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Critical Analysis of Radiographic and Patient Reported Outcomes Following Anterior/Posterior Staged vs. Same Day Surgery in Patients Undergoing Identical Corrective Surgery for Adult Spinal Deformity

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STUDY-DESIGN: Retrospective cohort study of a prospectively collected multi-center adult spinal deformity (ASD) database.

OBJECTIVE: To compare staged procedures to same-day interventions and identify the optimal time interval between staged surgeries for treatment of ASD.

BACKGROUND: Surgical intervention for ASD is invasive and complex procedure that surgeons often elect to perform on different days (staging). Yet, there remains a paucity of literature on the timing and effects of the interval between stages.

METHODS: ASD patients with two-year (2Y) data undergoing an anterior/posterior (A/P) fusion to the ilium were included. Propensity score matching (PSM) was performed for number of levels fused, number of interbody devices, surgical approaches, number of osteotomies/three-column osteotomy (3CO), frailty, Oswestry Disability Index (ODI), Charlson Comorbidity Index (CCI), revisions, sagittal vertical axis (SVA), pelvic incidence-lumbar lordosis (PI-LL), and UIV to create balanced cohorts of Same-Day and Staged surgical patients. Staged patients were stratified by intervening time-period between surgeries, using quartiles.

RESULTS: 176 PSM patients were included. Median interval between A/P staged procedures was 3 days. Staged patients had greater operative time and lower ICU stays postop ($p<0.05$). At 2Y, staged compared to same day showed a greater improvement in T1 slope – cervical lordosis (TS-CL), C2 sacral slope (C2SS), and SRS-Schwab SVA ($p<0.05$). Staged patients had higher rates of minimal clinically-important difference (MCID) for 1Y SRS-Appearance and 2Y physical component summary (PCS) scores. Assessing different intervals of staging, patients at the 75th percentile interval showed greater improvement in 1Y SRS Pain and Total postop as well as SRS Activity, Pain, Satisfaction, and Total scores ($p<0.05$) compared to patients in lower quartiles. Compared to the 25th percentile, patients reaching the 50th percentile interval were associated with increased odds of improvement in Global Alignment and Proportion (GAP) score proportionality (9.3[1.6-53.2], $p=0.01$).

CONCLUSIONS: This investigation is among the first to compare multicenter staged and same day surgery anterior/posterior adult spinal deformity patients fused to ilium using propensity-matching. Staged procedures resulted in significant improvement radiographically, reduced ICU admissions, and superior patient reported outcomes compared to same day procedures. An

interval of at least three days between staged procedures is associated with superior outcomes in terms of GAP score proportionality.

KEY POINTS:

1. Propensity-matched retrospective analysis of anterior/posterior (A/P) adult spinal deformity patients undergoing Staged versus Same-Day procedures demonstrated significantly greater radiographic improvement, reduced ICU admissions, and superior patient-reported outcomes in Staged patients.
2. Staged patients suffered significantly lower rates of neurological complications relative to Same-Day A/P fusion patients.
3. The optimal interval for staging relative to alignment improvement was determined to be greater than three days.

INTRODUCTION

Adult spinal deformity (ASD) is an increasingly common spinal condition that is frequently treated surgically. In this clinical setting, corrective surgery has been found to be effective but is also associated with elevated risk of complications ranging from 10% to 40% and a substantive morbidity profile.[1] To decrease the physiological stress and surgical burden of an extensive and invasive procedure, recent literature has suggested two smaller staged procedures to minimize blood loss, extended anesthesia time, surgeon fatigue, and potential interval reassessment of alignment goals.[2–4] The theoretical benefits of staged ASD interventions have been proposed in the literature, but there remains a paucity of data on the outcomes following staged versus same-day procedures in situations where there is clinical equipoise. Furthermore, the optimal interval between staged procedures for patients undergoing an anterior-posterior fusion has not been effectively characterized.[1,5–7]

Prior literature is prone to confounding by selection and indication, with more complex cases preferentially steered toward staged procedures, while simpler cases may undergo same-day surgery. In addition, the time interval between staged procedures could be influenced by conventional practices based on surgeon, or hospital care team preference, as well as being driven by the complexity of the procedure and patient level characteristics. In such scenarios, where there may be bias introduced by confounding by indication, propensity-score matching techniques may be an effective solution.

