Complications of the Luque—Galveston scoliosis correction technique in paediatric cerebral palsy

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Cerebral palsy; Scoliosis; Luque—Galveston technique; Moseley rod; Complications

Summary
Purpose of the study: Severe scoliosis is a very frequent condition in cerebral palsy children (CP). It is surgically managed, with unit rod instrumentation being the gold standard in English-speaking countries. The purpose of this work was to report on a small, homogeneous series of non-ambulatory, quadriplegic, spastic patients treated by the Luque—Galveston technique in Strasbourg, France. We present the radiographic outcome of the technique along with a full description of any post-operative complications encountered.

Materials and methods: Twenty-eight children were operated on according to the Luque—Galveston technique between January 1997 and January 2006. This instrumentation, with fusion, included the whole spine from the sacrum to level T2. All procedures were performed as a one-stage posterior arthrodesis. The spinal deformities were single thoraco-lumbar curvatures, except in one patient. Both curve magnitude and pelvic obliquity were measured by X-ray pre-operatively, post-operatively and after longest follow-up (over 24 months). Our study focused on the rate of complications of this treatment. Only 16 patients out of 28 were tracked since the remaining 12 were lost to follow-up.

Results: Mean curve magnitude was corrected from 80° to 34.8° (mean correction, 56.5%), and pelvic obliquity, from 20.9° to 4.2° (mean correction, 79.6%). Loss of correction at average 3.46-year follow-up was 3.9° of curve magnitude and 2.7° of pelvic obliquity. Mean operating time was 301.5 minutes, and average blood loss was 861.9 ml. Patients were discharged from hospital after an average 19.5-day stay, including mean 8.4-day intensive care unit stay. A single major complication, monocular blindness, occurred during the procedure, probably resulting from air embolism. Post-operative complications (totaling 57.1% of our 28 patients) were: one death, three pneumothoraces, six segmental atelectasias, seven pneumonias and one superficial wound infection. Late-onset complications (totaling 56.2% of our 16 patients at latest follow-up) were: seven broken sublaminar wires, one iliac perforation by the rod, one skin...
Introduction

Scoliosis in cerebral palsy (CP) is directly linked to the severity of central neurological damage [1]. According to Edebol-Tysk [2], 74% of tetraplegic, spastic CP patients have very significant scoliosis, often presenting as prominent kyphoscoliosis from spinal collapse with considerable frontal thoraco-lumbar curvature. It is recognized that medical treatment of the spasticity is ineffective in the prognosis of this condition, similarly to different kinesitherapy methods proposed and orthopaedic approaches with the use of corsets [3].

Thus, progressive scoliosis induced by CP must be addressed surgically [1,4], with instrumentation that must extend to the pelvis to counterbalance pelvic obliquity [5]. However, this surgery is undertaken in children with a precarious overall state and generalized osteoporosis which do not allow major constraints due to weakened bones [6]. In these particular cases, correction of the spinal deformities by rods and sublaminar wires has become the gold standard in developed countries [7].

We perform the Luque–Galveston technique at Strasbourg (Paediatric Traumatology and Orthopaedics Unit, Prof. J.M. Clavert, University Hospitals of Strasbourg, France) to correct severe spinal defects in non-ambulatory children with CP.

The goal of our study was to analyze the results achieved in the correction of deformities in this particular patient population, with the Luque–Galveston technique, as much in the frontal plane as at the level of the pelvic obliquity. Twenty-eight non-ambulatory children with CP had been operated by the technique between January 1997 and January 2006 in the Paediatric Orthopaedics Division at Strasbourg, were reviewed retrospectively. All interventions, performed by two senior surgeons (CK, JMC), were similar in practice and consisted of posterior arthrodesis in a single session with the Moseley rod [8] fixed to the spine by Luque sublaminar wires from the sacrum up to T2 or T3.

The inclusion criteria were: non-ambulatory children with CP to the exclusion of scoliosis of idiopathic origin or resulting from another disease, children with fused triradiate cartilage who had never undergone any other spinal surgery. Children who exclusively presented sagittal spinal deformities were not selected for this study. The choice of triradiate fused cartilage was dictated by our will not to risk any crankshaft effect after posterior arthrodesis.

