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ORIGINAL ARTICLE

Factors associated with surgical approach and outcomes in cerebral palsy scoliosis

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Abstract

Background Neuromuscular scoliosis is often treated with posterior spinal fusion, with or without anterior release, and either a same-day or staged, 2-day procedure.

Methods We retrospectively reviewed 222 patients from a prospectively collected, multi-center database of patients with cerebral palsy scoliosis with 2-year follow-up. Baseline characteristics, perioperative, radiographic, and HRQoL measures were compared in six sub-analyses: (1) staged versus same-day surgeries, (2) posterior-only fusion (PSF) versus anterior–posterior spinal fusion (APSF), (3) same-day versus staged PSF, (4) staged versus same-day APSF, (5) same-day PSF versus same-day APSF, (6) staged PSF versus staged APSF.

Results Staged patients had larger curves and more pelvic obliquity, longer anesthesia and surgical times, longer hospital and ICU stays ($p<0.001$), and more days intubated ($p=0.021$). The staged PSF group had larger curves ($p=0.006$), longer anesthesia ($p=0.020$) and surgeries ($p=0.007$), hospital ($p=0.009$) and ICU stays ($p=0.028$) compared to same-day PSF. The staged APSF group had longer hospital ($p<0.001$) and ICU stays ($p=0.004$) and anesthesia and surgeries ($p<0.001$). Same-day APSF was associated with larger curves ($p<0.002$), longer anesthesia ($p=0.012$) and surgeries ($p=0.042$), greater residual curves ($p=0.035$), and greater absolute correction ($p=0.007$) compared to same-day PSF. The staged APSF group had longer anesthesia times ($p<0.001$) compared to the staged PSF group. No sub-analysis revealed significant differences in baseline characteristics, complications, or HRQoL.

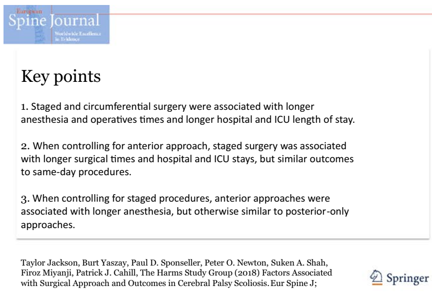
Conclusion Staged and circumferential approaches tend to be used for greater deformity, but were not associated with superior deformity correction, and were associated with longer operative time, hospital stays, ICU stays, and days intubated. However, for the most severe deformity, other patient factors may play more important roles in treatment decisions given that patients treated with a staged PSF or an APSF, whether staged or not, were similar at baseline.

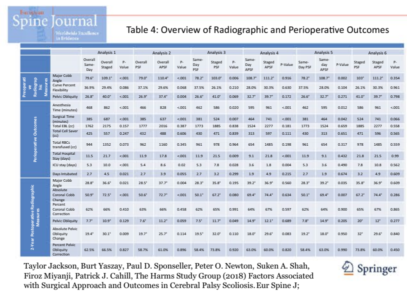
Level of evidence III.

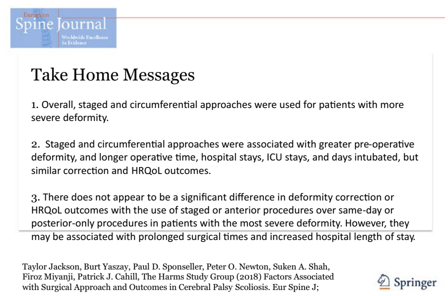
Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-018-5745-3) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.







Keywords Cerebral palsy · Neuromuscular scoliosis · Posterior spinal fusion · Anterior spinal fusion · Staged fusion

Introduction

CP surgery is challenging owing to the large deformity and medical complexity in this population [1–4]. Staged (i.e., 2-day) surgery is common, but utilization of staged surgery is variable. Both staged and same-day procedures (Figs. 1, 2) yield acceptable deformity correction and may be performed with or without anterior release (Figs. 3, 4) [5–8]. However, there is debate regarding the utility of and indications for various approaches [5–7, 9–11].

Anterior approaches have been a common component of surgery for some neuromuscular patients [5, 6]. In recent years, alternative approaches have gained popularity to limit morbidity associated with extensive surgery in a frail population [1, 12, 13]. Some have advocated staged approaches, citing superior correction, lower morbidity, reduced complication rates, and limiting surgeon fatigue [5–7]. Yet others have found increased complications, blood loss, and hospital stays with staged compared to same-day procedures [7, 9–11].

With this investigation, we seek to evaluate what patient factors are associated with treatment of choice and to compare radiographic, perioperative and health related quality of life (HRQoL) outcomes in patients treated with various strategies, including circumferential and all-posterior approaches, whether same-day or staged. However, due to a paucity of prospective data on staged and anterior/posterior surgery in neuromuscular spinal deformity, we seek to address the following questions:

- What patient factors may lead surgeons to select a same-day versus staged (2-day) surgical strategy?

