

# Surgical Correction of Scoliosis in Pediatric Patients With Cerebral Palsy Using the Unit Rod Instrumentation

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**Study Design.** Retrospective clinical and radiographic consecutive case series of 2 surgeons.

**Objective.** The purpose of this study was to present a large consecutive series of patients with cerebral palsy who were treated with the Unit rod instrumentation at a single institution. The goal was to report the incidence of surgical complications, degree of deformity correction, reoperation rate, prevalence of pseudarthrosis, and the caretakers' perceived outcome.

**Summary of Background Data.** Children with cerebral palsy frequently develop scoliosis that requires surgical correction. Segmental instrumentation has been the primary mode of treatment. There are no reported large series with long-term follow up.

**Methods.** This study was a retrospective review of 287 children treated with the Unit rod instrumentation. This instrumentation with fusion included the whole spine (between C7 and T3 into the pelvis) with 242 posterior-only and 45 anterior-posterior procedures. Of this group, 241 patients were observed for more than 2 years. This review focused on the rate of complications and radiographic outcome of the treatment. Parent and caretaker interviews were conducted to define perceived functional outcome after surgery.

**Results.** Scoliosis was corrected from a mean of 76° to 25° (68%). Pelvic obliquity was corrected from a mean of 17° to 5° (71%). In posterior-only procedures the average blood loss was 2.8 L, ICU stay was 4.9 days, and the hospital stay was 19.6 days. In combined procedures, the average blood loss was 3.4 L, ICU stay was 6.7 days, and the hospital stay was 24.5 days. Major complications included 3 perioperative deaths, 18 deep wound infections [12 early deep infections in a total of 287 patients (4.2%); 6 late deep infections in a total of 236 patients (2.5%)], and 2 patients with septicemia who recovered after prolonged antibiotic management. Caretakers' survey reported a 96% satisfaction rate.

**Conclusion.** The Unit rod instrumentation is a common standard technique and the primary instrumentation system for the treatment of pediatric patients with cerebral palsy and neuromuscular scoliosis because it is simple to use, it is considerably less expensive than most other systems, and can achieve good deformity correction with a low loss of correction, as well as a low prevalence of associated complications and a low reoperation rate.

**Key words:** cerebral palsy, scoliosis, spine deformity, surgical management, unit rod instrumentation. **Spine 2008;33:1133–1140**

Cerebral palsy (CP) is a static encephalopathy affecting the immature brain potentially leading to permanent motor disability and frequent spinal deformity. The overall incidence of spine deformity in CP has been reported at 20% to 25%, ranging from 5% in spastic diplegia to 64% to 74% in spastic quadriplegia,<sup>1–3</sup> and is proportionate to the severity of neurologic impairment<sup>1,4–10</sup> and ambulatory ability.<sup>4,11</sup> Scoliosis represents the most common pattern of spinal deformity in this group of patients. Scoliosis in CP is not responsive to orthotic management and causes significant trunk and pelvic imbalance.<sup>1,4–7,12–15</sup> During pubertal growth, the curve progresses rapidly at 2° to 4° per month,<sup>13,16</sup> curve stiffness increases, and progression occurs after skeletal growth ends.<sup>13,14,17</sup> Pelvic obliquity develops secondary to the scoliotic deformity extending to the pelvis or by means of asymmetric hip contractures.<sup>5,12</sup>

Instrumentation for the treatment of scoliosis in CP has evolved over time. Harrington instrumentation had a high incidence of pseudarthrosis and curve deterioration.<sup>18–20</sup> Luque developed the concept of segmental spinal fixation with sublaminar wires.<sup>18</sup> The Galveston technique of intramedullary rod placement into the iliac diaphysis improved pelvic fixation.<sup>21,22</sup> The Unit rod instrumentation was developed to use the Galveston pelvic fixation and sublaminar wires with a single rod to improve construct stiffness.<sup>23,24</sup> Previous reports have indicated early success with the use of the Unit rod in the treatment of neuromuscular scoliosis,<sup>25</sup> however, there has not been a large series with long-term follow up to evaluate the outcome of this instrumentation in children with cerebral palsy. The goal of this study is to report the incidence of surgical complications, degree of deformity correction, reoperation rate, prevalence of pseudarthrosis, and the caretakers' perceived outcome of a large se-

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ries of CP patients with scoliosis treated by instrumentation with the Unit rod.

## ■ Materials and Methods

The medical records and spine radiographs of 287 consecutive patients with CP and neuromuscular spine deformity who underwent Unit rod instrumentation with fusion to the pelvis between 1988 and 2000 at the AI duPont Hospital for Children by the 2 senior authors were reviewed. The reviews of the medical records, as well as the radiologic assessments were conducted by the authors who did not participate in any of the surgical procedures. Excluded from this review were revision procedures, spine fusions that did not extend to the pelvis, and any neuromuscular deformity not due to brain encephalopathy. The study included 153 females and 134 males whose age at surgery was  $13.9 \pm 3.3$  years. The pattern of involvement was quadriplegic in 282 and diplegic in 5; 249 had no ambulatory function, 14 could stand for assistive transfers, and 24 were community ambulators; 227 had severe mental retardation, 26 had moderate mental retardation, and 34 patients had normal cognitive function. A detailed retrospective chart review was preformed. The surgical complications were divided into intraoperative and postoperative. Postoperative complications were subdivided into early, occurring within the first 6 weeks postop, and late. Spine radiographs were taken with the patient standing for walking patients, or sitting on a specialized seating chair for patients who were wheelchair dependent and were all measured by the first author using the Cobb method.<sup>26</sup>

A telephone survey of the parents or primary caregivers of our patients was performed. A nonvalidated questionnaire assessing patients' functional improvement after spinal arthrodesis was formulated and administered to the parents through a telephone interview conducted by an independent investigator who did not have medical background and who was unrelated to the surgical team. The questionnaire focused on evaluating the effectiveness of the surgery on correcting spinal deformity, improving patients' physical appearance, ability to lie in bed, sitting tolerance, ability to stand or walk, head control, ability to eat or feed, respiratory function, back pain, mental capacity, ability to use hands, and ease of care, particularly bathing and dressing.

