MRI categorization).

From these results it is possible to conclude that there is a good correlation between gait ability as reflected in the NI and the site and type of the cerebral lesion, established on the basis of MRI. The gait pattern of patients with more severe brain injury is more impaired that that of patients with less severe brain injury.

Analyzing the relationship between the NI and the GMFM score, a negative correlation (r=-0.76) was found (Fig. 3). This meant that a higher NI (poor gait ability) was strong-
ly correlated with a lower GMFM score (poor functional ability). This is an important result since it highlights the relationship between various motor skills (GMFM) and gait (NI).

The relationship between NI and the section of the GMFM specifically related to walking, jumping and running (section E) was then considered. In this case, the correlation between the two evaluation tools proved to be stronger (r=-0.86) than that found between the NI and the global GMFM. It is therefore possible to conclude that the NI shows concordance with the GMFM in functional ability definition, in particular the relation is stronger when we consider specifically the GMFM dimension of walking and running.

It is important to underline that GA (in this case the NI) cannot replace GMFM, and vice versa. A complete clinical evaluation should include both these diagnostic tools: the GMFM considers not only gait but also other motor tasks, while the NI was created specifically for gait ability and gives quantitative and precise information about this motor aspect. Despite the small number of subjects included in this study, the analysis of the relationship both between NI and MRI and between NI and GMFM produced significant results and some important findings.

Discussion

Magnetic resonance imaging, the GMFM, and GA are methods commonly used in the assessment of children with CP, and these three diagnostic tools have very different and very specific characteristics. MRI is a technique for imaging the structures of the brain, and it gives important information about the size and the position of the lesion. However, MRI alone does not provide sufficient information to predict the patient’s functional limitations. The GMFM is a clinical tool developed for functional assessment; this measure gives global information about several abilities like sitting, walking and kneeling, and it is operator-dependent. The GMFM furnishes valuable information about function, but does not provide any detailed information about the subject’s gait. Gait analysis analyzes subjects objectively during a dynamic activity (such as walking) and it provides information related only to this motor task. Detailed information about walking is important for the identification of the patient’s problem and the planning of treatment, but its correlation with other functional tasks is not entirely clear. Indeed, while all these diagnostic tools contribute to the assessment of a child’s clinical picture, the relationships among them were not well understood. It was felt that greater understanding of the correlations and differences between these measures should make it possible to obtain a more complete clinical picture, covering the pathology, overall motor function, and gait proficiency.

The first aim of this study was thus to analyze the relationship between MRI lesions and clinical GA in children with CP. Since the focus of this work was an analysis of the functional limitations in children affected by CP, the use of a global index, able to synthesize walking ability and derived from GA data, was needed. On the basis of the findings of previous studies (1,20), the NI (1) was deemed an appropriate index for this purpose.

The MRI classification revealed that the pathological group could be considered representative of the CP population despite the low number of analyzed subjects. All the hemiplegics were affected by focal anoxia, whereas the majority of diplegics presented with periventricular leukomalacia of varying severity. Starting from these results, a strong correlation between MRI and NI was found, suggesting that a more pathological gait pattern corresponds to a more severe brain lesion. The less severely affected subjects (i.e. the hemiplegics) presented less severe damage on MRI and lower NI values, which signified a gait pattern which, compared to that of the diplegics, deviated less from the gait pattern of normal subjects. The correlation between the two functional measures (NI and GMFM) was found to be strong. Moreover, the correlation was stronger when only the GMFM score related to walking ability was considered. This suggests that there is a good concordance between these two evaluation methods, despite the fact that they have significantly different characteristics, and focus on different aspects of the child’s pathology. The GMFM is administered by a physiotherapist who scores a subject’s performance on different motor tasks like sitting, rolling, kneeling, walking, running and jumping; GA, on the other hand, considers only one motor task (gait) but is an objective and quantitative evaluation.

In conclusion, on the basis of the results of this study, it can be affirmed that there is a good correlation between gait ability represented by the NI and the nature of the cerebral lesion, determined on the basis of MRI findings. In addition, GA and the GMFM, which assess, respectively, gait and functional ability, seem to be effective tools for defining the pathological condition of patients affected by CP.

Although MRI is not a functional evaluation tool, the strong correlation that emerged between the MRI picture and the NI is consistent with the fact that hemiplegic children (affected by focal lesions) and children with mild PVL usually have better functional abilities in terms of independent walking than children with more severe brain lesions.

It is important to reiterate that a complete clinical evaluation should always include all the appropriate diagnostic and clinical assessments. This study demonstrates that GA may be used in conjunction with GMFM in order to obtain a better definition of the functional limitations related to a neurological condition.

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References