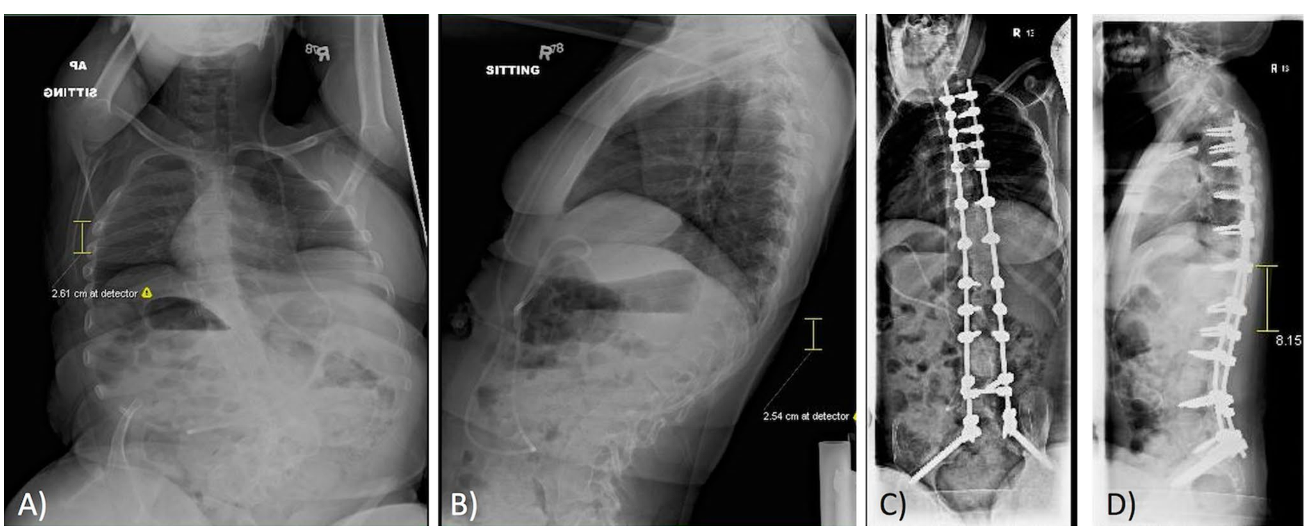


Fig. 1 Representative radiographs of the pre-operative **a** posteroanterior and **b** lateral views and the 2-year postoperative, **c** posteroanterior and **d** lateral views of a patient who underwent a same-day posterior-only spinal fusion

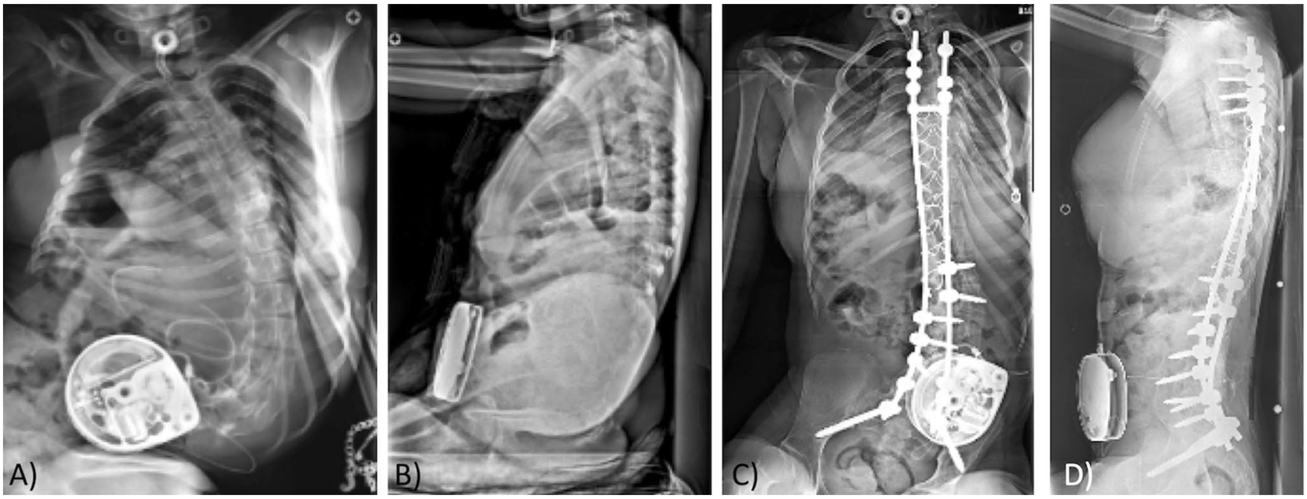


Fig. 2 Representative radiographs of the pre-operative **a** posteroanterior and **b** lateral views and the 2-year postoperative, **c** posteroanterior and **d** lateral views of a patient who underwent a staged posterior-only spinal fusion

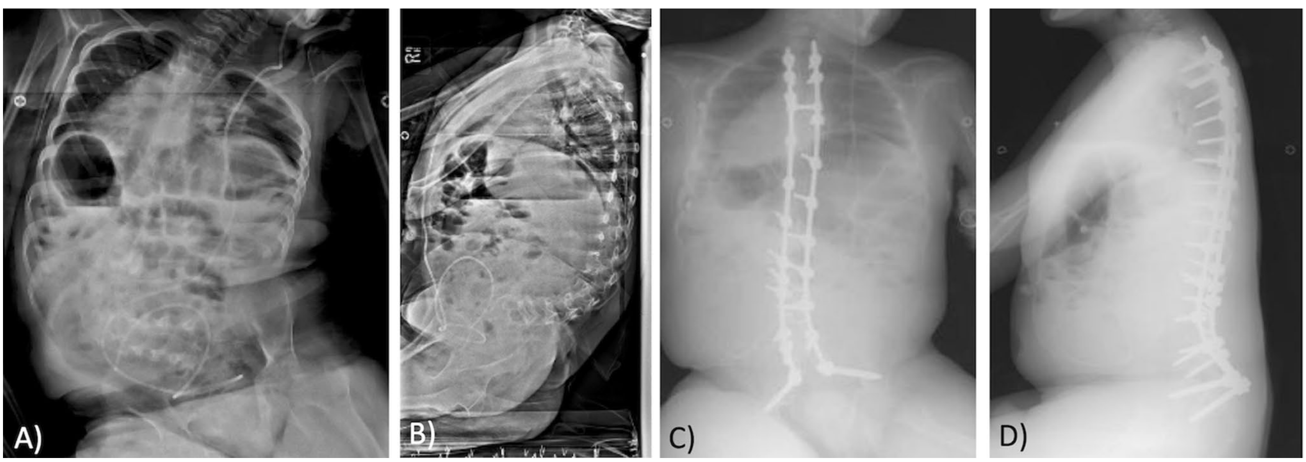


Fig. 3 Representative radiographs of the pre-operative **a** posteroanterior and **b** lateral views and the 2-year postoperative, **c** posteroanterior and **d** lateral views of a patient who underwent a same-day anterior/posterior spinal fusion

- What patient factors may lead a surgeon to perform an anterior–posterior procedure over a posterior-only fusion?
- Do these different approaches result in different radiographic, perioperative, and HRQoL outcomes or complication rates?