The chosen surgical indication was progression of spinal deformities in our patients whose growth was not completed. Curvatures of more than 60° were instrumented posteriorly before the deformity was fixed and would require anterior resection. In our patients with completed growth, deviation of more than 30° was a surgical indication. On the other hand, most patients, thus selected, presented ischiatric hyperpressure pain that justified the indication even more, although the latter data are not reproducible.

All patients underwent a preoperative visit by a cardiologist and a pneumologist to screen for all possible contraindications to the surgery.

A radial arterio-catheter and central venous access were chosen by the anaesthetists before surgery to regulate arterial blood pressure and better compensate for eventual blood losses. Per-operative blood loss were compensated by auto-transfusion with the CellSaver® system (Haemonetics®). Central venous access also allowed parenteral nutrition after the intervention.

The intervention consisted of exposing the laminae and transverse processes of the vertebrae from level T1 to the sacrum. The iliac wings were also exposed at the posterior iliac crests to the level of the sciatic opening. Doubled metal wires, 1.2 mm for the lumbar region and 0.9 mm for the thoracic region, were passed sublaminarily through each vertebral level from L5 to T1. According to the Galveston technique, insertion openings for the end of the Moseley rod (UNIT ROD®, Medtronic™) were drilled into the depth of irritation from extreme malnutrition needing hardware removal, and three superficial sacral decubitus ulcers.

Discussion: Our correction rate in children affected by CP and manifesting severe scoliosis is similar to that reported in the literature by different surgical teams. Moreover, we did not observe any deep wound infection, haematoma, sepsicaemia, neurological and digestive complications. Late-onset complications mainly involved asymptomatic sublaminar wire breakage at the two uppermost levels, but no major complication was due to hardware failure, and vertebral fracture did not occur. There was no need for re-intervention because of the hardware, except for one case in which extreme malnutrition provoked skin conflict with the rod. We encountered 10 “windshield wiper” effects in the iliac bone, but we believe they cannot be considered as complications since they seemed to disappear after fusion was fully obtained. Last but not least, unit rod instrumentation is not very expensive compared to more modern techniques.

Conclusion: Correction of scoliosis and pelvic obliquity, attributed to CP in non-ambulatory children, by the Luque–Galveston technique is both an effective and safe choice in such an indication. Moreover, it is far less expensive than most other techniques, an aspect which should be taken into consideration. Level of evidence: Level IV retrospective therapeutic study.
the iliac crest in a bilateral manner, under scopic control, to avoid creating cortical intrusion, towards the great sciatic opening. Once the Moseley rod was introduced in the iliac wings, its upper part was brought back towards the concavity of the thoraco-lumbar curve. The doubled sub-laminar wires were then tightened by torsion of two strands between them from L5 to T2, then a second tightening was undertaken since visco-elastic reduction of the spinal deformity had progressively made the first tightening insufficient. A transverse traction device was then fixed in the lumbar region to increase stability and rigidity of the instrumentation. The tightened wire ends were cut and folded towards the center line. Synthetic bone and resected bone material from the spinal processes were grafted preferentially at the lumbar level facing the stems.

After the intervention, the patients were resuscitated, kept intubated and ventilated for at least 24 hours, to better control pain and cardiorespiratory functions. They were reintegrated into the ward where WHO level three antalics (morphinics) were stopped, if intestinal transit had resumed in such a way to allow per os feeding or a naso-gastric catheter (even if part of feeding remained parenteral), if cardio-respiratory functions were stable and there was no infection.

Radiography consisted of measuring Cobb’s angle frontally as well as pelvic obliquity. X-rays were taken in a seated position. These measurements were carried out pre-operatively, post-operatively and at the longest follow-up. In the case of double curvature scoliosis, only the value of Cobb's angle was retained as the major curve. Pelvic obliquity was defined as the angle between a line linking the centers of T1 and S1 and the line perpendicular to a line joining the lower extremities of the sacro-iliac joints.

A retrospective review of all records was conducted for all patients, to identify all peri-operative complications. All patients were then reviewed to identify long-term complications. Any adverse event after surgery was considered to be a complication, without taking its seriousness into account.

