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REVIEW ARTICLE

Neuromuscular scoliosis progression and surgery as an option for children with cerebral palsy: a scoping review

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Abstract

Objective: To carry out a systematic review of the progression of scoliosis in patients with cerebral palsy. **Methods:** Systematic review study with searches for journals in the PubMed database from September to December 2020 with specific descriptors associated with the Boolean operator "or" "longitudinal" or "cohort" or "control-case" and "prospective" and " cerebral palsy" and "scoliosis" or "spine deformity" or "spinal deformity" or "neuromuscular". Eligibility criteria for inclusion and exclusion of studies were applied, with subsequent data tabulation. **Results:** A total of 986 articles were found, only seven articles were eligible for desired data extraction after applying eligibility criteria. **Conclusion:** Age and Gross Motor Function Classification System (GMFCS) can be clinical predictors of scoliosis progression. Scoliosis was more progressive in patients with GMFCS III, IV and V. Patients with a smaller Cobb angle during the bone growth period have a lower chance of curve progression.

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INTRODUCTION

Cerebral palsy (CP) was first described in 1843 by William John Little, an English orthopedist, who described the cases of children with spastic stiffness, believing that the etiology of the condition was tied to adverse circumstances at birth, such as difficulty in labor, preterm birth, delay in breathing and crying after birth, and seizures. The term chronic nonprogressive brain disorders appeared in 1897 to include several conditions that compromise the immature central nervous system, having motor disorder as the common most evident manifestation[1].

Motor disorder manifests through anomalous patterns of posture and motion, associated with anomalous postural tone. The injury that affects the brain does not progress, but interferes with the child's motor development[2]. Chronic nonprogressive brain disorders can be described based on the child's motion alterations and the anatomical location and topography of the injuries and symptoms. Cerebral palsy is divided into four groups: spastic, ataxic, dyskinetic, and mixed[3]. Spastic cerebral palsy, the most common, is subdivided into diplegia, quadriplegia, hemiplegia, and double hemiplegia. It is characterized by increased muscle tone with resistance to passive movement and exaggerated reflexes. Spasticity occurs due to increased tone (hypertonia) and reflexes (hyperreflexia) resulting from injury to the motor cortex[4] with upper motor neuron involvement[5], which causes increased stretch reflex in an anomalous neurological condition at the time of muscle contraction. Since spasticity predominates in some muscles and not in others, the appearance of deformities in cerebral palsy is common[6]. In the ataxic type, coordination and balance are impaired, the support base is widened with the presence of axial and appendicular ataxia, hypotonia, dysmetria, and impaired coordination, which indicate damage to the cerebellum or its pathways. In the dyskinetic type there is a fluctuation in tonus regulation and involuntary movements, mainly from basal ganglia injury[7]. The mixed type is characterized by different combinations of motor impairment[8].

Scoliosis is a three-dimensional morphological deformation of the spine characterized by the lateral inclination of the vertebrae in the frontal plane, rotation in the horizontal plane, and posteroflexion in the sagittal plane[9]. According to the Scoliosis Research Society (SRS), scoliosis is defined as a lateral curvature of the spine with a Cobb angle greater than 10°, measured on the anteroposterior radiograph scan with the patient in standing position[10].

Neuromuscular scoliosis develops secondarily to muscle imbalance, congenital disorders, degenerative diseases, or syndromes. The rate of progression is dependent on child growth[10]. Several diseases may affect spinal alignment, involving the upper motor neurons of the brain and spinal cord (as in cerebral palsy, syringomyelia, spinal cord tumors or spinal cord trauma), the lower motor neurons (as in poliomyelitis, radicular injury, viral myelitis and spinal muscular atrophy), or involving both in a combined manner (as in myelomeningocele)[11].

Spasticity, muscle weakness and incomplete muscle control seen in cases of cerebral palsy contribute to impaired trunk control and the development of spinal deformities[12]. Severe scoliosis may cause additional motor dysfunction, problems with sitting and in transitions between different postures and positions, impaired cardiopulmonary function, pain, and reduced quality of life[13].