Methods and materials

A retrospective review of a prospective, multi-center database on spinal deformity associated with cerebral palsy (CP). In total, 222 patients were evaluated. Inclusion criteria were surgical patients with scoliosis secondary to cerebral palsy treated with at least posterior fusion and a minimum 2-year postoperative follow-up. All anterior fusions were performed through an open approach, and anterior instrumentation was used in only three cases. Intraoperative halo traction was utilized in 76 patients (34%). Four of the patients treated with intraoperative traction had staged surgeries (17% of staged patients) and 72 had same-day surgeries (36% of same-day patients). A total of eleven sites and nineteen treating surgeons were involved. All surgical decisions were made at the treating surgeons' discretion. All surgeries were performed over a 5-year period between 2008 and 2014. All data were collected on a prospective basis using a standardized data collection protocol and transmitted to a central database.

Multiple sub-groups, based on surgical approach and whether the procedures were staged or not, were compared. A total of six sub-analyses were undertaken. The first

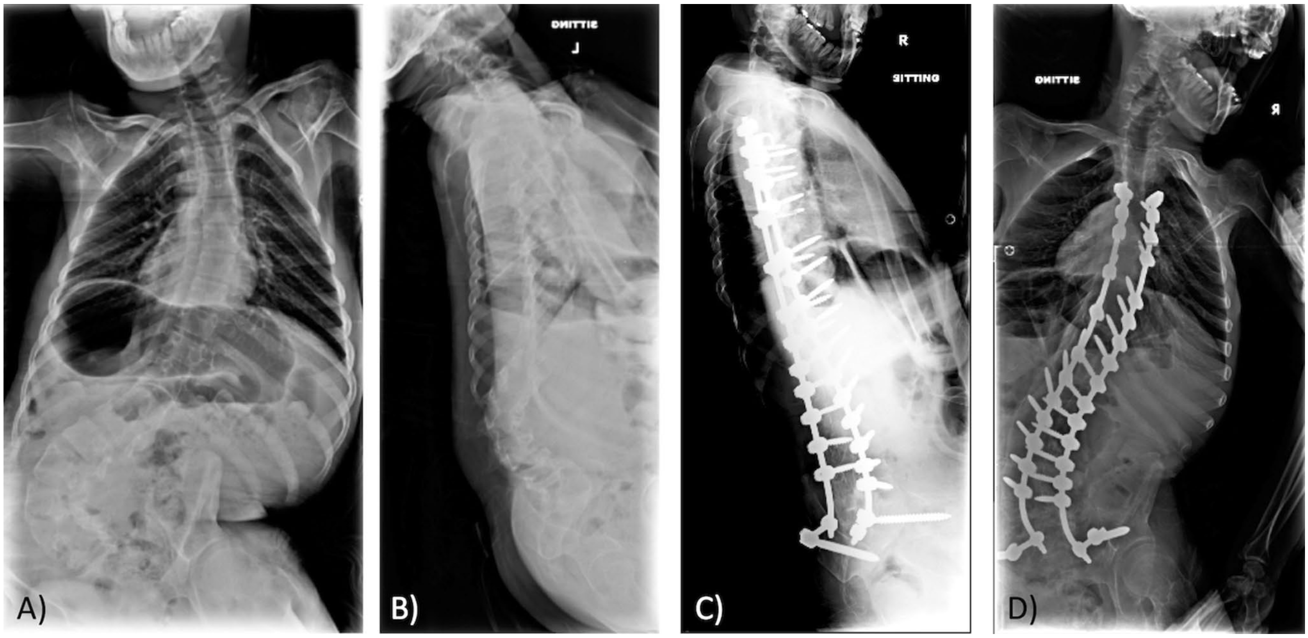


Fig. 4 Representative radiographs of the pre-operative **a** posteroanterior and **b** lateral views and the 2-year postoperative, **c** posteroanterior and **d** lateral views of a patient who underwent a staged anterior/posterior spinal fusion

analysis compared all staged with all same-day patients. The subsequent sub-analyses aim to isolate the potential effects of staging as distinct from the approach (i.e., posterior-only versus circumferential):

1. Same-day versus staged surgery: 222 patients; 199 same-day patients were compared to 23 staged patients.
2. PSF versus APSF: 222 patients; 196 posterior-only patients were compared to 26 anterior/posterior patients.
3. Same-day PSF versus staged PSF: 196 posterior-only patients; 190 same-day patients were compared to 6 staged patients.
4. Same-day APSF versus staged APSF: 26 anterior/posterior patients; 9 same-day patients were compared to 17 staged surgery patients.
5. Same-day PSF versus same-day APSF: 199 same-day patients; 190 posterior-only were compared to 9 anterior/posterior surgery patients.
6. Staged PSF versus staged APSF: 23 staged patients; 6 patients treated posterior-only patients were compared to 17 anterior/posterior surgery patients.

The baseline characteristics, functional status, preoperative and 2-year follow-up data for health related quality of life (HRQoL) and radiographic measures, and complication rates were compared. Only major complications were considered in our analysis, such as those that had a significant impact on the patients' hospital course or outcomes, resulted in permanent further disability, risked mortality, or resulted in death or required invasive interventions. These complications included hardware failure, serious infections such as postoperative pneumonia or pancreatitis, as well as the need for invasive procedures, such as insertion tubes and drains or incision and drainage, or additional operations. Minor complications, such as pressure ulcers or superficial infections were not included. The included complications are detailed in Table 1. HRQoL data were collected by use of the Caregiver's Priorities and Child Health Index of Life and Disabilities (CPCHILD). The CPCHILD questionnaire is a validated and reliable, disease-specific, patient-based outcomes questionnaire for CP and consists of six domains [14].