We were unable to follow 26 patients for a minimum of 2 years in our pediatric institution because they exceeded the age limit of 21 years (mean follow-up, 1.1 year). Also 12 patients failed to follow-up before the 2-year clinical visit. Five died before their 2-year follow-up, unrelated to the spinal arthrodesis and 3 died acutely. Therefore, the 241 patients who were followed for more than 2 years (mean,  $8.3 \pm 3.0$ ) after their spinal arthrodesis were included in our long-term assessment. The follow-ups occurred in the cerebral palsy clinic as part of the routine clinical management by the operating surgeons. Final radiographic follow up was shorter since we did not make radiographs at each visit. Radiographic follow up ( $>2$  years) was  $3.9 \pm 2.4$  years in 193 patients. Complications, both intraoperative and early postoperative, are reported on the whole group of 287 patients.

### **Surgical Technique and Postoperative Protocol**

The operative indication was for scoliosis of greater than  $40^\circ$  at the completion of growth or when growing children were having problems sitting or developing curve stiffness to the point that might require anterior release. Our goal was to avoid anterior release, but allow the child to have the potential for the

maximum longitudinal growth. All patients, regardless of neurologic severity, were offered spine fusions if the examining surgeon felt the child could tolerate the procedure. During this study period 3 children were refused surgery by the surgeon because their health was too fragile and the curves were too large; all 3 died within 18 months. Indications for an anterior spinal release and fusion included severe curves over  $100^\circ$  with increased rigidity determined by side bending on physical examination. Radiographs in side bending were not used in surgical planning. The goal of the anterior approach was to improve flexibility, anterior instrumentation was never used. Anterior release was also used for some stiff kyphotic deformities and large lordotic deformities.

The Unit rod instrumentation used in this study is a completely precontoured quarter inch (98% of cases) or 3/8 inch diameter rod (Jantek, Paso Robles, CA). The Unit rod was always used with the spinal arthrodesis with the goal to fuse to T1 to prevent follow up curves. If there is severe upper thoracic kyphosis we may extend to C7, however, T2 or T3 is adequate if the upper thoracic kyphosis is normal. Decortication of the transverse processes and lateral laminae with extensive facetotomies were routinely performed and the posterior spinal instrumentation was always reinforced with abundant freeze-dried granulated corticocancellous bone allograft mixed with autogenous bone harvested from the spinous processes. Wound drains were not used, but there was a meticulous closure of the lumbosacral fascia to obliterate dead space and prevent leakage of the deep hematoma.

All patients received prophylactic antibiotic treatment. After anesthesia induction, arterial and central venous lines were placed. Spinal cord monitoring with somatosensory and motor-evoked potentials was performed only in the ambulatory patients. The patients were transferred to the ICU in the immediate postoperative period. Nutritional support was provided by central venous hyperalimentation followed by nasogastric, nasojejunal or gastrostomy feeding based on individual need. No postoperative immobilization was used and a physical therapy program was started when the patient was medically stable. Their wheelchair was modified to adapt for their new corrected seating posture.

### **Statistical Methods**

Statistical analysis of the different parameters was performed with the application of the 2-tailed *t* test and the Pearson's correlation-coefficient test to document statistical significance. A level of significance was chosen as  $P < 0.05$ .

## ■ Results

Posterior spine arthrodesis alone was done in 242 and 45 patients underwent a combined anteroposterior spinal fusion. Anteriodorsal spine procedures were performed in a single stage for 30 patients and 15 were done in 2 stages. Spinal instrumentation extended from the pelvis to C7 in 11 patients, T1 in 244, T2 in 31, and T3 in 2 patients. Scoliosis was classified into idiopathic-like (Group 1) in 16 children and 271 had collapsing neuromuscular type (Group 2) according to the criteria described by Lonstein and Akbarnia.<sup>27</sup> Primary sagittal plane deformities (scoliosis  $<20^\circ$ ) occurred in 12 children. The intraoperative and postoperative results of patients undergoing a posterior only or a combined anterior-posterior procedure were similar (Table 1). No

**Table 1. Results**

	Posterior Only	Anterior-Posterior
Surgical time (h)	3.9 ± 0.8	7.1 ± 1.6
Blood loss (L)	2.8 ± 2.4	3.4 ± 1.7
ICU stay (d)	4.9 ± 5.3	6.7 ± 5.1
Hospitalization (d)	18.6 ± 13.0	24.5 ± 24.3
Magnitude of main curve preop (°)	74.6 ± 21.2	86.4 ± 40.1
Magnitude of main curve postop (degrees)	21.7 ± 13.1	29.2 ± 22.6
Main curve correction (%)	71	66
Loss of correction of main curve (°)	2.6	1.2
Preoperative kyphosis (°)	54.2 ± 28.8	65.7 ± 33.5
Postoperative kyphosis (°)	34.6 ± 10.7	38.2 ± 14.5
Preoperative lordosis (°)	35.4 ± 30.0	53.4 ± 38.8
Postoperative lordosis (°)	43.7 ± 9.2	41.1 ± 10.3
Preoperative pelvic obliquity (°)	16.7 ± 11.3	20.8 ± 13.6
Postoperative pelvic obliquity (°)	4.6 ± 3.8	5.4 ± 4.8
Loss of correction of pelvic obliquity (°)	0.5	0.2

patient who was ambulatory before surgery lost ambulatory ability after instrumentation (Figures 1 and 2).