In this context, we sought to compare cohorts of adult spinal deformity patients with clinical equipoise regarding optimal approach and evaluate differences in patient reported outcomes measures, complications, and achievement of optimal alignment. We also planned to determine the optimal time interval between staged procedures to maximize outcomes while minimizing the risk of adverse events. We used propensity score matching as a means to address the inherent confounding by indication. We hypothesized that staged surgical procedures would experience superior patient reported outcomes and have a greater likelihood of achieving optimal alignment while simultaneously experiencing a lower risk of complications.

MATERIALS AND METHODS

Study Design, Inclusion, and Exclusion Criteria

This was a retrospective cohort review of a prospective, multicenter adult spinal deformity (ASD) database. Patients were consecutively enrolled from 13 participating centers with Institutional Review Board Approval and informed consent obtained from all participants prior to initiation. Inclusion criteria for the dataset as a whole have been described extensively in previous investigations[8,9]. Operative adult spinal deformity patients who met database inclusion criteria and underwent an anterior/posterior (A/P) fusion to the ilium with radiographic and health related quality of life (HRQL) data at baseline and 2-years were selected for inclusion in this specific study. Anterior approach was defined as fusion of the anterior spinal column via anterior or lateral technique. All data collected at the participating sites were subject to rigorous quality control and has been extensively utilized in peer-reviewed literature. [7,10]

Data Collection and Radiographic Parameters

We abstracted demographic data including age, sex, body mass index (BMI), and Charlson Comorbidity Index (CCI). Surgical details included levels fused, estimated blood loss (EBL), operative time, surgical approach, performance of decompressions, and use of osteotomies. Patient reported outcome measures administered at baseline and follow-up intervals included: the Oswestry Disability Index (ODI), Scoliosis Research Society Outcomes Questionnaire (SRS-22), and Short Form-36 (SF-36) questionnaire. Minimal clinically importance difference (MCID) thresholds were applied to evaluate improvement in outcomes using previously published values for ODI (12.8), SF-36 (4.9), SRS-Pain (0.587), SRS-Appearance (0.8), SRS-Activity (0.375), and SRS-Mental (0.42).

Full length free-standing lateral spine radiographs (36-inch cassette) were collected and assessed at baseline and follow-up intervals. Radiographic images were analyzed using SpineView® (ENSAM, Laboratory of Biomechanics, Paris, France) software according to standardized and validated techniques previously published in the literature. Spinopelvic and cervical radiographic parameters measured were (but not limited to) pelvic tilt (PT), pelvic incidence (PI), C7-S1 sagittal vertical axis (SVA), and mismatch between pelvic incidence and lumbar lordosis (PI-LL), as well as Schwab classification, Roussouly shape, and Global Alignment and Proportion (GAP) score[11–13]. Complications and major/minor distinction thereof was based upon Klineberg et al. criteria.[14] Improvement in GAP was defined as improvement by at least 1 categorical marker from baseline to post-operative.

Statistical Analysis

Patients were propensity-score matched (PSM) for previous history of spine surgery, levels fused, number of levels treated with interbody device, surgical approach, number of osteotomies and three-column osteotomies (3CO), baseline ASD frailty index (ASD-FI) scores, Oswestry disability index (ODI), CCI, and revisions, SVA, PI-LL, and Upper Instrumented Vertebrae (UIV) to establish cohorts of Same-Day and Staged surgical patients. The variables used in PSM were selected using a conceptual model based on prior literature and had $p>.05$ for all values. PSM utilized the logit scale for matching with the caliper. Staged patients were further stratified into quartiles based on the number of days between procedures: 1) 25th Percentile (2 days); 2) 50th Percentile (3 days); 3) 75th Percentile (5 days). Staged procedures requiring separate hospitalization were excluded. Chi-square and independent sample t-tests assessed differences in baseline demographics, clinical data, and intervals of staging between the matched cohorts. All statistical analysis was conducted using SPSS software (v25.0 IBM, Armonk, NY).