Standard descriptive summaries (e.g., means and standard deviations for continuous variables such as age and percentage for categorical variables such as gender) were used to summarize demographic variables. Comparisons of categorical variables between groups were made using the Chi-square test or the Fisher's exact test in the case of a 2×2 table with expected count of any cell less than 5. Comparisons of continuous variables were completed using analysis of variance (ANOVA) or nonparametric tests depending on normality of distribution and homogeneity of variances. Alpha was set at $p < 0.05$ to declare significance. Statistics were performed utilizing SPSS v.24 (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.)

Table 1 Description of major complications* following surgical correction of CP scoliosis

Patient	Surgical approach	Complication description
1	Staged APSF	1. Post-op pneumonia 2. Deep infection (lumbar spine abscess) 3. Death (small bowel volvulus)
2	Staged APSF	1. Post-op pneumonia 2. Pancreatitis 3. C. difficile infection with ileus
3	Staged APSF	Pigtail chest tube for pleural effusions
4	Staged APSF	1. Post-op pneumonia 2. Loss of leg function (spontaneously resolved)
5	Staged PSF	Death (cause unknown)
6	Same-day PSF	Tracheostomy
7	Same-day PSF	I&D and partial hardware removal for deep infection
8	Same-day PSF	Repeated I&D for deep wound infection
9	Same-day PSF	Deep infection with implant removal
10	Same-day PSF	Tracheostomy for prolonged intubation for failure to wean from ventilation
11	Same-day PSF	Deep infection
12	Same-day PSF	Removal of upper segmental fixation for proximal junctional kyphosis
13	Same-day PSF	Surgical exploration for fistula at the base of the sacral spine with persistent drainage
14	Same-day PSF	Removal of instrumentation for deep infection with spontaneous drainage
15	Same-day PSF	Revision surgery for hardware failure
16	Same-day PSF	Ileus requiring small bowel resection and ileostomy
17	Same-day PSF	I&D for deep infection
18	Same-day PSF	1. Removal of prominent hardware 2. Death (respiratory infection)
19	Same-day PSF	1. Revision surgery for loss of fixation 2. Insertion of G-tube for difficulty with swallowing related to neck position
20	Same-day PSF	Bladder retention
21	Same-day PSF	I&D for wound infection
22	Same-day PSF	Suprapubic catheter followed by urethral sphincterotomy for bladder retention and recurrent UTI
23	Same-day PSF	I&D for deep infection
24	Same-day PSF	Revision surgery for pseudoarthrosis and hardware failure
25	Same-day PSF	Revision surgery for prominent pedicle screw
26	Same-day PSF	Revision surgery for loss of fixation
27	Same-day PSF	Revision surgery for loss of fixation
28	Same-day PSF	I&D for deep infection and removal of hardware
29	Same-day PSF	Septic shock; deep wound infection
30	Same-day PSF	Repeated I&D and hardware removal for deep infection
31	Same-day PSF	I&D for deep infection
32	Same-day PSF	I&D for deep infection
33	Same-day PSF	I&D for deep infection
34	Same-day PSF	I&D and hardware removal for deep infection
35	Same-day PSF	I&D and hardware removal for deep infection
36	Same-day PSF	I&D, re-instrumentation, and vertebrectomy for deep infection
37	Same-day PSF	Revision surgery for prominent hardware
38	Same-day APSF	Revision surgery for hardware failure

I&D incision and drainage, *UTI* urinary tract infection, *PSF* posterior spinal fusion, *APSF* anterior/posterior spinal fusion

*Major complication: Any complications that caused permanent further disability, risked mortality, or required additional surgical intervention or prolonged hospitalization

Table 2 Comparative baseline characteristics of CP scoliosis patients by surgical approach

Analysis 1: Same-day versus staged	Same-day	Staged	*p* value
Age (years)	14.2	14.3	0.895
Gender (female)	48.7%	34.8%	0.204
Total protein g/dL	11	7.5	0.459
Albumin g/dL	6.84	4.36	0.405
Seizures	67.9%	69.6%	0.305
Feeding tube	53.3%	60.9%	0.489
GMFCS level (IV or V)	93%	100%	0.207
Analysis 2: PSF versus APSF	**PSF**	**APSF**	***p* value**
Age (years)	14.2	14.5	0.646
Gender (female)	49%	34.60%	0.168
Total protein g/dL	10.95	7.41	0.475
Albumin g/dL	6.91	4.53	0.466
Seizures	67.40%	73.00%	0.764
Feeding tube	53.6%	57.7%	0.692
GMFCS level (IV or V)	93%	94%	0.165
Analysis 3: Same-day PSF versus staged PSF	**Same-day PSF**	**Staged PSF**	***p* value**
Age (years)	14.2	14.7	0.637
Gender (female)	49.5%	33.3%	0.683
Total protein g/dL	11.1	7.25	0.68
Albumin g/dL	7	4.2	0.786
Seizures	67.3%	66.7%	0.988
Feeding tube	53.2%	66.7%	0.514
GMFCS level (IV or V)	93%	93%	0.536
Analysis 4: Same-day APSF versus staged APSF	**Same-day APSF**	**Staged APSF**	***p* value**
Age (years)	15.0	14.2	0.525
Gender (female)	33.3%	35.3%	0.92
Total protein g/dL	6.97	7.63	0.095
Albumin g/dL	4.63	4.53	0.548
Seizures	77.8%	70.6%	0.121
Feeding tube	55.6%	58.8%	0.873
GMFCS level (IV or V)	100%	100%	NA
Analysis 5: Same-day PSF versus same-day APSF	**Same-day PSF**	**Same-day APSF**	***p* value**
Age (years)	14.2	15.0	0.394
Gender (female)	49.5%	33.3%	0.344
Total protein g/dL	11.085	6.967	0.154
Albumin g/dL	7	4.633	0.482
Seizures	67.3%	77.8%	0.269
Feeding tube	53.2%	55.6%	0.888
GMFCS level (IV or V)	92.9%	100%	0.406
Analysis 6: Staged PSF versus staged APSF	**Staged PSF**	**Staged APSF**	***p* value**
Age (years)	14.7	14.2	0.973
Gender (female)	35.3%	33.3%	0.930
Total protein g/dL	7.25	7.63	0.257
Albumin g/dL	4.18	4.48	0.476
Seizures	67%	71%	0.282
Feeding tube	66.7%	58.8%	0.735
GMFCS level (IV or V)	100%	100%	NA