Intraoperative complications for posterior spinal fusion alone occurred in 38 patients with the most common being 17 perforations of the ilium by the pelvic legs of the Unit rod (Table 2). Early postoperative complications occurred in 27 patients with 12 wound infections being most common (Table 3). Infections were treated with serial debridements, usually 2 debridements and dressing changes in the operating room, then daily dressing changes at the bed side. All developed a good fusion and none required hardware removal.

There were 3 acute deaths related to the spine surgery, 1 from coagulopathy and cardiac arrest at the end of the procedure; 1 from cardiac arrest secondary to hypovolemia during the first postoperative day; a third died from acute hemorrhagic pancreatitis 48 hours postoperative.

Late postoperative complications in those patients who underwent a posterior spinal fusion alone included 3 deep infections requiring surgical debridement and removal of part or the whole of the rod, 8 cases of a prom-

inent proximal end of the rod (this was removed in 3 patients), 6 cases of a prominent distal end of the rod (the pelvic leg was removed in 2 patients), 4 sacral decubitus ulcers, 2 cases of prominent sublaminar wires, which were also removed, 3 cases of broken sublaminar wires noted only on the radiograph, and 3 pseudarthrosis occurring more than 3 years after surgery, which were treated with replacement of the instrumentation and repeat bone grafting. Late complications in those patients who underwent a combined anterior-posterior spine arthrodesis included 3 posterior deep infections treated with surgical debridement and removal of the whole rod and all wires, 1 case of a prominent proximal end of the rod, which was removed, and 1 case of broken sublaminar wires noted on the radiographs (Table 4).

### Statistical Analysis

Variables were analyzed with Pearson Correlation coefficients to determine any significant relationships between variables. Increased preoperative scoliosis correlated positively with increased days in hospital ( $r = 0.24$ ) and in ICU ( $r = 0.20$ ), and to increased surgical time ( $r = 0.27$ ). Increased surgical time correlated with prolonged hospitalization ( $r = 0.20$ ). Lumbar hyperlordosis correlated with increased surgical time ( $r = 0.24$ ), intraoperative blood loss ( $r = 0.25$ ), and hospital stay ( $r = 0.27$ ), indicating that these cases are especially challenging. Technical complications related to the pelvic fixation developed in 16% (8 of 51) cases with lumbar lordosis over 60°. In contrast, pelvic instrumentation complications occurred in 3% (7 of 237) with lumbar lordosis less than 60°. Questionnaire survey was collected from the parents or primary caregivers of 190 children. The caretakers appreciated the dramatic correction of the spine deformity (mean score, 1), and the consequent improvement of their physical appearance (mean score, 1) (Table 5).



Figure 1. A 15-year-old boy with quadriplegic pattern CP has a severe scoliosis (A) and severe kyphosis (B). One week after unit rod instrumentation the boy's posture is corrected and he can sit independent with no lateral curvature (C) and normal sagittal plane alignment (D).