This study thus included 28 patients, 15 girls and 13 boys, with a median age of 16.4 years (12.5 to 27 years) before surgery. These patients presented scoliosis with considerable, single thoraco-lumbar curvature, the exception being a young girl manifesting double, major scoliosis with a regular pelvis. Patients in the group generally displayed a regular pelvis according to the classification of Dubousset [9], but we disregarded this parameter in the correction strategy, as the technique described achieved no more than global correction of pelvic obliquity by bringing the spine onto the Moseley rod planted in it. Among these 28 patients, 12 were lost to follow-up (10 of them stopped their follow-up early, and two died from respiratory failure in the year that followed the intervention). Thus, the early post-operative results were based on the initial population of 28 patients, while late results with 3.46 years of follow-up were based only on 16 patients not lost to follow-up or not deceased in this time interval.

Results

Average operating time for the 28 study patients was 310 minutes (5.2 hours), average blood loss was 845 ml (395—2,500 ml). No patient needed heterologous transfusion, because of Cellsaver® use.

Twenty-eight patients were kept on average 8.5 days in resuscitation (4 to 40 days) with standard deviation (SD) of 7.5 days. However, this high value can be explained by the prolonged stay of three patients, for 18, 25 and 40 days respectively, because of major respiratory infection which made it very difficult to take them off respiratory support. If these three patients were excluded from the calculation, average hospital duration was 6 days with a SD of 2 days. Total hospital stay was 20.4 days (12 to 46 days) with a SD of 7 days.

Pre-operative Cobb’s angle was 80° (41°—120°) on average, and pelvic obliquity, 20.6° (2°—55°). Post-operatively, as soon as the children could be seated for comparative X-rays, Cobb’s angle was 37.1° on average (12°—108°) and pelvic obliquity was 5.2° (0°—26°). We, therefore, achieved an average correction of 53.6% of Cobb’s angle and 74.8% of pelvic obliquity. These results were obtained in the entire population of 28 study patients.

Sixteen children had a late follow-up of more than 2 years post-operatively, with an average of 3.46 years (2—10 years). Descriptive analysis of these 16 patients gave an