The baseline characteristics of the patients in each sub-group are compared for each for the separate analyses

GMFCS gross motor function classification system, *PSF* posterior spinal fusion, *APSF* anterior/posterior spinal fusion

Results

Baseline characteristics, HRQOL, and complications

Table 2 summarizes the baseline characteristics of age, gender, GMFCS level, seizure status, feeding status, pre-operative total protein and albumin levels, for each sub-analysis. None revealed a statically significant difference between any of the sub-groups. Overall, 105 (47.3%) of the patients in the sample were female and the average age of the entire sample was 14.2 years. 200 (93.9%) patients were GMFCS level IV or V, and 151 (68%) patients had seizures. The average total protein was 10.7 g/dL, and the average albumin was 6.74 g/dL (overall results not shown). Additionally, there were no significant differences between groups in any of the sub-analysis in terms of HRQOL outcomes, summarized in Table 3. We did not identify any differences in rates of complications among any of the sub-analyses. The comparisons of complications rates are summarized in Table 4.

Analysis 1: Same-day versus staged surgeries

Overall, 222 patients were included in this analysis. There were 199 same-day patients and 23 staged patients. Staged patients had larger curves (109.1° vs. 79.6°, $p<0.001$) and more pelvic obliquity (POB) (40° vs. 26.8°, $p<0.001$). Both groups had similar flexibility (36.9% vs. 29.4%, $p=0.086$).

At 2-year follow-up, staged patients had larger deformity (36.6° vs. 28.8°, $p=0.021$), more absolute correction for Cobb angle (72.5° vs. 50.9°, $p<0.001$), but similar percent correction and POB. Staged patients have larger absolute pelvic obliquity correction (30.1° vs. 19.4°, $p=0.009$), though percent correction was similar.

Staged patients also had longer anesthesia (862 vs. 468 min, $p<0.001$) and surgical times (687 vs. 385 min, $p<0.001$), hospital (21.7 vs. 11.5 days, $p<0.001$) and ICU length of stay (10.0 vs. 5.3 days, $p<0.001$), and days intubated (4.5 vs. 2.7 days, $p=0.021$). There was similar EBL, cell saver transfused, and RBCs transfused (Table 5).

Analysis 2: Posterior-only versus anterior/posterior surgery

Overall, 222 patients were included in this analysis. There were 196 PSF patients and 26 APSF patients. The anterior/posterior group had more severe deformity with larger initial Cobb angles (110.4° vs. 79.0°, $p<0.001$) and pelvic obliquity (37.1° vs. 29.6°, $p=0.004$), though the curves had similar flexibility (29.6% vs. 37.1%, $p=0.068$).

At 2-year follow-up, APSF patients also had larger residual deformity (37.7° vs. 28.5°, $p=0.004$), but had greater absolute deformity correction (72.6° vs. 50.6°, $p<0.001$). Although percent correction was similar (66% vs. 63%, $p=0.458$), both groups had similar residual POB (11.2° vs. 7.6°, $p=0.059$), absolute correction (25.7° vs. 19.7°, $p=0.114$), and percent correction of POB (61% vs. 58.7%, $p=0.896$).

Anterior/posterior patients had longer anesthesia (828 vs. 466 min, $p<0.001$) and surgical times (637 vs. 385 min, $p<0.001$), hospital (17.8 vs. 11.9 days, $p<0.001$) and ICU stays (8.6 vs. 5.4 days, $p<0.020$), but similar number of days spent intubated (3.9 days vs. 2.7 days, $p=.055$). Both groups had similar EBL (1777 cc vs. 2016 cc, $p=0.387$), cell saver transfused (432 cc vs. 488, $p=0.606$), and RBCs transfused (962 cc vs. 1160 cc, $p=0.345$) (Table 5).

Analysis 3: Same-day PSF versus staged PSF

Overall, 196 patients were included in this analysis. There were 190 same-day PSF patients and 6 staged PSF patients. The staged group had larger initial Cobb angles (103° vs. 78.2°, $p=0.006$), but similar flexibility, and pelvic obliquity.

At 2-year follow-up both groups had similar major curves, absolute correction, and percent correction. The staged group had larger residual pelvic obliquity (11.7° vs. 7.51°, $p=0.049$), but similar absolute correction, and percent correction.

The staged group had longer hospital (21.5 vs. 11.9 days, $p=0.009$) and ICU length of stay (7.8 vs. 5.3 days, $p=0.028$), but similar days intubated. The staged group had longer anesthesia (586 vs. 462 min, $p=0.020$) and surgical times (524 vs. 381 min, $p=0.007$). Both groups had similar EBL, cell saver transfused, and RBCs (Table 5).

Analysis 4: Same-day APSF versus staged APSF

Overall, 26 patients were included in this analysis. There were 9 same-day APSF patients and 17 staged APSF patients. There was no significant difference between groups for major curve size, curve flexibility, or POB. At 2-year follow-up, there was no significant difference in all radiographic measures.

The staged group had longer hospital (21.8 vs. 9.1 days, $p<0.001$) and ICU length of stay (10.7d vs. 4.3 days, $p=0.004$), but similar days intubated did not reach statistical significance. The staged group had longer anesthesia (595 vs. 961 min, $p<0.001$) and surgical times (464 vs. 741 min, $p<0.001$). There was no significant difference total EBL, cell saver transfused, and RBCs (Table 5).

