ORIGINAL ARTICLE

Distal fusion level, complications, and reoperations in individuals with cerebral palsy undergoing surgery for scoliosis

I. Green-Petersen[1] · L. Magnano[2] · A. Charalampidis[1,3] · P. Gerdhem[1,4,5]

Abstract

Purpose To compare radiological outcome, complications and reoperations in individuals with cerebral palsy and scoliosis fused to the fifth lumbar vertebra (L5), the sacrum, or the ilia.

Methods 208 individuals were identified in the national quality registry Swespine. Lowest level of fusion was L5 in 58, the sacrum in 92, and the ilia in 58 individuals. A subanalysis on 58 matched pairs operated to L5 or the pelvis (sacrum = 42, ilia = 16) with similar pelvic obliquity ($\pm 5°$) was performed.

Results The median (interquartile range) follow-up for the last radiograph was 1.7 (1.7) years and for reoperations 6.0 (5.9) years. Preoperatively, median Cobb angle of the major curve was 65° (23°) in the L5 group, 68° (28°) in the sacrum group, and 78° (25°) in the ilia group ($p = 0.006$). Preoperative median pelvic obliquity according to Maloney was 16° (19°), 21° (13°), and 27° (28°), respectively ($p = 0.004$). Immediate postoperative Cobb angles were 28° (18°), 28° (16°), and 32° (25°), respectively ($p = 0.11$). Immediate postoperative pelvic obliquity was 7° (10°), 7° (8°), and 8° (10°), respectively ($p = 0.28$). The median change in pelvic obliquity from the first to the last postoperative radiograph was $-5°$ (7°), $-3°$ (6°), $-3°$ (6°), respectively ($p = 0.55$). 7 (12%), 11 (12%), and 7 (12%) patients required at least one reoperation ($p = 1.0$), respectively. In the matched analysis, no significant differences in the radiological outcomes were found (all $p \geq 0.38$).

Conclusions Maintained curve and pelvic obliquity correction with no significant difference in complication and reoperation rates were found irrespective of distal fusion level.

Keywords Cerebral palsy · Scoliosis · Pelvic obliquity · Surgery

Introduction

Individuals with cerebral palsy have a 25% overall prevalence of scoliosis, and the risk of developing scoliosis increases with motor function disability [1–3]. Pelvic obliquity is often prevalent in individuals with cerebral palsy and scoliosis and may lead to pain, pressure ulcers, poor seating posture and increased hip displacement risk [4–6].

Spinal fusion surgery is a standard treatment for neuromuscular scoliosis as it will decrease the spinal deformity and the pelvic obliquity [7, 8]. Previous studies have often recommended pelvic fixation over ending the fusion at the fifth lumbar vertebra (L5) when patients have more prominent scoliosis and pelvic obliquity, or in case of lumbosacral instability [9–13]. However, most previous studies have evaluated outcomes depending on distal level of instrumentation either in heterogeneous populations or in diagnoses other than cerebral palsy [9, 10, 12, 13]. To our knowledge only two previous studies, containing 55 and 47 patients, have yet focused solely on patients with cerebral palsy [11, 14].

We hypothesized that surgery to the fifth lumbar vertebra, the sacrum, or the ilia all lead to maintained curve and pelvic obliquity correction with no significant differences in complications and reoperation rates.

✉ P. Gerdhem
paul.gerdhem@uu.se

1 Department of Clinical Science, Intervention and Technology (CLINTEC), Karolinska Institutet, Stockholm, Sweden

2 Department of Trauma and Orthopaedics, Enna Hospital, Sicily, Italy

3 Department of Reconstructive Orthopedics, Karolinska University Hospital, Stockholm, Sweden

4 Department of Orthopedics and Hand Surgery, Uppsala University Hospital, Uppsala, Sweden

5 Department of Surgical Sciences, Uppsala University, Uppsala, Sweden

Materials and methods

Study population

In the Swedish national quality registry of spinal surgery (Swespine) in which individual level data are available, we searched for individuals with cerebral palsy treated for scoliosis with fusion surgery to L5, the sacrum or the ilia between the years 2006 and 2019. Variables retrieved included age at surgery, sex, mental capacity, operative time, inpatient stay, blood loss, any complications during the first three months (thrombosis, emboli, surgical site infection), and data for any reoperations up until 2021 (minimum 2 years, or until death). Radiographs for these patients were searched for at the treating hospitals. In this study, we included individuals (i) who had been treated with surgery between the ages of 10 through 25 years and (ii) had preoperative and first postoperative radiographs taken 6 months or less from the date of surgery. The flowchart of the study cohort is shown in Fig. 1. Mortality data were retrieved from the official Swedish mortality registry through 2021.