A study including 962 individuals with cerebral palsy found an incidence of 15% (140 cases) of moderate and severe scoliosis. The incidence of scoliosis was related to age and level of gross motor function. The number of persons with scoliosis increased up to the age of 20-25 years (140 cases). Three quarters of the individuals with a lower level of gross motor function had a Cobb angle > 40° at the age of 20 years[14].

Since patients with cerebral palsy are at risk of developing scoliosis and suffering from the impacts that the disease has on function and comorbidity, it is important to learn the risk factors tied to curve progression in these individuals. This article presents a review of the factors associated with progression of neuromuscular scoliosis and the treatment options for patients with cerebral palsy.

METHOD

Searches were performed on PubMed for articles published from September 2020 to December 2020, with the following keywords: "longitudinal" or "cohort" or "control--case" and "prospective" and "cerebral palsy" and "scoliosis" or "spine deformity" or "spinal deformity" or "neuromuscular".

The following inclusion criteria were used: observational longitudinal study; patients with cerebral palsy assessed for scoliosis in at least two different time periods; Cobb angle measurements of the curves over the assessment period; assessment for gross motor function (GMFCS). Cross-sectional studies, literature reviews, book chapters, and abstracts published in annals were excluded.

The Gross Motor Function Classification System (GMFCS) was used in functional evaluation. The GMFCS is divided into five levels and includes the following age groups: 0-2 years, 2-4 years, 4-6 years, 6-12 years, and 12-18 years. Children in Level I have the greatest level of independence and individuals in Level V the greatest motor impairment. Each age group has specific motor performance expectations. Levels are distinguished based on functional limitations, need to use a handheld mobility device or a wheelchair. Below is a generic description. Ideally, patients should be categorized within their respective age ranges.

Level I - Unrestricted walking with limitations in more complex motor tasks (running, jumping);

Level II - Walking without mobility devices, but limitations in walking in the community;

Level III - Walking with mobility devices, with limitations in walking in the community;

Level IV - Mobility is limited, requires wheelchair in the community;

Level V - Severely limited mobility even with use of assistive technology.

The Cobb angle is the most widely adopted parameter for quantifying the magnitude of spinal deformities using a panoramic radiograph of the spine. The first step is to define the limiting vertebrae, the ones with the steeper angles in the ends of the curve. The second is setting the plateaus of the upper and lower limiting vertebrae. Then lines are drawn along the upper vertebra (upper plateau) with the steeper angle at the top and along the lower vertebra (lower plateau) with the steeper angle at the bottom. Next, two other perpendicular lines are drawn to the point where they intersect, and the angle between them is measured in degrees. The Cobb angle is a universal standard measurement for diagnosing scoliosis. It informs healthcare teams of whether the curve has stabilized or worsened.

The data collected from the articles included name of the article, year of publication/author, description of the patients in the case group, baseline data, and description of the factors analyzed during follow-up (table 1).

RESULTS

A total of 77 articles were found using keywords "longitudinal" OR "cohort" OR "control-case" AND "prospective" AND "cerebral palsy" AND "scoliosis" OR "spine deformity" OR "spinal deformity" OR "neuromuscular scoliosis". The titles and abstracts were read, and then articles were included or excluded based on the established criteria. Fifteen articles were deemed eligible. They were read in full, and seven were used as sources of data.

Table 1 summarizes the data extracted and the results of the studies analyzed, their authors and year of publication, description of the case group patients, length of follow-up, function (usually via the GMFCS), Cobb angle of the scoliotic curve, and proposed surgical and conservative interventions.

DISCUSSION

The study was based on selected articles from which the following were analyzed: population, incidence, angles, gross motor function, and type of cerebral palsy. Most studies included children with severe disability, scoliosis progression and significant gross motor function impairment. The reported incidence of scoliosis in individuals with cerebral palsy varies, since studies use different definitions for scoliosis, age groups, and gross motor function distributions. Most studies report an incidence of 20-25%[15].