Analysis 5: Same-day PSF versus same-day APSF

Overall, 199 patients were included in this analysis. There were 190 same-day PSF patients and 9 same-day APSF

Table 3 Comparative change in pre- to postoperative health related quality of life by surgical approach

Analysis 1: CPCHILD domain	Non-staged	Staged	*p* value
ADL	4.8	3.7	0.824
Positioning, transferring and mobility	9.7	10.3	0.904
Comfort and emotions	6.4	8.5	0.764
Communication and social interaction	2.2	2.3	0.983
Health	6.3	2.6	0.465
Overall quality of life	8.1	14.1	0.393
Total score	5.8	7.3	0.669
Analysis 2: CPCHILD domain	PSF	APSF	*p* value
ADL	4.7	4.2	0.91
Positioning, transferring and mobility	9.6	11.0	0.753
Comfort and emotions	6.0	11.2	0.419
Communication and social interaction	1.9	4.7	0.419
Health	6.7	0.6	0.191
Overall quality of life	8.2	12.4	0.515
Total score	5.9	6.3	0.9
Analysis 3: CPCHILD domain	Non-staged PSF	Staged PSF	*p* value
ADL	4.7	6.6	0.878
Positioning, transferring and mobility	9.6	10.9	0.842
Comfort and emotions	5.3	25.1	0.113
Communication and social interaction	2.0	−2.6	0.629
Health	6.8	0.00	0.708
Overall quality of life	7.8	25	0.218
Total score	5.6	15.2	0.197
Analysis 4: CPCHILD domain	Non-staged APSF	Staged PSF	*p* value
ADL	6.7	3.0	0.892
Positioning, transferring and mobility	12.8	10.1	0.462
Comfort and emotions	26.4	1.1	0.181
Communication and social interaction	6.9	3.4	0.165
Health	−4.2	3.3	0.482
Overall quality of life	15.0	10.8	0.697
Total score	9.0	4.7	0.142
Analysis 5: CPCHILD domain	Same-day PSF	Same-day APSF	*p* value
ADL	4.7	6.7	0.963
Positioning, transferring and mobility	9.6	12.8	0.406
Comfort and emotions	5.3	26.4	0.090
Communication and social interaction	2.0	6.9	0.354
Health	6.8	−4.2	0.189
Overall quality of life	7.8	15.0	0.433
Total score	5.9	9.1	0.425
Analysis 6: CPCHILD domain	Staged PSF	Staged APSF	*p* value
ADL	6.6	3.0	0.945
Positioning, transferring and mobility	10.9	10.1	0.949
Comfort and emotions	25.1	1.1	0.148
Communication and social interaction	−2.7	3.4	0.676
Health	0.0	3.3	0.505
Overall quality of life	25.0	10.8	0.412
Total score	15.2	4.7	0.379

The pre- to postoperative changes in the CPCHILD scores of the patients in each sub-group are compared for each for the separate analyses

CPCHILD Caregivers Priorities and Child Health Index of Life with Disabilities, *ADL* activities of daily living, *PSF* posterior spinal fusion, *APSF* anterior/posterior spinal fusion

Table 4 Comparison of complication rates for CP scoliosis patients by surgical approach

Analysis 1	Non-staged	Staged	*p* value
Proportion with a complication	17%	22%	0.559
Mean	0.19	0.39	0.403
Analysis 2	PSF	APSF	*p* value
Proportion with a complication	17%	19%	0.782
Mean	0.1888	0.3462	0.611
Analysis 3	Non-staged PSF	Staged PSF	*p* value
Proportion with a complication	17%	17%	0.991
Mean	0.19	0.17	0.973
Analysis 4	Non-staged APSF	Staged APSF	*p* value
Proportion with a complication	11%	24%	0.628
Mean	0.11	0.47	0.560
Analysis 5	Same-day PSF	Same-day APSF	*p* value
Proportion with a complication	17%	11%	0.651
Mean	0.19	0.11	0.640
Analysis 6	Staged PSF	Staged APSF	*p* value
Proportion with a complication	17%	24%	0.726
Mean	0.17	0.47	0.759

The complication rates of the patients in each sub-group are compared for each for the separate analyses

PSF posterior spinal fusion, *APSF* anterior/posterior spinal fusion

patients. The APSF group had larger pre-operative major Cobb angles (108.7° vs. 78.2°, $p=0.002$), but no significant difference in flexibility or pelvic obliquity.

At 2-year follow-up the APSF group had greater residual coronal deformity (39.2° vs. 28.3°, $p=0.035$) and greater absolute correction (69.4° vs. 50.1°, $p=0.007$). There were no significant differences in percent coronal correction, residual pelvic obliquity, absolute correction, and percent correction of pelvic obliquity.

The APSF group had longer anesthesia (595 vs. 462 min, $p=0.012$) and surgical times (464 vs. 381 min, $p=0.042$). There were no significant differences in total EBL, cell saver transfused, RBCs transfused, hospital length of stagy, ICU days, or days intubated (Table 5).

Analysis 6: Staged PSF versus staged APSF

Overall, 23 patients were included in this analysis. There were 6 staged PSF patients and 17 staged APSF patients. There was no significant difference between groups for major curve size, curve flexibility, or pelvic obliquity. At 2-year follow-up there was no significant difference in all radiographic measures.

The APSF group had longer anesthesia times (961 vs. 586 min, $p<0.001$); however, the differences in surgical times did not reach significance (741 vs. 524 min, $p=0.066$). There was no significant difference in total EBL, cell saver transfused, RBCs transfused, hospital length of stagy, ICU days, or days intubated (Table 5).

Discussion

A staged approach was traditionally advocated for neuromuscular scoliosis in an effort to limit the morbidity from an anterior and posterior approach attempted in a single, extensive operation [7]. More recently, there has been controversy over whether a same-day or a staged approach produces the optimal results with the least morbidity [5, 7, 9–11]. While the utility of an anterior approach has been questioned in recent literature, some argue that an anterior release may be required in particularly large, stiff or short angle curves, or those with hyperlordosis [1, 8, 15–20].