Radiological evaluation

The radiographs were analyzed by one of the authors, AUTHOR1 or AUTHOR2, after training of proficiency together with the senior authors (AUTHOR3 and AUTHOR4). Any uncertainties were brought up with AUTHOR3 and AUTHOR4 for consensus. For radiological evaluation the Sectra Workstation model IDS7 (Sectra AB, Linköping, Sweden) was used.

Preoperative, first postoperative, and last available postoperative radiographs were analyzed. Measurements were made for the major curve using the Cobb method [15], pelvic obliquity using the Maloney method (Fig. 2) [16, 17], lumbar lordosis (upper endplate of L1 to upper endplate of the first sacral vertebra; S1) and thoracic kyphosis (upper endplate of the fifth thoracic vertebra, T5, to the lower endplate
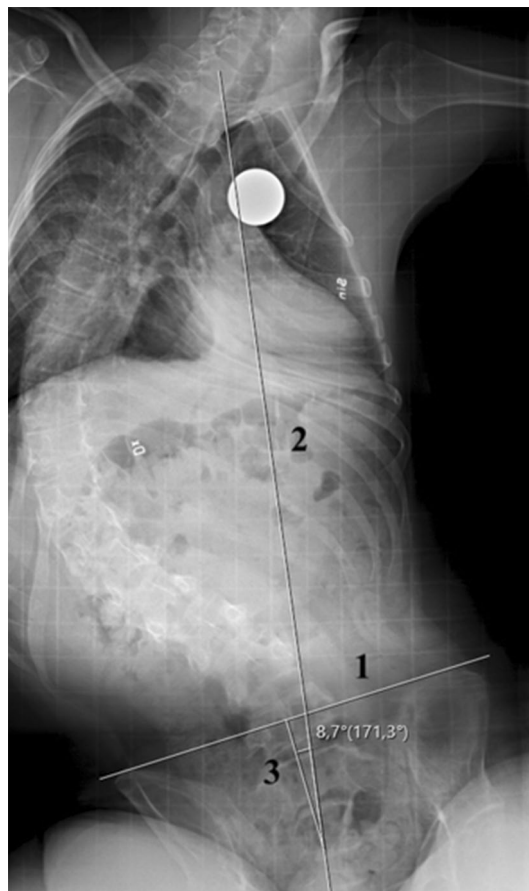
Fig. 2 The Maloney method for measuring pelvic obliquity on a frontal full spine radiograph was chosen due to superior inter- and intrarater reliability and consistency compared to other pelvic obliquity measurement methods [16, 17, 19]. A line is first drawn across the iliac crests (line 1). A second line is drawn from the center of the first thoracic vertebra (T1) to the center of the sacrum (line 2). Then, a third line (line 3) is drawn perpendicular to the first one (line 1). The angle formed at the intersection of the second and third line represents the pelvic obliquity, in this case 8.7 degrees

Fig. 1 Flowchart of the study cohort
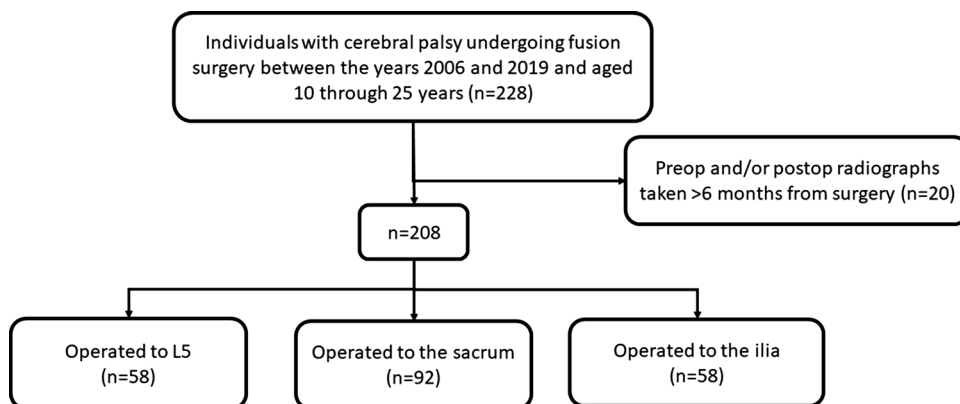
of T12). Not all radiographs allowed all measurements to be performed. Positioning at the preoperative radiograph was noted (standing vs sitting/supine).

Fusion levels were assessed from the radiographs. Implant density was reported as the total number of implants (screws, hooks or wires) divided by the total number of vertebras in the fusion area times two [18]. Pedicle screw ratio was reported as number of pedicle screws divided by the total number of implants [18].