Figure 1 Preoperative X-rays showing (A) a right double thoracic and predominantly left lumbar scoliosis (Cobb angle to 120°) with regular oblique pelvis (42°) and flat back (B) instrumented up to T3. The results obtained post-operatively appear in C and D with complete correction of the pelvic obliquity and Cobb lumbar angle brought back to 50°. At latest follow-up, instrumentation has hardly moved at the spinal level with Cobb lumbar angle of 44°. However, an iliac mobility halo can be seen in the pelvis (F).
Table 1  Early and latest follow-up results and complications in 16 patients at longest (2-year) follow-up.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Age</th>
<th>Scoliosis type</th>
<th>Pre-op Cobb (°)</th>
<th>Pelvic obliquity (°)</th>
<th>Post-op Cobb (°)</th>
<th>Post-op obliquity (°)</th>
<th>Procedure duration (min)</th>
<th>ICU stay (days)</th>
<th>Total hospital stay (days)</th>
<th>Post-operative complications</th>
<th>Estimated blood loss (ml)</th>
<th>Follow-up (years)</th>
<th>Cobb at longest follow-up (°)</th>
<th>Pelvic obliquity at longest follow-up (°)</th>
<th>Complications at longest follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>17</td>
<td>Thoracolumbar R</td>
<td>66</td>
<td>6</td>
<td>34</td>
<td>2</td>
<td>270</td>
<td>40</td>
<td>46</td>
<td>Pulmonary at D + 2 (atelectasia)</td>
<td>2500</td>
<td>2</td>
<td>28</td>
<td>2</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>17</td>
<td>Thoracolumbar R</td>
<td>90</td>
<td>20</td>
<td>36</td>
<td>4</td>
<td>285</td>
<td>10</td>
<td>22</td>
<td>Pneumothorax at D + 6</td>
<td>500</td>
<td>2</td>
<td>38</td>
<td>8</td>
<td>Decubitus sacral ulcer</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>27</td>
<td>Thoracolumbar L</td>
<td>96</td>
<td>40</td>
<td>42</td>
<td>0</td>
<td>180</td>
<td>12</td>
<td>24</td>
<td>Segmentary atelectasia</td>
<td>1400</td>
<td>2</td>
<td>44</td>
<td>0</td>
<td>N</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>15,5</td>
<td>Thoracolumbar L</td>
<td>90</td>
<td>24</td>
<td>46</td>
<td>4</td>
<td>305</td>
<td>9</td>
<td>21</td>
<td>Pneumopathy with pGural affusion</td>
<td>1000</td>
<td>2</td>
<td>50</td>
<td>6</td>
<td>T3 wire failure</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>15,5</td>
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<td>52</td>
<td>12</td>
<td>21</td>
<td>0</td>
<td>270</td>
<td>5</td>
<td>15</td>
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<td>N</td>
</tr>
<tr>
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<td>F</td>
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<td>36</td>
<td>6</td>
<td>360</td>
<td>5</td>
<td>16</td>
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<td>N</td>
</tr>
<tr>
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<td>M</td>
<td>19</td>
<td>Thoracolumbar L</td>
<td>65</td>
<td>12</td>
<td>38</td>
<td>0</td>
<td>300</td>
<td>6</td>
<td>15</td>
<td>Segmentary atelectasia</td>
<td>395</td>
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<td>30</td>
<td>0</td>
<td>T2 wire failure</td>
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<td>24</td>
<td>Thoracolumbar R</td>
<td>41</td>
<td>16</td>
<td>24</td>
<td>2</td>
<td>300</td>
<td>7</td>
<td>17</td>
<td>Monocular cecity</td>
<td>650</td>
<td>2.25</td>
<td>32</td>
<td>10</td>
<td>T2 and T3 4 wire failure</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>17</td>
<td>Thoracolumbar R</td>
<td>80</td>
<td>55</td>
<td>20</td>
<td>3</td>
<td>300</td>
<td>5</td>
<td>15</td>
<td>N</td>
<td>600</td>
<td>2.33</td>
<td>28</td>
<td>12</td>
<td>T2 and T3 4 wire failure, unit rod iliac perforation Decubitus sacral ulcer</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>13</td>
<td>Thoracolumbar R</td>
<td>92</td>
<td>12</td>
<td>52</td>
<td>12</td>
<td>300</td>
<td>6</td>
<td>23</td>
<td>Pneumopathy</td>
<td>1650</td>
<td>3.0</td>
<td>56</td>
<td>12</td>
<td>T2 wire failure</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>16</td>
<td>Lumbar L</td>
<td>46</td>
<td>16</td>
<td>18</td>
<td>0</td>
<td>330</td>
<td>6</td>
<td>13</td>
<td>N</td>
<td>800</td>
<td>3.0</td>
<td>40</td>
<td>22</td>
<td>T2, T3, T4 wire failure and instrumentation removed after 18 months because of skin irritation N</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>13</td>
<td>Thoracolumbar R</td>
<td>110</td>
<td>23</td>
<td>62</td>
<td>16</td>
<td>310</td>
<td>4</td>
<td>27</td>
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<td>600</td>
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<td>70</td>
<td>24</td>
<td>T2 wire failure</td>
</tr>
<tr>
<td>13</td>
<td>F</td>
<td>17</td>
<td>Lumbar L</td>
<td>120</td>
<td>42</td>
<td>50</td>
<td>0</td>
<td>365</td>
<td>7</td>
<td>17</td>
<td>N</td>
<td>750</td>
<td>3.0</td>
<td>44</td>
<td>0</td>
<td>N</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>19</td>
<td>Thoracolumbar R</td>
<td>118</td>
<td>23</td>
<td>48</td>
<td>3</td>
<td>420</td>
<td>4</td>
<td>15</td>
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<td>625</td>
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<td>N</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>17</td>
<td>Thoracolumbar R</td>
<td>40</td>
<td>2</td>
<td>12</td>
<td>0</td>
<td>265</td>
<td>4</td>
<td>13</td>
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<td>600</td>
<td>5.3</td>
<td>20</td>
<td>2</td>
<td>N</td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>21</td>
<td>Thoracolumbar L</td>
<td>72</td>
<td>8</td>
<td>18</td>
<td>6</td>
<td>265</td>
<td>5</td>
<td>14</td>
<td>N</td>
<td>520</td>
<td>6.5</td>
<td>18</td>
<td>2</td>
<td>T2 wire failure</td>
</tr>
</tbody>
</table>
average Cobb angle of 80.1° (40°—120°) pre-operatively, 34.8° (12°—62°) post-operatively, thus, with average correction of 56.5%. Similarly, pelvic obliquity in these 16 patients was 20.9° (2°—55°) pre-operatively and 4.2° (0°—16°) post-operatively, for average correction of 79.6%.