Our results indicate surgeons were more likely to pursue a staged approach for larger magnitude curves and pelvic obliquity (Table 5: Analysis 1). For posterior-only approaches, the staged patients overall had larger curves (103° vs. 78.2°, $p=.006$) and more POB (41° vs. 26.6°, $p=0.069$) than their non-staged counterparts, although the difference in POB did not reach statistical significance (Table 5: Analysis 3). On the other hand, when evaluating only APSF patients, there was not a significant difference

Table 5 Overview of radiographic and perioperative outcomes of CP scoliosis patients by surgical approach

	Analysis 1			Analysis 2			Analysis 3			Analysis 4			Analysis 5			Analysis 6		
	Overall Same-Day	Overall Staged	*p* value	Overall PSF	Overall APSF	*p* value	Same-Day PSF	Staged PSF	*p* value	Same-Day APSF	Staged APSF	*p* value	Same-Day PSF	Same-day APSF	*p* value	Staged PSF	Staged APSF	*p* value
Pre-operative radiographic measures																		
Major Cobb Angle	79.6°	109.1°	< 0.001	79.0°	110.4°	< 0.001	78.2°	103.0°	0.006	108.7°	111.2°	0.916	78.2°	108.7°	0.002	103°	111.2°	0.354
Curve percent flexibility	36.9%	29.4%	0.086	37.1%	29.6%	0.068	37.5%	26.1%	0.210	28.0%	30.3%	0.630	37.5%	28.0%	0.104	26.1%	30.3%	0.961
Pelvic obliquity	26.8°	40.0°	< 0.001	26.9°	37.4°	0.004	26.6°	41.0°	0.069	32.7°	39.7°	0.172	26.6°	32.7°	0.271	41.0°	39.7°	0.798
Perioperative Outcomes																		
Anesthesia time (min)	468	862	< 0.001	466	828	< 0.001	462	586	0.020	595	961	< 0.001	462	595	0.012	586	961	< 0.001
Surgical time (min)	385	687	< 0.001	385	637	< 0.001	381	524	0.007	464	741	< 0.001	381	464	0.042	524	741	0.066
Total EBL (cc)	1762	2175	0.157	1777	2016	0.387	1773	1885	0.838	1524	2277	0.181	1773	1524	0.659	1885	2277	0.558
Total cell saver (cc)	425	557	0.247	432	488	0.606	430	471	0.839	313	597	0.111	430	313	0.651	471	596	0.565
Total RBCs transfused (cc)	944	1352	0.073	962	1160	0.345	961	978	0.964	654	1485	0.198	961	654	0.317	978	1485	0.559
Total hospital stay (days)	11.5	21.7	< 0.001	11.9	17.8	< 0.001	11.9	21.5	0.009	9.1	21.8	< 0.001	11.9	9.1	0.432	21.8	21.5	0.99
ICU stay (days)	5.3	10.0	< 0.001	5.4	8.6	0.020	5.3	7.8	0.028	3.6	1.8	0.004	5.3	3.6	0.490	7.8	10.8	0.562

Table 5 (continued)

	Analysis 1			Analysis 2			Analysis 3			Analysis 4			Analysis 5			Analysis 6		
	Overall Same-Day	Overall Staged	*p* value	Overall PSF	Overall APSF	*p* value	Same-Day PSF	Staged PSF	*p* value	Same-Day APSF	Staged APSF	*p* value	Same-Day PSF	Same-day APSF	*p* value	Staged PSF	Staged APSF	*p* value
Days intubated	2.7	4.5	0.021	2.7	3.9	0.055	2.7	3.2	0.299	1.9	4.9	0.215	2.7	1.9	0.674	3.2	4.9	0.609
2-Year postoperative radiographic measures																		
Major Cobb angle	28.8°	36.6°	0.021	28.5°	37.7°	0.004	28.3°	35.8°	0.195	39.2°	36.9°	0.560	28.3°	39.2°	0.035	35.8°	36.9°	0.609
Absolute coronal Cobb change	50.9°	72.5°	< 0.001	50.6°	72.7°	< 0.001	50.1°	67.2°	0.080	69.4°	74.4°	0.634	50.1°	69.4°	0.007	67.2°	74.4°	0.286
Percent coronal Cobb correction	62%	66%	0.410	63%	66%	0.458	62%	65%	0.991	64%	67%	0.597	62%	64%	0.900	65%	67%	0.865
Pelvic obliquity	7.7°	10.9°	0.129	7.6°	11.2°	0.059	7.5°	11.7°	0.049	14.9°	12.1°	0.689	7.8°	14.9°	0.205	20°	12°	0.277
Absolute pelvic obliquity change	19.4°	30.1°	0.009	19.7°	25.7°	0.114	19.5°	32.0°	0.110	18.0°	29.6°	0.083	19.2°	18.0°	0.950	32°	29.6°	0.840
Percent pelvic obliquity correction	62.5%	66.5%	0.827	58.7%	61.0%	0.896	58.4%	73.8%	0.920	63.0%	60.0%	0.820	58.4%	63.0%	0.990	73.8%	60.0%	0.450

Radiographic and perioperative outcomes of the patients in each sub-group are compared for each for the separate analyses

PSF posterior spinal fusion, *APSF* anterior/posterior spinal fusion in curve magnitude between staged and same-day patients, as patients who were treated with anterior release had average coronal deformity > 100° and POB of > 30°, regardless if staged or same-day (Table 5: Analysis 4). Additionally, the average deformity in the staged patients was also > 100 degrees and POB of approximately 40 degrees, regardless if treated with PSF or APSF (Table 5: Analysis 6). This finding may indicate that factors other than deformity may play important roles in decision-making for patients with the worst deformity. Additionally, three of the staged procedures were unplanned and converted to staged procedures in response to unforeseen intraoperative complications. The operation was aborted and subsequently completed as a staged procedure for excessive blood loss, suspected anaphylactic reaction to blood products, and cardiac arrhythmia, respectively, in these three patients.