Sub-analyses

Whether age at surgery affected correction was studied by comparing patients 10 through 18 years with patients 19 through 25 years. Patients with sitting or supine positioning at the preoperative radiograph were separately analyzed for curve size and pelvic obliquity. To look at longer-term radiographic results, we did a separate analysis of patients having the last postoperative radiograph 2 years or more from surgery.

To further investigate whether the distal fusion level was associated with radiographic outcome, we matched patients based on their preoperative pelvic obliquity ($\pm 5°$). One individual operated to L5 was matched manually with one individual operated to the pelvis (sacrum or ilia) until a dataset of 58 pairs had been created.

Statistical analysis

By visual estimation we found that many of the variables were non-normally distributed. Distribution of data was therefore reported as median and interquartile range (IQR), or number (%).

For group comparisons of continuous data, we used Kruskal–Wallis or Mann–Whitney U tests. If level of significance was less than 0.05 for a Kruskal–Wallis test,

Dunn tests with Bonferroni correction were used to identify group differences. Categorical data were analyzed using the Chi-square test, or if observed or expected cell counts were less than five, Fisher's exact test. Missing data were handled through pair-wise exclusion in the analyses. Outlier data were omitted from the corresponding analyses; bleeding > 10 L ($n = 1$) or operative time < 100 min ($n = 5$). Survival analyses for reoperation and mortality rates were compared with Kaplan–Meier curves and log rank tests. The level of significance was set to $p < 0.05$.

A sample size estimation was determined before data collection with 80% power and a 5% level of significance. Based on an earlier study by Tøndevold et al. [13], our own assumption that more than a 5 degree difference in pelvic obliquity would be clinically relevant, and a standard deviation of 8 degrees, the resulting required sample size was 41 individuals in same sized groups.

Statistical analysis was performed in RStudio version 1.3.1093 (RStudio Team, PBC, Boston, MA, USA) and IBM SPSS for Windows, version 28 (IBM, Armonk, NY, USA).

Results

Baseline characteristics

Table 1 shows demographic and inpatient data for the groups. Upper instrumented level was between T1 and T3 in 53 out of 58 individuals (91%) in the L5 group, 83 out of 92 (90%) individuals in the sacrum group, and 49 out of 58 (84%) individuals in the ilia group.

The median implant density was 93% (19%) in the L5 group, 88% (16%) in the sacrum group, and 88% (19%) in the ilia group ($p = 0.52$), with a median pedicle screw ratio of 1.0 (0.0) in the L5 group, 0.96 (0.1) in the sacrum group and 1.0 (0.1) in the ilia group ($p < 0.001$). A significantly

Table 1 Demographic and inpatient data shown as median (IQR), or number (%)

Distal fixation to	L5 ($n=58$)	S1 ($n=92$)	Ilia ($n=58$)	p value
Female sex	26 (45%), $n=58$	46 (50%), $n=92$	34 (59%), $n=58$	0.32[C]
Median age at operation (years)	15.1 (4.7), $n=58$	14.9 (4.8) ($n=92$)	15.6 (5.1), $n=58$	0.54[†]
Mental capacity[a]	$n=53$	n=80	n=56	0.10[†]
Normal	2 (4%)	5 (6%)	1 (2%)	
Slight mental disability	8 (15%)	11 (14%)	3 (5%)	
Severe mental disability	43 (81%)	64 (80%)	52 (93%)	
Median operative time (min)	315 (128), $n=53$**[i]	320 (137), $n=84$**[i]	365 (143), $n=54$	0.001[†]
Median blood loss (L)	1.5 (2.0), $n=55$**[s]	0.9 (0.9), $n=85$	1.1 (1.1), $n=56$	0.017[†]
Median inpatient stay (days)	9 (5), $n=55$	9 (4), $n=82$	9 (2), $n=45$	0.07[†]

N number of patients with available data

[a]Assessed by the surgeon preoperatively

[C]Chi square, [†]Kruskal–Wallis test

Dunn test: comparison with the group operated to the ilia[i] or the sacrum[s], **$p < 0.01$

higher pedicle screw ratio was seen in the L5 group compared to the other two groups (Dunn tests, $p \leq 0.02$). Sacral fixation was made with pedicle screws. Iliac fixation was made with screws with the exception of one patient, who had been treated with Galveston fixation.

Curve size and pelvic obliquity

The radiological measurements are summarized in Table 2. The preoperative major curve Cobb angles was significantly larger in the group operated to the ilia than in the other two groups. No significant major curve Cobb angle differences were seen at the first and the last postoperative follow-up, even though the ilia group tended to have a higher major curve Cobb angle at the last radiological follow-up. The median change in major curve Cobb angle from the first postoperative radiograph to the last postoperative radiograph was $-3°$ (9°) in the L5 group, $-3°$ (10°) in the sacrum group and $-4°$ (10°) in the ilia group ($p = 0.41$).