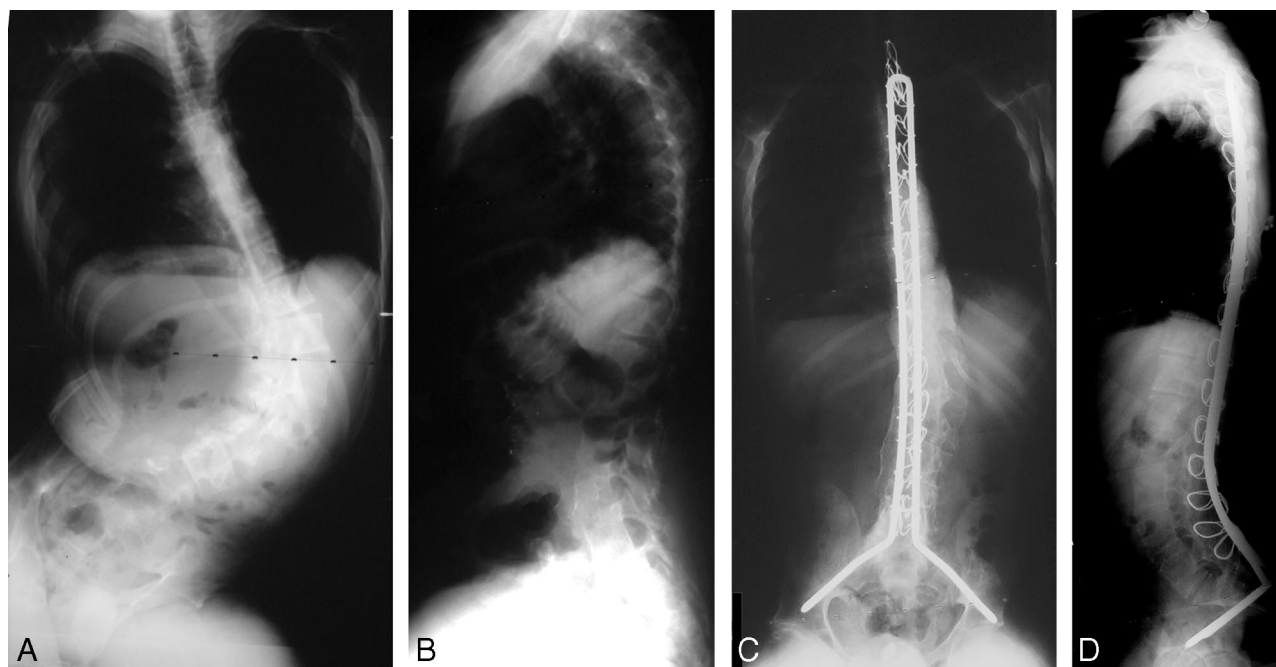


Figure 2. The preoperative radiograph shows a 95° thoracolumbar scoliosis with severe pelvic obliquity (A) and 80° of kyphosis (B). Two years after surgical correction excellent curve correction with a full fusion maintains good alignment (C) and good sagittal plane correction (D).

## Discussion

Neuromuscular scoliosis developing in children with CP continues to be a complex and challenging problem related to both the type of spinal deformity and the patients' general medical condition. CP scoliosis can be classified as Group 1 which resembles idiopathic scoliosis or Group 2 curves which are long thoracolumbar or lumbar C-shaped curves associated with pelvic obliquity.<sup>1,27</sup> In our series, all patients were treated with the same instrumentation and we found no difference in the outcome of spinal surgery between patients with type 1 and 2 curve patterns. A few patients with very mild neurologic involvement, whose curves were idiopathic pattern and limited to the thoracic spine, were treated with short instrumentation and are not included in this series. Except for these few patients, we do not find any clinical significance in this classification in terms of selection of treatment or outcome.

The specific indication for surgical correction of spinal deformities in CP needs to consider the child as a whole, and as the scoliosis increases, sitting tolerance and comfort decreases which may increase custodial care. Cardiac and pulmonary complications may also occur, especially if the curve size is so severe that the patient can not spend a significant amount of time sitting.<sup>11</sup> Spinal fusion is indicated in the presence of curve progression and a curve size of 50° in children 10 years of age or older, especially if there is a documented deterioration in their functional skills.<sup>1,9-11</sup> Restoration of coronal and sagittal trunk balance is the primary goal of curve correction and we prevented proximal drop-off kyphotic deformity by extending the fusion to the upper thoracic region above T3. Including the pelvis to maximize sitting balance is also important.

In this study, we allowed curves to progress up to 90° if they remained relatively flexible on physical examina-

**Table 2. Intraoperative Complications in Our Patient Population**

Intraoperative Complications	Posterior Spinal Fusion	Anterior-Posterior Spinal Fusion
Death (cardiac arrest)		1
Perforations of the ileum	14	3
Sublaminar wires cutout	13	1
Dural tears	3	1
Pleural/peritoneal tear		1
Loss of somatosensory evoked potentials	1	
<b>Total</b>	<b>31</b>	<b>7</b>

**Table 3. Early Postoperative Complications in Our Patient Population**

Early Postoperative Complications	Posterior Spinal Fusion	Anterior-Posterior Spinal Fusion
Death (acute hemorrhagic pancreatitis)	1	
Death (cardiac arrest)		1
Wound hematomas	3	1
Sacral decubitus ulcers	4	
Sacroiliac inflammation		1
Deep wound infections	10	2
Septicemia	2	
<b>Total</b>	<b>20</b>	<b>7</b>

**Table 4. Late Postoperative Complications in Our Patient Population**

Late Postoperative Complications	Posterior Spinal Fusion	Anterior-Posterior Spinal Fusion
Painful protruding proximal end of the instrumentation	8	1
Painful protruding distal end of the instrumentation	6	
Sacral decubitus ulcers	4	
Broken sublaminar wires	3	
Deep wound infections	3	3
Pseudarthrosis	1	
<i>Total</i>	<i>25</i>	<i>4</i>

tion to allow for maximum height gain, in children not having pain or problems associated with the scoliosis. At the end of spinal growth, curves over 40° were recommended for correction because of the expectation of progression into adulthood.<sup>14</sup> In stiff spinal curves an additional anterior release was performed through

multilevel discectomies to maximize the flexibility of the deformity and allow for increased correction through the posterior instrumentation, which can be performed under 1 or 2 anesthetic sessions.<sup>1,7,28</sup> These combined procedures can achieve better curvature correction, decrease the incidence of pseudarthrosis, and prevent recurrent deformity through a circumferential fusion.<sup>12,14,19,27,29-32</sup> Our main goal in doing an anterior release is to gain flexibility for curve correction, since the unit rod seems to prevent crankshafting, therefore the concept of circumferential fusion is less important.<sup>33,34</sup> One-stage anterior-posterior fusion can provide comparable deformity correction, however, the single-stage procedures are associated with increased morbidity, a higher incidence of technical complications and a higher perioperative mortality rate.<sup>35</sup> Therefore, patients with very severe deformities in the presence of concomitant medical problems, may have a lower risk of complications if the anterior surgery is performed a week before the posterior procedure.<sup>35</sup>