At longest follow-up, Cobb’s angle was 38.75° (18°—70°), and pelvic obliquity, 6.9° (0°—24°). Loss of correction was minimum with 3.9° on average in the frontal plane and 2.7° on average for pelvic obliquity (Fig. 1). The number of patients lost to follow-up was indeed significant in this study, but the 16 patients followed up in the study remained homogeneous compared to the initial population from which they originated. The results on these 16 patients are summarized in Table 1.

We reported one peri-operative complication, namely, monocular blindness, that was attributed to a gas embolism during the intervention.

Post-operatively, 16 of the 28 patients were affected by early complications in the 3 months following the intervention (i.e. 57.1% of patients). The complications were never related to instrumentation hardware, but were of a general nature during the course of surgery. A patient died from unexplained heart failure 24 hours after the intervention. We found six lower lobe atelectasias, treated principally by double antibiotherapy, seven segmental pneumopathies, also treated by double antibiotherapy, a superficial skin infection at the lumbar level, treated by local care and resolvable within a few days, as well as three pneumothoraces of the concave side of the scoliosis curve, including only one that needed drainage by pleuro-catheter (Table 2).

At longest follow-up, nine patients out of 16 presented at least one complication during the course of follow-up (i.e. 56.2% of patients followed-up long-term). However, most often the complications were due to the hardware, as seen in seven cases of asymptomatic sublaminar wire breakage at the level of the T2 and T3 vertebrae, in one case of iliac perforation of one of the Moseley rod extremities in the left buttock that was entirely asymptomatic, in one case the hardware had to be removed 18 months after placement for arthrodesis as the patient became very cachectic and presented skin irritation. This was the sole case of later re-intervention. Three patients also presented sacral bedsores that were treated by local care and did not provoke infection of the material that was still in place (Tables 1 and 3).

### Table 2: Early post-operative complications (< 3 months) in 28 patients.

<table>
<thead>
<tr>
<th>Early post-operative complications</th>
<th>Number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>1</td>
</tr>
<tr>
<td>Digestive complications</td>
<td>0</td>
</tr>
<tr>
<td>Neurological complications</td>
<td>0</td>
</tr>
<tr>
<td>Respiratory complications</td>
<td></td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>3</td>
</tr>
<tr>
<td>Segmentary atelectasia</td>
<td>6</td>
</tr>
<tr>
<td>Infections</td>
<td></td>
</tr>
<tr>
<td>Pneumopathies</td>
<td>7</td>
</tr>
<tr>
<td>Superficial wound infections</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Monocular cecity</td>
<td>1</td>
</tr>
</tbody>
</table>

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### Table 3: Late-onset complications (> 3 months) in 16 patients with longest (over 2-year) follow-up.

<table>
<thead>
<tr>
<th>Late-onset complications</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2-T3 sublaminar wire failure</td>
<td>7</td>
</tr>
<tr>
<td>Iliac perforation</td>
<td>1</td>
</tr>
<tr>
<td>Cutaneous irritation</td>
<td>1</td>
</tr>
<tr>
<td>Decubitus sacral ulcer</td>
<td>3</td>
</tr>
<tr>
<td>Late-onset infections</td>
<td>0</td>
</tr>
</tbody>
</table>

The overall results summarized in Table 4 concern 16 patients with at least 2 years of post-operative follow-up.

The 12 patients lost to long-term follow-up thus only illustrated the results obtained immediately post-operatively, and for the identification of early complications.