Our results have corroborated previous series showing that staged cases are associated with longer hospitalizations and longer ICU stays [7, 9, 11]. We also demonstrate that staged approaches were associated with longer operative times. This was found even when the groups were stratified by approach, implying that the extra operative time is primarily staging the procedure and not just from the added complexity of the anterior portion of the case (Table 5: analysis 4 and 6). However, even with overall longer operative times, considerations for surgeon stamina and fatigue prevention, as well as patient concerns about hemodynamic stability and coagulopathy, may sway surgeons toward returning for a second day of surgery [7]. Conversely, these considerations should be balanced against the additional costs to families and the healthcare system for the prolonged operations and hospitalization, such as costly ICU stays. Furthermore, potential harm from prolonged operations and hospitals stays should be balanced against potential harm resulting from surgeon and surgical team fatigue.

Furthermore, the benefits of a staged procedure are unclear, from deformity correction or HRQoL standpoint. When evaluating only patients with an anterior approach, staged procedures were associated with prolonged hospital stays and operative times, but not with improved deformity correction, despite the deformity being similar at baseline (Table 5: Analysis 4). Additionally, when controlling for staged procedures these data suggest no increase in deformity correction with anterior release, despite similar preoperative and postoperative deformity and curve rigidity (Table 5: Analysis 6). However, these results are limited by a small sample size of staged PSF patients, some of who had an unplanned staged procedure.

Other retrospective series show no increase in correction from anterior approaches [8, 13, 16]. In a cohort of non-ambulatory, spastic quadriplegic CP patients all treated with intraoperative halo traction, Keeler et al. retrospectively compared PSF to APSF and found that the APSF group had longer operations (6.1 h compared to 10.3 h), more EBL (873 cc compared to 1361 cc) and more pulmonary complications, but similar radiographic outcomes [13]. There was no difference in pre-operative or postoperative Cobb angle, deformity correction, pelvic obliquity, or C7 plumb line [13]. However, this was in a cohort of patients who were all treated with the use of intraoperative halo traction, whereas only 34% of our patients had intraoperative traction. Given the medically frail nature of NMS patients, alternatives to an anterior approach have been advocated, including vertebral column resections (VCR), pre- and intraoperative halo traction, and osteotomies [1, 4, 9, 10, 13, 15, 21]. For patients in whom halo-gravity traction is contraindicated, such as patients with cervical instability, fixed cervical kyphosis [22], stenosis, hip flexion contractures, temporary internal distraction rods may be a viable alternative [23]. A review of ten children, with average Cobb angles of 104°, the use of internal distraction rods was associated with 80% deformity correction with no neurological deficits or infections [23].

Other retrospective studies have found anterior and staged approaches to increase complications [9, 11, 16], we found no difference in major complication rate between any of the sub-groups. Ferguson et al. found a 124% complication rate in staged patients compared to 88% complication rate in the same-day group (63% and 35% of patients having a major or minor complication, respectively [9]. However, they did find higher reintubation rates and pulmonary complications in the same-day group [9]. The staged group also had longer hospital stays, longer operative times, increased blood loss and transfusions, and decreased nutritional parameters [9]. Nishnianidze et al. found that patients with feeding tubes had higher rates of complications [24]. However, we did not find a higher rate of complications among patients with feeding tubes. Furthermore, there were no significant differences in the proportion of patients with feeding groups in any of our sub-analyses. Overall, our prospective study did not find significant differences in complication rates, implying that same-day procedures may be just as safe as staged procedures. Patients staying in hospital in anticipation of the second surgery may explain the difference in overall hospital length of stay, as well as ICU stay. Additional detail regarding the nature of the complications can be found in Table 1.

Limitations of our study include the non-randomized nature of the methodology. There may be increased variability in the data given differences in specific protocols used by the individual treating surgeons and centers included in the study. However, the inclusion of diversity may increase the generalizability of our findings. The use of any supplementary techniques, such as VCR, osteotomies, or halo traction, may confound the results. Additional factors, such as patient physiology, familiarity and skill of the post-op care team, or level of training of the first assistant may play a more important role than the degree or type of deformity in treatment decisions, particularly in the most severe curves. Further prospective studies may help control for those differences and further analyze which cases should be staged or performed as a single procedure and which patients would benefit most from the addition of an anterior approach.

The complexity of neuromuscular scoliosis and the litany of available treatment options compound the difficulty of therapeutic decision-making. There is little consensus concerning the determination to utilize a staged and/or combined circumferential approach or not. While a surgeon may consider a wide range of factors in these decisions, it seems that magnitude of deformity plays an important role. A same-day, posterior-only approach seems to be reserved for patients with relatively less severe deformity. However, it appears that there is much overlap in patients treated with staged, 2-day procedures and/or anterior releases. Given the similarities in baseline characteristics and radiographic measures for these most severe cases it appears that factors other than just radiographic parameters may be of greater importance when deciding between surgical options. In these most severe cases, it is not clear whether staged or anterior approaches produce superior deformity correction over same-day or posterior-only approaches.

Based on the results, no definitive recommendations can be made for which cases should or should not be staged or utilize an anterior approach in addition to an instrumented spinal fusion. The authors suggest that those patients who are low demand (GMFCS V, severe cognitive impairment, etc.) may be better served with a single-stage procedure. Conversely, those patients in whom large deformity is present and maximizing curve correction is more of a priority, a staged procedure may justify the additional burden of care (increased length of hospitalization, ICU stay, etc.). The best course of action is even less clear for patients with the most severe deformity, and improved understanding of the indications for staged and anterior approaches may help better target the patients who stand to benefit most, and limit unnecessary medicalization.

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