**Table 5. Questionnaire Addressed to the Parents or Primary Caretakers of Our Patients**

**Section A.** Please answer each of the following questions by circling the no. that represents best how the children you have known have responded to the back surgery performed on them

1 means Much Improved, 2 means A Little Better, 3 means No Change, 4 means A Little Worse, 5 means Much Worse, 6 means I Cannot Comment

1. After surgery the spine deformity is	1	2	3	4	5	6
2. The child's physical appearance is	1	2	3	4	5	6
3. The child's ability to lye in one position at night and sleep	1	2	3	4	5	6
4. The ability to sit and the extent of comfort in the sitting position	1	2	3	4	5	6
5. The child's ability to stand or walk is	1	2	3	4	5	6
6. The child's head control is	1	2	3	4	5	6
7. The child's ability to eat or feed is	1	2	3	4	5	6
8. The child's breathing is	1	2	3	4	5	6
9. The child's amount of pain is	1	2	3	4	5	6
10. The child's alertness or mental ability is	1	2	3	4	5	6
11. The child's ability to use his/her hands is	1	2	3	4	5	6
12. Bathing the child is	1	2	3	4	5	6
13. Dressing the child is	1	2	3	4	5	6
14. Would you recommend back surgery to a family?	Y	N	U			

Section B	No.	Questions (Mean Scores)	Parents/Primary Caregivers (190)
	1	Spine deformity	1
	2	Physical appearance	1 (1)
	3	Lying	1.7 (3)
	4	Sitting	1.1 (1)
	5	Standing/Walking	2.6 (2)
	6	Head control	2.1
	7	Eating/Feeding	2.2 (3)
	8	Breathing	1.5 (1)
	9	Back pain	1.7 (1)
	10	Mental ability	3
	11	Hand use	2.8 (1)
	12	Bathing	1.7 (4)
	13	Dressing	1.7 (4)
	14	Recommendation for surgery	182Y, 6U, 2 N
<b>Section C</b>			
(combined functions)	1	Appearance	1
	2	Gross motor	2
	3	Oral motor	1.9
	4	ADL	1.7
	5	Overall function	1.8

(I) indicates no. of answers reporting deterioration (Section B); Y, yes; U, unsure; N, no; ADL, activities of daily living.

The long-term outcome of spine deformity correction in CP remains debatable. A preliminary report of 31 patients indicated a positive impact of corrective spine surgery.<sup>25</sup> Even though severely affected individuals with CP face multiple medical problems that can potentially complicate an inherently challenging operative procedure, previous studies have documented a very high satisfaction rate among parents and caregivers, who seem to highly appreciate the impact of corrective procedures on the children's level of function and the ease of nursing care.<sup>29,36,37</sup> A report of 37 institutionalized patients found 95% of custodial institutional caregivers believed those who had spinal fusions were more comfortable.<sup>36</sup> Interviews of 60 caregivers reported 85% positive responses concerning patients' comfort, function, and care after spinal arthrodesis.<sup>29</sup> In the same study, 15% of the caretakers were not satisfied with the results of the surgery, due to poor initial curve correction or development of after surgery significant deformity.<sup>29</sup> Our current results validate very similar outcomes of the parents' and caregivers' functional perceptions, however, since all our patients had satisfactory correction of and maintained their correction, there were no negative evaluations due to poor deformity correction. The perception of educators, therapists, schoolteachers, and chronic care staff also had a positive opinion on the general benefits of scoliosis correction.<sup>38</sup> Most of the parents (95.8%) and professional caregivers (84.3%) in this study considered that the benefits from correcting scoliosis offset the risks of the procedure. No patient with preoperative ambulatory ability lost function after unit rod instrumentation.<sup>39</sup>

The use of the Unit rod instrumentation for correction of neuromuscular scoliosis has been previously reported in smaller patient populations. Unit rod instrumentation was first reported in 34 pediatric patients with neuromuscular scoliosis, 17 had CP.<sup>24</sup> A mean preoperative scoliosis angle of 66° was corrected by 47% to 35°. A preoperative pelvic obliquity of 18° was corrected by 57.8% to 7.6°. Another series of 34 children with CP reported 82% correction from 89° to 16°.<sup>30</sup> The pelvic obliquity was corrected by 86.8% from 34 to 4.5°. Another report of 22 children with CP out of a total number of 46 patients with neuromuscular scoliosis with instrumentation using single Luque rods found 47% correction from 74° to 39° with pelvic obliquity correction of 47%.<sup>40</sup> All reported follow-ups were less than 3 years. In the current study of 241 patients followed for 8.3 years, the Unit rod achieved correction rates similar to previous studies and substantially better than the reports from the unconnected rods. The posterior instrumentation extended to the first or second thoracic vertebrae in most patients and prevented the development of junctional add-on kyphosis. Bilateral pelvic fixation is inherently part of the unit rod surgical technique and was performed to correct pelvic obliquity and improve sitting balance.