### Discussion

Spastic tetraplegic scoliosis patients are particularly difficult to treat because of extreme curvatures associated with an often precarious general condition [7]. All these scoliosis-correcting techniques must therefore comply with the dual imperative of not fracturing bone elements, while assuring correct reduction of the deformity with respect to cardio-pulmonary balance that is sometimes difficult to maintain during the intervention. Miladi et al. [10] emphasized the difficulties in treatment, particularly in regard to complications: broken hardware and notably tearing of the sacral fixation, loss of lumbar lordosis and also a significant rate of pseudoarthrosis.

Thus, interest in the Luque—Galveston method compared to other techniques that can be used, such as Cotrel—Dubousset (CD) material, lies in visco-elastic deformity reduction. Spinal fixation is segmental in this case and provides good distribution of constraints all along the spine. It is extremely resistant, solid and auto-stable, avoiding post-operative restraint. Progressive reduction allows the re-distribution of constraints to protect the fragile bones of these patients. It is undertaken in two stages: first, by initial wire tightening in the caudo-cranial direction, then in the opposite direction, on a rod that is pushed towards...
the spine. Wire tightening never completely aligns the spine towards the median line but participates in the process. Curvatures in the sagittal plane are modeled on the pre-formed Moseley rod, but vertebral rotation is imperfectly corrected by the technique, even sometimes aggravating the gibbus in these patients.

It is not always easy to decide on surgical indications. Miller [1] recommends surgery on children with Cobb’s angle greater than 60°, or even if Cobb’s angle is greater than 30°, if curve reduction is stiff on bending X-rays. He also recommends waiting for fusion of triradiate cartilage, to avoid any crankshaft effect after posterior arthrodesis. We must, however, be able to operate before the occurrence of visceral complications that risk increasing their level per- and post-operatively [9]. M’Rabet and Dubousset [11] cite different factors that must dictate the indication: scoliosis progression, disturbance of respiratory functions, worsening of pelvic obliquity, which will promote hip dislocation in a context of muscle imbalance that is also attributed to CP. They also emphasized nursing difficulties in these patients with a deviated pelvis and a collapsed trunk. Neurological, motor and functional state as well as the living environment of these patients seem to take precedence over other factors in the choice of arthrodesis timing. As for us, we decided to limit our indications to the inclusion criteria enumerated earlier, as well as to the skin irritations due as much to ischiatic hyperpressure as exaggerated closure of the ilio-lumbar angle in the choice of intervention timing.

It appears that the corrections we achieved in our series are comparable to those of Tsrirkos et al. [7], Bulman et al. [12], Bell et al. [8], and Rinsky [13]. These four groups respectively reported corrections of 71%, 61.7%, 54% and 82% of Cobb’s angle post-operatively. Our series has the characteristic of being homogeneous regarding inclusion criteria in relation to other series in the literature, because it contained only non-ambulatory, tetraplegic children afflicted by thoraco-lumbar scoliosis with a large, single curve operated in one stage by the posterior route according to the same technique. We attained slightly lower correction than in other series with 56.5%, but for a primitive Cobb angle that was higher, which prevented any large-scale corrections because of potential neurological risk. Similarly, these authors reported pelvic obliquity correction rates of 72.5%, 79.3%, 42% and 86.8%, respectively, whereas we obtained correction of 79.6%.

At later follow-up, loss of correction in our series was minimal: 3.9° for Cobb’s angle on average, and 2.7° for pelvic obliquity. The study by Miller, which contained the largest number of patients, with 287 children, reported losses of 2.6° and 0.5°, respectively, at longest follow-up. This tends to prove that the post-operative results are stable over time.

Onimus et al. [14], after analyzing the literature, defended the double approach in arthrodesis of scoliosis in non-ambulatory CP children before the beginning of puberty, to guarantee better results. According to them, isolated posterior surgery gives correction of only 30 to 50% on average, while the double approach provides between 51 and 75% of correction. In contrast, from the preceding studies, it appears possible to obtain comparable corrections only by the posterior route if we wait long enough for triradiate cartilage fusion to occur.