The individuals included in the articles analyzed in this review were aged four to 23 years. Results varied substantially, with more severe forms of scoliosis developing in children in GMFCS levels IV and V. Most of the reviewed studies were retrospective and had sizable populations. Only one of the studies involved physical therapists, whose participation was limited to a periodic examination and did not include a physical therapy intervention program, indicating that the main form of scoliosis repair was surgery in the included studies.

Patients with cerebral palsy referred to surgery were aged between six and 22 years, had a Cobb angle > 40° and were in GMFCS levels III, IV and V[14]. The surgical repair for scoliosis that shows the best results is the procedure performed with transpedicular screws, universal clamps and hooks with posterior access for stabilization of the spine. The authors reported satisfactory deformity repair compared to other procedures, shorter operating time and decreased blood loss during surgery. After one year of follow-up, the authors found that there was a small loss of correction in cases of thoracic kyphosis without, however, compromising the restoration of the physiologic curvature. The mean loss of correction was 7° ± 2° in the coronal plane and 2° ± 1° in the sagittal plane. In cases of kyphosis, lordosis or hyperkyphosis, the procedure mentioned above proved to be effective, presenting good results, without postoperative complications, while maintaining and restoring physiological curves. It was not possible to assess the effectiveness of surgical repair in cases of thoracic kyphosis due to the absence of comparative values.

The risk of individuals with cerebral palsy developing scoliosis increases with age and gross motor function impairment levels. Persson-Bunke et al.[15] found that impairment level in the GMFCS was the only significant factor in Cobb angle increases, and showed that children in levels IV and V have a 50% chance of developing moderate or severe scoliosis at 18 years of age, and are at risk of deformity progression. The study also indicated that children in levels I and II have a lower chance of developing scoliosis. The authors suggested that scoliosis surveillance programs in children with cerebral palsy should be based on age and GMFCS level, and that cerebral palsy subtype is not significant for the development of scoliosis. The authors described a prevalence of 29% of scoliosis in individuals with cerebral palsy. One of the clinical procedures with the greatest impact on the overall health of individuals with cerebral palsy is regular and preventive supervision of hip dislocation and scoliosis progression, which are frequent in patients in GMFC levels IV and V[20].

Patients between 11 and 15 years of age in GMFCS levels IV and V experience a marked progression of scoliosis, with severe deformity appearing by the age of 30. The Cobb angle is an important predictor of progression. In patients aged 18 years, it differentiates between mild and moderate cases. The study showed that patients with a Cobb angle equal to or greater than 50° before the age of 15 years have a greater chance of progressing to severe scoliosis, whereas patients with an angle less than 20° at the end of puberty have a greater chance of stagnation or minimal progression in scoliosis. Patients in GMFCS level V develop severe scoliosis by the age of 20 years. Although the Cobb angle has been described as an indicator of scoliosis progression and a clinically important factor in these cases and in follow-up, the authors pointed out that the study had limitations regarding the measurement of angles, since patients with severe scoliosis cannot sit or stand properly and had their angles measured in dorsal decubitus, which is susceptible to errors, albeit not significant[16].

Table1.