Single stage posterior spinal instrumentation was associated with a reduced surgical time ( $P < 0.001$ ), and less

days in the ICU ( $P < 0.05$ ) compared to the combined anteroposterior procedures. However, there was no difference noted in blood loss, total stay in hospital, complication rate, or degree of deformity correction between the 2 groups, even though the patients who underwent an additional anterior release had the most stiff and more severe curves. Based on this result, we believe that the addition of the anterior release does not add much risk of increased morbidity. However, patients with severe associated medical risk may be best served with a staged anterior and posterior procedure.<sup>35</sup>

After spinal arthrodesis, there was a maximum loss of deformity correction at the final follow-up radiograph of 4 degrees with statistically significant loss in all deformity planes, however, we do not consider this small loss to be clinically significant. Major complications after spinal instrumentation included 3 perioperative deaths, 18 deep wound infections treated only with serial debridements and the 6 patients with late infections who required removal of part or all the instrumentation. All the early infections healed with good callus formation and no need for hardware removal. All late infections required hardware removal but none had evidence of pseudoarthrosis. The best predictor for the development of postoperative complications in children with CP who undergo spinal surgery is the degree of neurologic disability.<sup>11</sup> The presence of associate medical problems and a curve magnitude greater than 70° also increased the risk of postoperative complications. The presence of other factors such as poor nutrition, gastrostomy feedings, antiseizure medication, tracheal abnormalities or tracheostomy did not constitute major additional risk.<sup>11</sup> Conversely, other investigators have suggested that inadequate nutritional status increases the risk of urinary infections, prolonged patient intubation and hospital stay.<sup>41</sup>

Intraoperative complications related to pelvic fixation of the rod occurred in 17 patients. Preoperative lumbar hyperlordosis was correlated with increased morbidity and a greater incidence of technical complications associated with the pelvic fixation. Sagittal spine deformity in patients with CP has a reported prevalence of 7% in patients with scoliosis.<sup>30,42,43</sup> This level is lower than the prevalence found in the current study where 19% had hyperlordosis. Considerations to manage significant sagittal plane deformity concomitant with scoliosis includes selecting a slightly shorter rod size for hyperkyphosis, and slightly longer rod size for hyperlordosis; and the possible need to cut and reconnect the rod in cases of severe hyperlordosis to avoid rod penetration through the inner pelvic table when placing the pelvic limb of the rod.<sup>44</sup>

Reoperations due to mechanical problems related to the instrumentation were performed in 12 patients; with 3 detected pseudoarthrosis, and except for the pseudoarthrosis repair, these procedures were all minor with most of them performed as outpatient procedures.

Controversy remains on performing scoliosis surgery in the child with cerebral palsy, especially when complex

medical problems are also present. There is limited published data on the predicted life expectancy of patients with CP<sup>45,46</sup>; however, previous reports presumed that individuals with CP have lower survival rates than the general population.<sup>47-50</sup> The most significant determinants for reduced life expectancy in pediatric patients with CP are the coexistence of other significant comorbidities, such as respiratory malfunction, epilepsy, or feeding disorders.<sup>46-54</sup> Respiratory disease, may be the predominant cause of death.<sup>50,55,56</sup> Contrary to these reports,<sup>47-49</sup> more recent studies have documented substantially better survival rates even for patients with total-body involvement.<sup>50-53</sup> As a consequence, children with CP and neuromuscular scoliosis should now be considered as having a chronic disability with which one lives, often a comparable time to the unaffected population. The management of related medical and orthopaedic conditions should be based on this new reality.

Based on the Kaplan-Meier survival analysis, 68% of patients who have spine instrumentation are expected to survive at least 11 years.<sup>57</sup> The most predictive determinant for survival rates among this population were the number of days the patient had to spend after surgery in the ICU, which reflects the general preoperative medical condition and is predominantly related to abnormal respiratory function. There was also a weak correlation to hyperkyphosis of curves greater than 90° and scoliosis greater than 100°.<sup>57</sup>

The present study demonstrates the ability to gain excellent correction of the spinal deformity using the Unit rod instrumentation with relatively short operative times. Currently, there is an increasing interest in third generation instrumentation systems using multiple pedicle screws in the treatment of spine deformity including neuromuscular scoliosis. These systems are based on the same principle of segmental fixation as the unit rod substituting pedicle screws and iliac bolts. As these newer techniques become common and widely used, it is essential to establish benchmarks for degree of deformity correction and complication rates related to the technical aspects of the individual procedure. As new instrumentation is being introduced, there is also a significant increase in implant cost, which should be balanced against benefits obtained by the use of these new techniques.

In conclusion, scoliosis is a very common orthopaedic condition in children with CP, especially those with quadriplegia. Since there is a well-documented high degree of caretaker satisfaction after deformity correction, the selection of the appropriate operative technique and type of instrumentation should depend on achieving optimum correction of the curvature while minimizing the complication rate. In contrast, the specific instrumentation used is not likely to reduce the risk for the common medical complications related to such a major surgical undertaking. However, a good multidisciplinary approach should be able to effectively manage the multitude of problems that may arise in this patient population. The Unit rod instrumentation may be

considered the gold standard technique and the primary instrumentation system for the treatment of pediatric patients with CP and neuromuscular scoliosis because it is simple to use, although it is technically more difficult in patients with hyperlordosis. It is also considerably less expensive than most other systems. The Unit rod can achieve good deformity correction with a low loss of correction, as well as a low prevalence of associated complications and reoperation rate.

### ■ Key Points

- Scoliosis due to cerebral palsy can be successfully corrected with the Unit rod instrumentation.
- Multiple complications may occur as part of this treatment.
- Caretakers have a very positive opinion of the outcome of this procedure.
- Unit rod instrumentation is cost effective compared to other modern segmental instrumentation for spinal arthrodesis.