We reported only one per-operative complication, namely, a case of monocular blindness. This complication was recorded by the ophthalmologists on account of gas embolism. Ophthalmological examination revealed total retinal ischaemia, in the central and peripheral zones; this occurs sometimes after ocular globe compression during the intervention which increases intra-cavity pressure in the posterior chamber of the eye and evokes ischaemia. However, it is certain that there was no ocular compression in this patient; the most likely etiology that could explain a pan-retinal vascular interruption of this magnitude remains obstruction of the central retinal artery by an embolic phenomenon, the most probable being gaseous in the opinion of the ophthalmologists consulted, even though it has also been described in the literature in a case of fatty pulmonary embolism in the course of such surgery [15].

There was no need for heterologous transfusion because of systematic Cellsaver® application. Although its use is contested by many authors and it does not reduce blood losses per-operatively, which are essentially venous and at the intervention end [1], we feel that for those of our patients who bled profusely up to 2,500 ml, this device still helped to recover some autologous blood and compensate for blood loss to avoid any heterologous transfusion.

No deaths occurred per-operatively, and none of the complications was attributed to hardware installation. There were no significant neurological complications during sublaminar passage of the wires and their tightening. Early post-operative complications affected 57.1% of 28 patients in our series, with one death 24 hours after surgery, resulting from heart failure, the etiology of which was uncertain. In their series, Benson et al. [16] reported 24 complications in 17 patients, predominantly infectious and respiratory problems. They did not distinguish between early and late complications. Half of the complications they encountered were urinary infections, whereas we did not have a single such case. The use of a urinary balloon catheter pre-operatively remains systematic according to a classic disinfection protocol in four stages with an iodine disinfectant. This helps avoid urine retention which is a very frequent condition post-operatively under morphinics. The catheter is then removed after resuscitation when morphinics have been stopped. In addition, those of our patients treated for lung superinfection may have been spared from urinary tract infection because of their current antibiotherapy.

We observed many pulmonary complications (3 pneumothoraxes, 7 pneumopathies, i.e. 6 segmental atelectasias), and Benson et al. [16], in comparable proportions, reported four complications in 17 patients (1 pleural effusion, 1 severe hypoxia with re-intubation in emergency, 1 prolonged intubation, and 1 pneumonia). In a series of 20 patients instrumented by Luque wires, Lascombes et al. [17] found one pneumothorax and nine respiratory infections, two of them severe. Miller reported 12 infections, i.e. 10 at the level of the surgical site and two septicaemias not labeled in their series of 287 patients. The infections encountered, therefore, remain relatively rare. Similarly, the same digestive complications are infrequent in the literature, Benson et al. [16] report only one case of chronic ileus reflex, and Miller, one case of fatal pancreatitis. We did not identify any such complication.
At latest follow-up, complications were most often mechanical. We observed no major mechanical problems requiring re-intervention, aside from chronic bursitis in a patient who became very cachectic and suffered skin irritation caused by the instrumentation. Most groups have reported one or two cases of rod breakage [8,16]. It is very uncommon to find articles dealing with the number of patients affected by the “windshield wiper” effect at the iliac level (Fig. 2). We noted 10 asymptomatic cases among 16 patients followed long-term, and Tolo et al. [18] reported 11 such cases among 54 instrumented patients. Three of these 11 cases showed Moseley rod extremity protrusion in the buttock without any particular inconvenience, while only had one similar case. Banta et al. [19] observed 13 cases in a retrospective series of 33 patients, of which nine were in the process of progressive resorption. These intra-iliac mobilities have also not been taken into account among the complications in our series as we consider that they were normal and part of the mechanical consequences of material adaptation to constraints during trunk movements of the children until arthrodesis was undertaken. As Banta et al. [19] pointed out, and this is the case in seven out of 10 patients in whom it was encountered in our series, these intra-iliac “halos” tended to disappear in a mean 18 months delay. Miladi et al. [10] compared different methods of pelvic fixation with posterior instrumentation of neuromuscular scoliosis. They underlined the hazardous stability of iliac fixation according to the Galveston technique. Our study and analysis of the literature did find iliac mobility but it does not compromise the final results and does not lead to complications while providing comparable corrections. Camp et al. [20], in a 1990 biomechanical and clinical study, even noted similar constraint patterns for the Galveston technique and fixation by ilio-sacral screws. Furthermore, Miladi et al. [10], more than 10 years after a first work with Dubousset et al. [21], underscored the risk of the spinal assembly breaking away from the pelvis in case of insufficient rod-screw tension, which can occur with the Moseley rod.