RESULTS

Cohort Overview

176 propensity score matched adult spinal deformity patients with complete baseline and two-year follow-up met inclusion criteria. The mean patient age was 63.0±10.1 years, body mass index (BMI) of 28.7±5.4, kg/m^2, Charlson Comorbidity Index (CCI) of 1.9±1.6, ASD-FI of 3.9±1.5, with 78% of patients being female. Operatively, patients had a mean levels fused of 12.3±3.8, an estimated blood loss of 1956±1484 mL, and operative time of 557±5 minutes. All patients underwent an anterior/posterior (A/P) fusion to the ilium with 47% having an osteotomy, 47% a decompression, and 58% having prior spine surgery **(Table 1)**. Prior to propensity

matching, patients were comparable in baseline demographic, clinical, and radiographic characteristics including age, gender, BMI, number of osteotomies and 3CO, and both sagittal and coronal profiles (all p>.05). However, Staged patients did report significantly higher baseline ODI prior to PSM (51.4 vs 56.9, p=.002).

Baseline Radiographic Presentation and Health Related Quality of Life

Radiographically at baseline, patients presented with a mean pelvic tilt (PT) of 26.6±10.0, PI-LL of 24.4±19.3, SVA 100.4±93.6, and T1PA of 28.3±13.0. The cohort had an average baseline GAP score of 8.6±3.7, with 8.7% categorized as GAP-Proportioned, 22.1% GAP-Moderately Disproportioned, and 69.2% GAP Severely Disproportioned. According to SRS-Schwab Classification, 34% of patients were ++ for PT, 48.9% ++ for SVA, and 60.2% ++ for PI-LL. According to the Roussouly classification system, 6.3% were Type 1, 12.5% were Type 2, 42.6% were Type 3, and 38.6% were Type 4. With respect to health related quality of life, patients had an average baseline ODI of 49.8±15.7, SRS-Activity 2.6±0.78, SRS-Pain 2.3±0.78, SRS-Appearance 2.3±0.68, SRS-Mental 3.4±0.93, SRS-Satisfaction 2.7±1.1, and SRS-Total of 2.7±0.61.

Staged vs. Same-Day Anterior-Posterior Fusion

Overall, 88 patients had staged anterior-posterior (A/P) fusions and 88 patients had a same-day A/P fusion. The median interval between staged procedures was 3.0 day ±2.6. Staged patients had significantly greater total operative time (649 minutes vs. 505 minutes, p<0.001), lower rates of intensive care unit (ICU) admissions postoperatively (76.6% vs. 100%, p<0.001), but did not differ significantly in length of stay (11.8 days vs. 9.9 days, p= 0.162) (**Table 2 & 3**).

Radiographically at two years, Staged patients compared to Same-Day showed significantly greater improvement in T1 slope minus cervical lordosis (TS-CL), C2 Sacral Slope (C2SS), and C7-S1 SVA according to SRS-Schwab classification (all $p<0.05$) (**Table 4**). There were no significant differences in improvement in GAP proportionality or matching Roussouly type at two years (all $p>.05$) (Figure 1). In terms of clinical outcomes, Staged patients reported greater improvements in SRS-Appearance at six weeks (p=0.041) and had higher rates of a gain in MCID for SRS-Appearance at 1-year (p=0.001) and in PCS at 2-year (p=.040). Gross comparison of 2-year patient-reported outcomes is further provided in **Table 5**.

Incidence of Complications

With respect to complications, Staged patients had significantly lower incidence of neurological complications (6.8% vs. 19.3%, p=0.014) relative to same-day A/P fusion patients. Although not significant, staged patients also had lower rates of infection (6.8% vs. 14.8%, p=0.089) post-operatively. Reoperation was recorded in 28.4% of cases, and was not statistically different between groups ($p>.05$).