### References

1. Lonstein JE. Spine deformities due to cerebral palsy. In: Weinstein SL, ed. *The Pediatric Spine: Principles and Practice*. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins, 2001:797-807.
2. Edebol-Tysk K. Epidemiology of spastic tetraplegia cerebral palsy in Sweden. I. impairments and disabilities. *Neuropediatrics* 1989;20:41-5.
3. Madigan RR, Wallace SL. Scoliosis in the institutionalized cerebral palsy population. *Spine* 1981;6:583-90.
4. Ferguson RL, Allen BL Jr. Considerations in the treatment of cerebral palsy patients with spinal deformities. *Orthop Clin North Am* 1988;19:419-25.
5. Banta JV, Drummond DS, Ferguson RL. The treatment of neuromuscular scoliosis. In: Zuckerman JD, ed. *Instruct Course Lectures*. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1999;48:551-62.
6. Bradford DS. Neuromuscular spinal deformity. In: Bradford D, Lonstein J, Ogilvie J, et al, ed: *Moe's Textbook of Scoliosis and other Spinal Deformities*. Philadelphia, PA: WB Saunders Co., 1987;271-305.
7. Herring JA. Disorders of the brain. In: Herring JA, ed. *Tachjian's Pediatric Orthopaedics*. Philadelphia, PA: WB Saunders Co., 2002;1121-248.
8. Labelle H, Grimard G. Pediatric Spine. In: Koval K, ed. *Orthopaedic knowledge update 7: Home Study Syllabus*. Rosemont, IL: American Academy of Orthopaedic Surgeons, 2002;581-92.
9. Lipton GE, Miller F, Dabney KW, et al. Factors predicting post-operative complications following spinal fusions in children with cerebral palsy. *J Spinal Disord* 1999;12:197-205.
10. Renshaw TS. Cerebral Palsy. In: Morrissy RT, Weinstein SL, ed. *Lovell and Winter's Pediatric Orthopaedics*. Philadelphia, PA: Lippincott Williams & Wilkins, 2001;563-99.
11. Kalen V, Conklin MM, Sherman FC. Untreated scoliosis in severe cerebral palsy. *J Pediatr Orthop* 1992;12:337-40.
12. McCarthy RE. Management of Neuromuscular scoliosis. *Orthop Clin North Am* 1999;30:435-49.
13. Miller A, Temple T, Miller F. Impact of orthoses on the rate of scoliosis progression in children with cerebral palsy. *J Pediatr Orthop* 1996;16:332-5.
14. Thometz JG, Simon SR. Progression of scoliosis after skeletal maturity in institutionalized adults who have cerebral palsy. *J Bone Joint Surg Am* 1988;70:1290-6.
15. Zimble S, Craig CL, Harris S. Orthotic management of severe scoliosis in spastic neuromuscular disease: results of treatment. *Orthop Trans* 1982;6:70.
16. Saito N, Ebara S, Ohotsuka K, et al. Natural history of scoliosis in spastic cerebral palsy. *Lancet* 1998;351:1687-92.
17. Garrett AL, Perry J, Nickel VL. Paralytic scoliosis. *Clin Orthop* 1961;21:117-24.
18. Luque ER. Segmental spinal instrumentation for correction of scoliosis. *Clin Orthop* 1982;163:192-98.