Banta et al. [19] also reported excessive ossification of arthrodesis in 14 out of 33 cases, it is the only study we found that mentioned this complication and in such proportions. In addition, this ossification presented complete pseudoarthrosis with the sacrum each time. As for us, the problem has never been encountered.

Taking spinal osteoporosis in these patients into consideration, it is interesting to note the absence of bone fractures in the literature. As Miller [1] emphasized, the occurrence of a fracture can only be a technical error during tightening of the wires. Gayet et al. [6] have shown, in biomechanical experiments, that segmental fixation affords better distribution of traction forces on the posterior arches of different instrumented vertebrae, unlike CD instrumentation where compression-distraction forces are exerted on some chosen reference vertebrae.

Few articles dealing with CD material, specifically in children with CP, are found in the literature. Sanchez-Sotelo and Sanchez Perez-Gruese [22] reported a series of 30 patients with neuromuscular scoliosis operated by CD instrumentation, 21 with sacral fixation. They achieved frontal correction of 56%, correction of sagittal balance of the spine, and correction of pelvic obliquity of 24° to 11°. There was no loss of correction on the longest follow-up, and the complications recorded were 10 infections and four hardware breakages, from which the authors concluded that the technique gives a high complication rate.

Comparison of Luque and Isola instrumentations in neuromuscular scoliosis does not reveal differences in terms of radiological outcome, complications and patient satisfaction in the literature [23]. The posterior spinal arch is the strongest part of the vertebrae. Parsons et al. [24] also demonstrated that the doubling of sublaminar wires has largely decreased shearing and erosion on the instrumented laminae. All patients in our series were instrumented with doubled wires. Recently, a new instrumentation system, sublaminar polyester bands known as the Universal Clamp® (ZimmerSpineTM), appeared on the market. The first publications seem to show equivalent correction with few complications, but the main study, focusing on idiopathic scoliosis with mixed instrumentation, notably investigated instrumentation by pedicular screws at the lumbar level [25].

In contrast, we observed wire breakage at higher levels in seven cases, due to cervical kyphosis rather than lamina fractures. These ruptures all occurred on a fused spine, and there was no loss of correction at that level. However, these ruptures often resulted from the occurrence of junctional cervical kyphosis subjacent to the instrumentation. The stress induced at the level of the sublaminar wires led to their fatigue and breakage. Instrumentation by sublaminar wires at the upper chest level remains more unstable than classic pedicle-transversal hook instrumentation, in which failure is seldom encountered. Unfortunately, pre-, post-operative and at latest follow-up sagittal X-rays were not all of adequate quality to allow segmental angulation measurements at the level of the cervico-thoracic junction, which is why this study did not figure in our report of complications. It would be interesting to perform studies of this particular region, and especially with new materials such as the Universal Clamp®.

Finally, it seems worth it to underline, in the current context of financial shortfalls in hospitals, that the Luque—Galveston method is much less expensive than most alternative techniques for this indication in a ratio of about 1
to 5. For example, full Luque–Galveston instrumentation is currently five times less expensive than CD instrumentation spread from L5 to T2–T3 let aside the sacral fixation device. This element becomes important considering the correction results that are very satisfactory for the incidence of serious complications and re-interventions that remain very low.

The Luque–Galveston technique appears to be adapted to treat scoliosis in spastic, tetraplegic, non-ambulatory children. It provides satisfactory correction of spinal deformities and pelvic obliquity, with remarkable holding of the corrections obtained over time, confirmed by the present study. The fairly high complication rates reflect the fragility of operated children and underline the weight of such a procedure, but it is clear that most complications are treated easily and without consequences for subsequent care. This seems to be the most interesting argument to underline in favour of a technique that is fairly easy to implement, less expensive, and can effectively stabilize the spine of these fragile young patients.

**Conflict of interest**

None.

**References**