Author/ Year of publication	Patient description	Length of follow-up	Function	Were patients offered surgery during follow-up?	Were patients managed conservatively during follow-up?	Degree of scoliosis (baseline)	Degree of scoliosis (at the end of the study)
Hägglund *et al.*, 2018[14]	962 individuals born from 1990 to 2012 in southern Sweden.	4 to 6 years.	Level I: n= 393 Level II: n=190 Level III: n=95 Level IV: n=135 Level V: n=149	Patients on Levels III (n = 2), IV (n = 15) and V (n = 53) underwent arthrodesis.	No	The median preoperative Cobb angle was 72° (40°-115°).	The incidence of scoliosis increased with age and GMFCS level. At the age of 10 years, about 1% of the children were in GMFCS levels I-II, 5% in GMFCS level III, 10% in GMFCS level IV and 30% in GMFCS level V had moderate or severe scoliosis. At age of 20, no children in GMFCS levels I-II developed scoliosis with a Cobb angle > 40°
Persson--Bunke *et al.*, 2012[15]	666 children with cerebral palsy aged 4-18 years with mild, moderate, or severe scoliosis.	14 years.	Almost all children with moderate or severe scoliosis diagnosed based on clinical or radiographic findings. Patients in GMFCS levels III-V had curves of more than 20°. All children in GMFCS levels IV-V were operated on for scoliosis.	Scoliosis surgical treatments chosen based on each case (authors did not describe types).	Participating children were examined by their local hospital physiotherapists twice a year from the time of inclusion in the program, usually from 2 years of age until 6 years of age, and then once a year	116 (17%) of the 666 children had mild scoliosis and 76 (11%) had moderate or severe scoliosis based on clinical examination. Radiographic examination showed a Cobb angle greater than 10° in 54 (8%) children and a Cobb angle greater than 20° in 45 (7%) children	Risk of scoliosis increased with age and GMFCS level. Risk of moderate or severe scoliosis in children in GMFCS Levels IV-V was about 50% at the age of 18 years.
Oda *et al.*, 2017[16]	92 patients with severe paralysis aged 2 to 30 years.	7-10 years	Level I: n= 1 Level II: n= 10 Level III: n= 8 Level IV: n= 23 Level V: n= 50	Patients had spinal surgery and individuals with congenital scoliosis were excluded	No	Mean Cobb angle was 55° (0 to 150°). Severe curve group: Cobb angle ≥50° in 15 years. Moderate curve group: <50° at 15 years and ≥20° at 18 years. Mild curve group: <20° at 18 years	Mean Cobb angles at the end of follow-up were 129°± 9.5°, 53°±15° and 13° ± 11° in the severe, moderate and mild groups. Severe scoliosis cases had increased angles compared to mild and moderate cases in GMFCS IV and V.

Yoshida *et al.*, 2018[17]	113 patients with cerebral palsy and scoliosis were followed retrospectively.	16 years	Patients in GMFCS I, II, III, IV and V	No	No	Mean Cobb angle was 55.1° (range: 10° to 169°),	After the age of 20 years, 13 of 40 patients (32.5%) developed more than 10° of scoliosis. There was no significant difference in progression for degree of curvature at maturity, subtype of cerebral palsy, or and GMFCS level
Senaran *et al.*, 2007[18]	107 patients with spastic cerebral palsy treated with baclofen. 92 quadriplegic, 5 diplegic and 10 mixed between quadriplegia and athetosis.	6 years	Patients GMFCS levels IV and V.	Patients underwent implantation of an intrathecal programmable pump (Synchromed EL or II, Medtronic, Inc., Minneapolis, MN).	No	Baclofen Group: Baseline: 24.1° +16° Control Group: Baseline: 28.2° + 17.5°	Baclofen Group: PO: 4.5°+ 6.2° Follow-up: 65.2°+ 24.7° PO Follow-up: 13.5° + 9.0° Mean curve progression after intervention was 16.3° a year. Control Group: PO: 5.7° + 6.7° Follow-up: 73.0° + 21.8° PO Follow-up: 14.2° + 10.6°
Baldwin *et al.*, 2020[19]	211 patients with cerebral palsy and cachexia aged 8 to 21 years.	13 years.	Patients in GMFCS level III	Cobb angle, pelvic obliquity, and hyperlordosis repair.	No	Mean scoliosis 82.2° and mean pelvic obliquity 27.6°.	PO: Scoliosis 7,9° and pelvic obliquity 7,9°. Surgery did not cause weight gain.

High levels in the GMFCS have been associated with significant risk of developing scoliosis, with incidence peaking in 20-25-year-olds. The author further stated that children categorized as level V in the GMFCS often develop severe scoliosis[14-16].

Patients diagnosed with scoliosis before the age of six years, with unilateral or bilateral hip dislocation, a Cobb angle of 30° before the age of 10 years, and spastic cerebral palsy may at risk of scoliosis progression. The study further states that 32.5% of the patients saw their curves increase after the age of 20 years. Sixty-four percent of the patients had spastic quadriplegia and 73% were in the GMFCS level V. However, the author reiterated that the population was mostly made up of patients with spastic cerebral palsy, which caused the distribution not to be homogeneous. As in other studies, the period of increase in the Cobb angle coincided with the period of individual growth and maturation, with the onset of scoliosis between one and 16 years of age[17].