19. Bonnett C, Brown JC, Grow T. Thoracolumbar scoliosis in cerebral palsy. Results of surgical treatment. *J Bone Joint Surg Am* 1976;58:328–36.
20. McDonnell MF, Glassman SD, Dimar JR, et al. Perioperative complications of anterior procedures on the spine. *J Bone Joint Surg Am* 1996;78:839–47.
21. Allen BL Jr, Ferguson RL. L-rod instrumentation for correction of scoliosis in cerebral palsy. *J Pediatr Orthop* 1982;2:87–96.
22. Gau YL, Lonstein JE, Winter RB, et al. Luque-Galveston procedure for correction and stabilization of neuromuscular scoliosis and pelvic obliquity: a review of 68 patients. *J Spinal Disord* 1991;4:399–410.
23. Dias RC, Miller F, Dabney K, et al. Revision spine surgery in children with cerebral palsy. *J Spinal Disord* 1997;10:132–44.
24. Bell DF, Moseley CF, Koreska J. Unit rod segmental spinal instrumentation in the management of patients with progressive neuromuscular spinal deformity. *Spine* 1989;14:1301–7.
25. Dias RC, Miller F, Dabney KW, et al. Surgical correction of spinal deformity using a unit rod in children with cerebral palsy. *J Pediatr Orthop* 1996;16:734–40.
26. Cobb JR. Outline for the study of scoliosis. In: American Academy of Orthopaedic Surgeons, ed. *Instructional Course Lectures*. Ann Arbor, MI; JW Edwards, 1948;261–275.
27. Lonstein JE, Akbarnia A. Operative treatment of spinal deformities in patients with cerebral palsy or mental retardation. An analysis of one hundred and seven cases. *J Bone Joint Surg Am* 1983;65:43–55.
28. Bradford DS, Hu SS. Neuromuscular Spinal Deformity. In: Lonstein JE, Winter RB, Bradford DS, Ogilvie JW, ed. *Moe's Textbook of Scoliosis and other Spinal Deformities*. 3rd ed. Philadelphia, PA: W B Saunders Co., 1995; 295–322.
29. Comstock CP, Leach J, Wenger DR. Scoliosis in total-body-involvement cerebral palsy. Analysis of surgical treatment and caregiver satisfaction. *Spine* 1998;23:1412–24; discussion 1424–5.
30. Rinsky LA. Surgery of spinal deformity in cerebral palsy. Twelve years in the evolution of scoliosis management. *Clin Orthop* 1990;253:100–9.
31. Brown JC, Swank S, Specht L. Combined anterior and posterior spine fusion in cerebral palsy. *Spine* 1982;7:570–3.
32. Swank S, Cohen D, Brown J. Spinal fusion in cerebral palsy with L-rod segmental spinal instrumentation: a comparison of single and two-stage combined approach with Zielke instrumentation. *Spine* 1989;12:750–9.
33. Smucker JD, Miller F. Crankshaft effect after posterior spinal fusion and unit rod instrumentation in children with cerebral palsy. *J Pediatr Orthop* 2001; 21:108–12.
34. Westerlund LE, Gill SS, Jarosz TS, et al. Posterior-only unit rod instrumentation and fusion for neuromuscular scoliosis. *Spine* 2001;26:1984–9.
35. Tsirikos AI, Chang W-N, Dabney KW, et al. Comparison of one-stage versus two-stage anteroposterior spinal fusion in pediatric patients with cerebral palsy and neuromuscular scoliosis. *Spine* 2003;28:1300–5.
36. Cassidy C, Craig C, Perry A, et al. A reassessment of spinal stabilization in severe cerebral palsy. *J Pediatr Orthop* 1994;14:731–39.
37. Sponseller PD, Whiffen JR, Drummond DS. Interspinous process segmental spinal instrumentation for scoliosis in cerebral palsy. *J Pediatr Orthop* 1986; 6:559–63.
38. Tsirikos AI, Chang W-N, Dabney KW, et al. Comparison of parents' and caregivers' satisfaction after spinal fusion in children with cerebral palsy. *J Pediatr Orthop* 2004;24:54–8.
39. Tsirikos AI, Chang W-N, Shah SA, et al. Preserving ambulatory potential in pediatric patients with cerebral palsy who undergo spinal fusion using unit rod instrumentation. *Spine* 2003;28:480–3.
40. Boachie-Adjei O, Lonstein JE, Winter RB, et al. Management of neuromuscular spinal deformities with Luque segmental instrumentation. *J Bone Joint Surg Am* 1989;71:548–61.
41. Jevsevar DS, Karlin LI. The relationship between preoperative nutritional status and complications after an operation for scoliosis in patients who have cerebral palsy. *J Bone Joint Surg Am* 1993;75:880–4; erratum in *J Bone Joint Surg Am* 1993;75:1256.
42. Song EW, Lenke LG, Schoencker PL. Isolated thoracolumbar and lumbar hyperlordosis in a patient with cerebral palsy. *J Spinal Disord* 2000;13:455–60.
43. Shook JE, Lubicky JP. Paralytic scoliosis. In: Bridwell KH, Dewald RL, ed. *Textbook of spinal surgery*. 2nd ed. Philadelphia, PA: Lippincott-Raven, 1977;835–79.
44. Dabney KW, Miller F, Lipton GE, et al. Correction of sagittal plane spinal deformities with unit rod instrumentation in children with cerebral palsy. *J Bone Joint Surg Am* 2004;86(suppl 1 Pt 2):156–68.
45. Nelson KB, Swaiman KF, Russman BS. Cerebral Palsy. In: Swaiman KF, ed. *Pediatric Neurology*. St Louis, MO: Mosby, 1994;471–88.
46. Strauss DJ, Shavelle RM, Anderson TW. Life expectancy of children with cerebral palsy. *Pediatr Neurol* 1998;18:143–9.
47. Crichton JU, MacKinnon M, White CP. The life expectancy of persons with cerebral palsy. *Dev Med Child Neurol* 1995;37:567–76.
48. Eyman RK, Grossman HJ, Chaney RH, et al. The life expectancy of profoundly handicapped people with mental retardation. *N Engl J Med* 1990; 323:584–89.
49. Eyman RK, Grossman HJ, Chaney RH, et al. Survival of profoundly handicapped people with severe mental retardation. *Am J Dis Child* 1993;147: 329–36. Erratum in: *Am J Dis Child* 1993;147:508.
50. Evans PM, Evans SJ, Alberman E. Cerebral palsy: why we must plan for survival. *Arch Dis Childhood* 1990;65:1329–33.
51. Plioplys AV, Kasnicka I, Lewis S, et al. Survival rates among children with severe neurologic disabilities. *South Med J* 1998;91:161–72.
52. Hutton JL, Cooke T, Pharoah PO. Life expectancy in children with cerebral palsy. *BMJ* 1994;309:431–35.
53. Hutton JL, Colver AF, Mackie PC. Effect of severity of disability on survival in northeast England cerebral palsy cohort. *Arch Dis Childhood* 2000;83: 468–74.
54. Anderson TW. Life expectancy in cerebral palsy. *Lancet* 1997;349:283–4.
55. Chaney RH, Eyman RK, Miller CR. Comparison of respiratory mortality in the profoundly mentally retarded and in the less retarded. *J Ment Defic Res* 1979;23:1–7.
56. Tarjan G, Brooke CE, Eyman RK, et al. Mortality and cause of death in a hospital for the mentally retarded. *Am J Public Health Nations Health* 1968; 58:1891–900.
57. Tsirikos AI, Chang W-N, Dabney KW, et al. Life expectancy in paediatric patients with cerebral palsy and neuromuscular scoliosis who underwent spinal fusion. *Dev Med Child Neurol* 2003;45:677–82.