Median pelvic obliquity correction from the preoperative to the first postoperative radiograph was 6° (12°) in the L5 group, 12° (13°) in the sacrum group, 16° (22°) in the ilia group ($p = 0.007$, significant for L5 compared to the ilia group, Dunn test $p = 0.002$). The median correction ratio of

pelvic obliquity was 47% (62%), 57% (57%) and 58% (47%), respectively ($p = 0.23$).

The median difference in pelvic obliquity from the first postoperative radiograph to the last postoperative radiograph was $-5°$ (7°) in the L5 group, $-3°$ (6°) in the sacrum group and $-3°$ (6°) in the ilia group ($p = 0.55$).

Complications, reoperations and mortality

The prevalence of thrombosis, emboli, and surgical site infection three months postoperative did not differ between the groups (Table 3). Median blood loss was significantly higher in the L5 group than in the sacrum group (Table 3). Crude reoperation and mortality rates did not differ between the groups (Table 3). Also, when taking the follow-up times into account, reoperation rates did not differ significantly between the groups (Fig. 3), and the log rank test for mortality when comparing the three groups was $p = 0.96$.

Sub-analyses

Median pelvic obliquity at the first postoperative radiograph was 7 (9) degrees for those 10 through 18 years and 9 (11) degrees for those being 19 through 25 years ($p = 0.17$), and for the last postoperative radiograph 10 (12) vs 12 (15)

Table 2 Radiographic data for the group operated to L5, the group operated to the sacrum and the group fixated to the ilia shown as median (IQR)

Distal fixation to	L5 ($n = 58$)	Sacrum ($n = 92$)	Ilia ($n = 58$)	p value[†]
Median Cobb angle (degrees)				
Preoperative[a,b,c]	65 (23), $n = 58$**	68 (28), $n = 92$**	78 (25), $n = 58$	0.006
First postop	28 (18), $n = 55$	28 (16), $n = 92$	32 (25), $n = 58$	0.11
Last postop	29 (18), $n = 48$*	31 (16), $n = 63$*	35 (29), $n = 45$	0.055
Median pelvic obliquity (degrees)				
Preoperative	16 (19), $n = 58$**	21 (13), $n = 87$*	27 (28), $n = 56$	0.004
First postop	7 (10), $n = 55$	7 (8), $n = 91$	8 (10), $n = 57$	0.28
Last postop	11 (16), $n = 45$	10 (11), $n = 64$	11 (13), $n = 45$	0.48
Median thoracic kyphosis (degrees)				
Preoperative	38 (30), $n = 45$	30 (24), $n = 82$	32 (23), $n = 49$	0.77
First postop	24 (19), $n = 49$	22 (18), $n = 81$	32 (20), $n = 49$	0.08
Last postop	24 (15), $n = 38$	23 (17), $n = 59$	26 (17), $n = 41$	0.21
Median lumbar lordosis (degrees)				
Preoperative[a]	40 (30), $n = 45$	34 (33), $n = 81$	32 (35), $n = 49$	0.70
First postop	44 (20), $n = 49$	46 (17), $n = 82$	44 (23), $n = 49$	0.77
Last postop	39 (21), $n = 38$*	46 (22), $n = 60$	52 (19), $n = 41$	0.031

[a]Position preoperative radiograph L5 group: 40 (69%) sitting, 16 (28%) supine and 2 (3%) standing

[b]Position preoperative radiograph S1 group: 51 (55%) sitting, 35 (38%) supine, and 6 (6%) standing

[c]Position preoperative radiograph ilia group: 45 (78%) sitting, 12 (21%) supine, and 1 (2%) standing

N number of patients with available data. The median follow-up time for the first postoperative radiograph was 6 (6) days, and for the last 1.7 (1.7) years

[†] Kruskal–Wallis test

Dunn tests with *$p < 0.05$, **$p < 0.01$, or ***$p < 0.001$ when compared to the group with distal fixation to the ilia