Regarding novel therapies for scoliosis, a correlation has been observed between the use of Intrathecal Baclofen Therapy (ITB) and improvements in spasticity in 107 people diagnosed with spastic cerebral palsy. Factors such as sex, age, ambulatory potential, spasticity pattern, and GMFCS classification were taken into consideration. However, the results obtained showed no significant difference between groups, indicating that ITB did not interfere with curve progression[18].

Assuming that spinal deformities affect the gastrointestinal system and hinder nutrient intake of patients with cerebral palsy, a possible relationship between surgical repair of scoliosis in patients with cerebral palsy and changes in patient body weight was investigated. Although no direct relationship between improvements in the Cobb angle and weight gain was found, children older than five years gained weight in the first year after surgery, indicating that patients with a Cobb angle less than 40° had gained weight after surgery. This fact was considered clinically important and supported the theory in which surgical repair aiming at an angle of less than 40° might decrease lower esophageal sphincter pressure, minimize reflux episodes, and increase patient tolerance to food. However, this theory lacks scientific evidence and further studies are needed on the subject[19].

In contrast, the respiratory deficits caused by scoliosis are well known in the literature. Scoliosis limits the movement of the rib cage, alters respiratory mechanics, displaces the organs contained in the thoracic cavity, decreases lung complianc, and consequently increases respiratory effort and, due to the associated muscle weakness, may cause chronic respiratory failure[21]. Impaired chest expansion may result in rapid, paradoxical breathing patterns. The weaker muscles of patients with cerebral palsy do not optimally balance gravitational forces, and the development of the chest is significantly affected. Impaired lung function is the most common cause of death in cerebral palsy[22-23]. Surgical intervention for neuromuscular scoliosis is complex and, although it may improve respiratory function, 22.7% of patients experience perioperative and postoperative pulmonary adverse events[24] such as pneumonia, lung infiltrates, pneumothorax, atelectasis, pleural effusion, prolonged mechanical ventilation, and longer stay in an intensive care unit (ICU). Thus, it is of paramount importance to understand the postoperative risks of scoliosis repair and the fact that delaying surgery may worsen lung involvement as the deformity becomes more severe[25]. Despite the high rate of adverse events, a substantial decrease of approximately 10% in postoperative complications has been observed in recent years, with fewer infections and respiratory complications, which might serve as encouragement to proceed with studies on the subject to obtain better outcomes and improved patient quality of life[26].

The limitations present in our study must be considered. Our initial goal was to analyze the risk factors for scoliosis progression in children with cerebral palsy in cohort studies. However, we found only one study in which there was no surgical intervention of any kind, with patients followed up conservatively over the years. For this reason, we had to include observational studies in which patients received some form of intervention over the years. As a result, we ended up commenting on treatment delivered to patients throughout the studies, even though this was not the primary endpoint evaluated in our review. In contrast, there are still few randomized controlled trials in this population. The purpose of this review was not to evaluate the efficacy of surgery, but rather to describe scoliosis progression in patients. Further systematic reviews on the effectiveness and efficacy of proposed treatments for scoliosis in children with cerebral palsy are required.

CONCLUSION

We found that surgery is mostly performed in patients with high GMFCS levels and Cobb angles greater than 40°. The best intervention is the so-called hybrid approach, in which screws and hooks are associated with universal staples, yielding better outcomes and lower risk of complications. Our study also indicated that surgery prioritizing the attainment of residual angles less than 40° may produce better long-term results.

The topographic subtypes of cerebral palsy are not a determining factor in scoliosis progression. On the other hand, factors such as categorization in GMFCS levels IV and V, increased Cobb angle, age group, and hip dislocation may be clinically important predictors of scoliosis progression. We hope that this study may guide future research and shed light questions regarding interventions in cases of scoliosis involving patients with cerebral palsy.

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