Table 3 Complications for the groups operated to L5, the sacrum, or the ilia within 3 months, and reoperations and mortality over a median follow-up of 6.0 years. Data shown as median (IQR) or number (%)

| Distal fixation to	L5 ($n = 58$)	Sacrum ($n = 92$)	Ilia ($n = 58$)	p value
Dural tear	1 (2%), $n = 58$	2 (1%), $n = 92$	0 (0%), $n = 58$	0.79[f]
Thrombosis or pulmonary embolism within 3 months[a]	0 (0%), n = 58	0 (0%), $n = 92$	2 (1%), $n = 58$	0.50[f]
Surgical site infection treated with antibiotics within 3 months[a]	3 (5%), $n = 58$	5 (5%), $n = 92$	5 (9%), $n = 58$	0.76[f]
Mortality within 3 months	1 (2%), $n = 58$	2 (2%), $n = 92$	0 (0%), $n = 58$	0.79[f]
Total follow-up time for mortality and reoperation (years)	8.3 (6.3), $n = 58$***	6.9 (6.2), $n = 92$***	4.9 (4.0), $n = 58$	<0.001[†]
At least one reoperation[b]	7[a] (12%), $n = 58$	11[b] (12%), $n = 92$	7[c] (12%), $n = 58$	1.00[C]
Mortality over the total follow-up (median 6.0 years)	11 (19%), $n = 58$	15 (16%), $n = 92$	8 (14%), $n = 58$	0.75[C]

[a]Reported by patient or caregiver

[b]Reason for reoperation in each group; L5 group: Wound infection ($n = 1$), pseudoarthrosis ($n = 1$), implant related ($n = 1$), deformity progression ($n = 1$), not given ($n = 3$), S1 group: Wound infection ($n = 1$), pseudoarthrosis ($n = 2$), implant related ($n = 4$), deformity progression ($n = 1$), not given ($n = 3$), ilia group: Wound infection ($n = 4$), implant related ($n = 3$)

[C]Chi square test, f = Fisher's exact test

[†]Kruskal–Wallis test

N number of patients with available data

Dunn test with ***$p < 0.001$ when compared to the group with distal fixation to the ilia
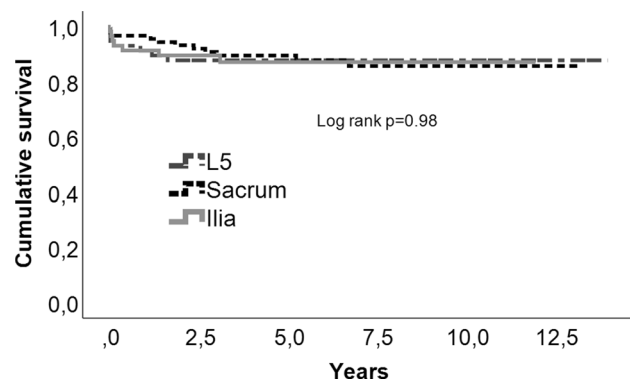
Fig. 3 Kaplan–Meier curve for reoperations during the follow-up. Follow-up (in years) is shown on the x-axis, and the maximum follow-up time was 14 years

degrees ($p = 0.23$). Data for the first and the last radiograph major curve Cobb angle were 28 (17) vs 34 (22) ($p = 0.14$) and 29 (17) vs 36 (28) degrees ($p = 0.042$). Including only individuals with sitting or supine preoperative radiographs ($n = 199$) yielded similar results as for the whole cohort (data not shown).

The radiographic results of the patients with the last postoperative radiographs 2 years or more from surgery yielded similar results as for the complete cohort (Table 4). The median difference in pelvic obliquity from the first postoperative radiograph to the last postoperative radiograph did not differ significantly between the groups ($p = 0.20$).

In the matched analysis based on pelvic obliquity comparing the L5 group with individuals operated to the pelvis

(sacrum: $n = 42$, ilia: $n = 16$) no significant differences in the radiological outcomes were found (all $p \geq 0.38$) (Table 5).

Discussion

In this nationwide study based on data from the Swedish spine registry we found that distal fusion to the L5, the sacrum and to the ilia resulted in similar sustained correction of the major curve and pelvic obliquity, and a similar rate of complications and reoperations.

Ending instrumentation at the L5 or at the pelvis results in significant scoliosis and pelvic obliquity correction [9–14]. One parameter which has been proposed to correlate with sustained pelvic obliquity correction is degree of preoperative pelvic obliquity. Modi et al. and Tøndevold et al. [10, 13] in samples of individuals with various types of underlying diseases resulting in neuromuscular scoliosis found that pelvic obliquity correction was maintained to a higher degree with pelvic fixation.

In our data, maintaining correction was independent on distal level of fusion, the L5, the sacrum or the ilia, confirming the results of the two previous smaller studies specifically on patients with cerebral palsy [11, 14].

McCall and Hayes used predominantly rods and wires in their surgical constructs, while the technique used is not specified in the more recent study by Strom et al. [11, 14]. The present cohort consisted of individuals that had undergone contemporary segmental instrumentation with both high implant density and high proportion of screws. The mean change in Cobb angles and pelvic obliquity over

Table 4 Radiographic data shown as median (IQR) for the group fixated to L5, the group fixated to the sacrum and the group fixated to the ilia with the last radiographs 2 years or more from surgery

Distal fixation to	L5 (n = 27)	Sacrum (n = 28)	Ilia (n = 16)	p value†
Median Cobb angle (degrees)				
Preoperative[a]	63 (24), n = 27	68 (26), n = 28	76 (19), n = 16	0.08
First postop	26 (20), n = 25	27 (12), n = 28	33 (22), n = 16	0.09
Last postop	29 (18), n = 27*	31 (12), n = 28	51 (33), n = 15	0.030
Median pelvic obliquity (degrees)				
Preoperative[a]	19 (14), n = 27	19 (13), n = 25	26 (30), n = 15	0.35
First postop	6 (9), n = 26*	7 (7), n = 28	14 (15), n = 16	0.018
Last postop	11 (16), n = 45	11 (12), n = 64	17 (20), n = 45	0.45
Median thoracic kyphosis (degrees)				
Preoperative[a]	38 (30), n = 21	33 (25), n = 28	34 (16), n = 14	0.99
First postop	24 (15), n = 20	29 (17), n = 28	32 (8), n = 13	0.30
Last postop	28 (15), n = 20	22 (15), n = 28	25 (18), n = 13	0.39
Median lumbar lordosis (degrees)				
Preoperative[a]	34 (28), n = 21	28 (27), n = 28	26 (38), n = 14	0.69
First postop	41 (16), n = 22	45 (19), n = 27	44 (8), n = 13	0.28
Last postop	40 (21), n = 20	42 (23), n = 28	43 (16), n = 13	0.47

[a]Preoperative radiographs were in the standing position for 1 individual in the L5 group, 1 individual in the S1 group, and 0 individuals in the ilia group. All other radiographs were in the sitting or supine position

N number of patients with available data. The median follow-up time for the first postoperative radiograph was 7 (6) days, and for the last 2.9 (3.3) years

†Kruskal–Wallis test

*Dunn test $p < 0.05$ when compared to the group with distal fixation at the ilia

Table 5 Matched analysis based on preoperative pelvic obliquity. In the pelvis group 42 patients had their distal fixation to the sacrum and 16 had their distal fixation to the ilia

Distal fixation to	L5 (n = 58)	Pelvis (n = 58)	p value†
Mean pelvic obliquity (degrees)			
Preop	16 (19), n = 58	16 (19), n = 58	0.95
First postop	7 (8), n = 55	9 (9), n = 58	0.51
Last postop	11 (16), n = 45	10 (9), n = 46	0.63
Mean correction of pelvic obliquity (degrees)	6 (12), n = 55	7 (15), n = 58	0.95
Median correction ratio of pelvic obliquity (%)	48 (62), n = 55	41 (65), n = 58	0.69
Mean change in pelvic obliquity between first postoperative and last follow-up (degrees)	− 5 (7), n = 44	− 4 (8), n = 46	0.38

Data shown as median (IQR). *N* number of patients with available data

†Mann–Whitney *U* test

time was small, and similar or lower than in previous reports [10–13].

Spasticity is common in cerebral palsy, with a higher prevalence in those with scoliosis that requires treatment [2]. Data from individuals with flaccid neuromuscular scoliosis are in contrast with both our own and previous studies on individuals with cerebral palsy [11, 14, 20]. Despite significant preoperative differences in pelvic obliquity in the L5, sacrum and ilia groups in our study, both immediate and follow-up postoperative pelvic obliquity was similar.

We found that the mean intraoperative time increased with a more distal fusion level. This was expected since the patients operated more distally receive more implants and require a larger exposure. Regarding intraoperative blood loss, we found that the mean intraoperative blood loss was higher in the L5 group than in the sacrum group. We have no clear explanation for this but noted that distal fusion to the L5 was more common earlier in the series, as indicated by the follow-up times in Table 2. Nevertheless, the risk of other complications was not increased.

This study has some apparent strengths. The national quality registry Swespine has a high degree of data validity with more than 99% correctly diagnosed, and full coverage of all the institutions in Sweden performing scoliosis surgery, giving external validity [18]. Another is the homogenous population compared to most previous studies on

neuromuscular scoliosis. The data fulfilled the prespecified sample size for the analyses of pelvic obliquity, and the number of individuals with cerebral palsy undergoing scoliosis surgery in this study is also the largest to date. Only 9% of the individuals fulfilling the inclusion criteria were omitted due to missing radiographs. We also analyzed individuals operated to the sacrum, which seldom seems to be discussed as an option in the literature.

Our study has some limitations. Just like previous reports, the lack of randomization makes the study prone to bias. A selection bias for distal level of fusion is apparent. It was obvious that pelvic fixation was used in cases with larger pelvic obliquity. A parameter which has been proposed as an indication for pelvic fixation is lumbosacral instability, represented as degree of preoperative L5 tilt (defined as the angle between the upper end plate of L5 and the tips of the iliac crests) [11, 14, 21], but this was not measured in the present study.

We lacked certain data in the registry which could have clinical relevance, such as formal classification of gross motor function, skeletal maturity assessment, patient-reported outcome measures and hip status. Radiographs were not standardized since several hospitals were involved and routines vary. We cannot be certain that all complications were noted in the registry, but it is reasonable to believe that there is no systematic bias toward any of the groups. We also lacked information regarding ambulatory status. As a proxy for this, we noted the preoperative radiographic posture. Only a few of the individuals in both groups underwent standing radiographs, indicating that the L5 and the pelvis group contained similar proportions of non-ambulatory individuals with severe impairment of motor function. We decided not to include patients with their distal fixation cranially to the L5. From our own experience, this may be an alternative in ambulatory patients, but they were not the focus of this study.

Another limitation was the availability of radiographs adequately depicting the pelvis. We could therefore not measure pelvic obliquity for all individuals pre- and postoperatively.

Radiographs were measured by only one of two single reviewers, but these were independent and not involved in the care of the patients. The radiographic review process does not differ from other studies [9–13]. Reviewer experience differed but that does not seem to affect reliability for the Maloney method for pelvic obliquity measurements [17].

Coronal and sagittal imbalance has been proposed as indicators of the need of pelvic fixation [13]. However, we chose not to measure these parameters since measurements of sagittal balance in non-ambulatory individuals are likely to be uncertain due to variations in sitting position between examinations and centers. We think the Maloney method for pelvic obliquity measurements used here better reflects the global coronal balance (Fig. 2). It is independent of the need of radiographic distance calibration and measurements, as opposed to measurements of coronal or sagittal alignment.

Not all patients had a follow-up radiograph. The median radiographic follow-up time was only 1.7 years. There are several reasons for this. One is that some centers in Sweden do not routinely perform radiographs after the first postoperative radiographic control. The small radiographic change over time supports this strategy, and the sub-analysis of individuals with radiographs 2 years or more after surgery showed similar results as in the complete cohort. Frailty, as indicated by the mortality data, may affect the follow-up frequency in this population, but mortality rates did not differ between the groups. Mortality figures are similar to a previous Swedish nationwide study [22].

Conclusion

In patients with cerebral palsy, both fusions to the L5, the sacrum and the ilia result in significant and sustained correction of the pelvic obliquity up to 1.7 years, and with similar risk of complications and reoperations up to 6.0 years. We suggest that the choice of distal fusion level in individuals with cerebral palsy can be individualized, even though longer follow-ups may be required to definitely settle the question.

Declarations

Conflict of interest The authors have no conflicts of interest.

Ethical approval Ethical permit was granted before retrieval of the study data by the Ethical Review Authority in Sweden (Numbers 2018/2705-31/2 and 2019-00136).

References

1. Weigl DM (2019) Scoliosis in non-ambulatory cerebral palsy: challenges and management. Isr Med Assoc J 21:752–755
2. Persson-Bunke M, Hagglund G, Lauge-Pedersen H, Wagner P, Westbom L (2012) Scoliosis in a total population of children with cerebral palsy. Spine (Phila Pa 1976) 37:E708-713. https://doi.org/10.1097/BRS.0b013e318246a962
3. Saito N, Ebara S, Ohotsuka K, Kumeta H, Takaoka K (1998) Natural history of scoliosis in spastic cerebral palsy. Lancet 351:1687–1692. https://doi.org/10.1016/S0140-6736(98)01302-6
4. Hagglund G (2020) Association between pelvic obliquity and scoliosis, hip displacement and asymmetric hip abduction in children with cerebral palsy: a cross-sectional registry study. BMC Musculoskelet Disord 21:464. https://doi.org/10.1186/s12891-020-03484-y
5. Helenius IJ, Viehweger E, Castelein RM (2020) Cerebral palsy with dislocated hip and scoliosis: what to deal with first? J Child Orthop 14:24–29. https://doi.org/10.1302/1863-2548.14.190099
6. Porter D, Michael S, Kirkwood C (2007) Patterns of postural deformity in non-ambulant people with cerebral palsy: what is the relationship between the direction of scoliosis, direction of pelvic obliquity, direction of windswept hip deformity and side of hip dislocation? Clin Rehabil 21:1087–1096. https://doi.org/10.1177/0269215507080121
7. Cloake T, Gardner A (2016) The management of scoliosis in children with cerebral palsy: a review. J Spine Surg 2:299–309. https://doi.org/10.21037/jss.2016.09.05
8. Blevins K, Battenberg A, Beck A (2018) Management of scoliosis. Adv Pediatr 65:249–266. https://doi.org/10.1016/j.yapd.2018.04.013
9. Mubarak SJ, Morin WD, Leach J (1993) Spinal fusion in Duchenne muscular dystrophy–fixation and fusion to the sacropelvis? J Pediatr Orthop 13:752–757. https://doi.org/10.1097/01241398-199311000-00012
10. Modi HN, Suh SW, Song HR, Yang JH, Jajodia N (2010) Evaluation of pelvic fixation in neuromuscular scoliosis: a retrospective study in 55 patients. Int Orthop 34:89–96. https://doi.org/10.1007/s00264-008-0703-z
11. McCall RE, Hayes B (2005) Long-term outcome in neuromuscular scoliosis fused only to lumbar 5. Spine (Phila Pa 1976) 30:2056–2060. https://doi.org/10.1097/01.brs.0000178817.34368.16
12. Sengupta DK, Mehdian SH, McConnell JR, Eisenstein SM, Webb JK (2002) Pelvic or lumbar fixation for the surgical management of scoliosis in duchenne muscular dystrophy. Spine (Phila Pa 1976) 27:2072–2079. https://doi.org/10.1097/00007632-200209150-00020
13. Tondevold N, Lastikka M, Andersen T, Gehrchen M, Helenius I (2020) Should instrumented spinal fusion in nonambulatory children with neuromuscular scoliosis be extended to L5 or the pelvis? The Bone Joint J 102-B:261–B267. https://doi.org/10.1302/0301-620X.102B2.BJJ-2019-0772.R2
14. Strom SF, Hess MC, Jardaly AH, Conklin MJ, Gilbert SR (2022) Is it necessary to fuse to the pelvis when correcting scoliosis in cerebral palsy? World J Orthopedics 13:365–372. https://doi.org/10.5312/wjo.v13.i4.365
15. Cobb J (1948) Outline for the study of scoliosis. Instructional Course Lectures, The American Academy of Orthopaedic Surgeons (AAOS), Ann Arbor, pp 261–275
16. Maloney WJ, Rinsky LA, Gamble JG (1990) Simultaneous correction of pelvic obliquity, frontal plane, and sagittal plane deformities in neuromuscular scoliosis using a unit rod with segmental sublaminar wires: a preliminary report. J Pediatr Orthop 10:742–749. https://doi.org/10.1097/01241398-199011000-00007
17. Shrader MW, Andrisevic EM, Belthur MV, White GR, Boan C, Wood W (2018) Inter- and intraobserver reliability of pelvic obliquity measurement methods in patients with cerebral palsy. Spine Deformity 6:257–262. https://doi.org/10.1016/j.jspd.2017.10.001
18. Charalampidis A, Moller A, Wretling ML, Brismar T, Gerdhem P (2018) Implant density is not related to patient-reported outcome in the surgical treatment of patients with idiopathic scoliosis. Bone Joint J 100-B:1080–1086. https://doi.org/10.1302/0301-620X.100B8.BJJ-2017-1114.R1
19. Karkenny AJ, Magee LC, Landrum MR, Anari JB, Spiegel D, Baldwin K (2021) The variability of pelvic obliquity measurements in patients with neuromuscular scoliosis. JB JS Open Access 6. https://doi.org/10.2106/JBJS.OA.20.00143
20. Saito W, Inoue G, Shirasawa E, Imura T, Nakazawa T, Miyagi M, Kawakubo A, Uchida K, Kotani T, Akazawa T, Takaso M (2021) Limitations of posterior spinal fusion to L5 for flaccid neuromuscular scoliosis focusing on pelvic obliquity. Spine Deformity 9:559–565. https://doi.org/10.1007/s43390-020-00214-1
21. Takaso M, Nakazawa T, Imura T, Ueno M, Saito W, Shintani R, Takahashi K, Yamazaki M, Ohtori S, Okamoto M, Masaki T, Okamoto H, Okutomi T, Ishii K, Ueda Y (2010) Can the caudal extent of fusion in the surgical treatment of scoliosis in Duchenne muscular dystrophy be stopped at lumbar 5? Eur Spine J 19:787–796. https://doi.org/10.1007/s00586-010-1347-4
22. von Heideken J, Iversen MD, Gerdhem P (2017) Rapidly increasing incidence in scoliosis surgery over 14 years in a nationwide sample. Eur Spine J. https://doi.org/10.1007/s00586-017-5346-6