Intervals of Staging

When assessing different intervals of staging, statistical analysis revealed that patients reaching the 75th percentile interval showed greater improvement in SRS-Pain and Total scores postoperatively as well as SRS-Activity, Pain, Satisfaction, and Total at 1-year (all $p<0.05$) versus those in lower quartiles. Relative to the 25th percentile interval of staging, patients reaching the 50th percentile were associated with significantly increased odds of improvement in GAP proportionality at 2-years (OR: 9.3 [1.6-53.2], p=0.01). However, there were no significant differences in rates of complications between the different intervals of staging. Adjusting for institution and surgeon, patients at the 50th percentile interval continued to show a higher rate of improvement in GAP proportionality at 2-years ($p<0.05$).

Case Examples

A case example of a 65 year old female undergoing staged 14 level fusion with 2Y follow up is depicted in Figure 2. An additional case example of baseline and 2 year radiographs of a 57 year old female undergoing a same-day procedure is depicted in Figure 3. Both patients reported no major complications up to 2Y post-operatively.

DISCUSSION

Despite advances in operative techniques and peri-operative management, corrective adult spinal deformity surgery is still associated with a substantial physiologic insult and elevated rates of mechanical and surgical complications. Focusing on minimizing risks while simultaneously improving surgical efficiency, a staged approach may reduce the risk of adverse outcomes while maximizing the prospect of surgical benefit.[15,16]

While previous studies have touted the advantages of a staged approach, the putative outcomes associated with such a strategy may be confounded by a selection bias. Though focusing on paediatric spinal deformity, Shufflebarger et al. were among the first to analyze the impact of staged versus same-day combined anterior-posterior spinal fusion. While their results supported a continuous procedure leading to decreased blood loss, lessened length of stay, and greater deformity correction, their study was limited in generalizability due to a young patient population and heterogeneous indications for deformity correction. [17,18] To our knowledge, there remains a paucity of literature comparing staged as opposed to same-day procedures with identical anterior-posterior spinal fusion approaches.

Our study indicates that staged patients experienced lower ICU admissions postoperatively, significantly greater radiographic improvement at two-years, and higher rates of achieving minimal clinically-important difference (MCID) for patient reported outcomes at 1- and 2-years. When evaluating staged procedure intervals, we found the 50th percentile (three days) was associated with the greatest improvement in GAP proportionality, independent of institution and surgeon. With significant reductions in postoperative neurologic complications associated with staged procedures among deformity patients, there may be substantial benefit in dividing an extensive spinal fusion procedure into two smaller scale interventions. Furthermore, the interval between staged procedures may allow surgeons to reassess surgical strategy based on initial correction and provide an idealized spine fusion construct.[19]

The preference for a staged procedure versus a same-day procedure can be dependent on a multitude of factors including co-morbidity burden of the patient, frailty, availability of institutional resources, and surgical efficiency. Hospitals with limited intensive care unit space or understaffed post-operative care teams may consider staging to minimize resource overutilization associated with extended hospital length of stay[18,20]. Furthermore, the reduction in complications and reoperations associated with a staged procedure may improve long-term cost-effectiveness of adult spinal deformity procedures despite the initial increase in costs associated with the performance of two separate interventions.[21] Future studies may aid in developing an algorithm to help with the decision-making process regarding when to stage that can account for these parameters.

We acknowledge several limitations associated with this study. Despite our reliance on prospectively collected, standardized data, this remains a retrospective review with a restricted sample and limited event rate. While we used propensity score matching to assemble cohorts with clinical equipoise, the nature of the data is such that we must recognize the prospect for residual confounding and our trimming of the cohort as a whole could have contributed to loss of power in certain secondary areas. There is the potential for expertise bias in addition, as the contributing members of the ISSG all have well developed spinal deformity practices, with extensive clinical experience. As such, these findings may not translate to all other clinical settings and surgical environments. External validation of our study findings is therefore necessary, before definitive endorsement is possible.

CONCLUSIONS

This investigation is among the first to compare multicenter staged and same-day surgery anterior/posterior adult spinal deformity patients fused to ilium using propensity-matching. Staged procedures resulted in significant improvement radiographically, reduced ICU admissions, and superior patient reported outcomes compared to same-day procedures. An interval of at least three days between staged procedures also appears to be associated with superior outcomes in terms of GAP proportionality.

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Figure 1. Graphical depiction of GAP proportionality in Same-Day versus Staged patients at two-years post-operatively.

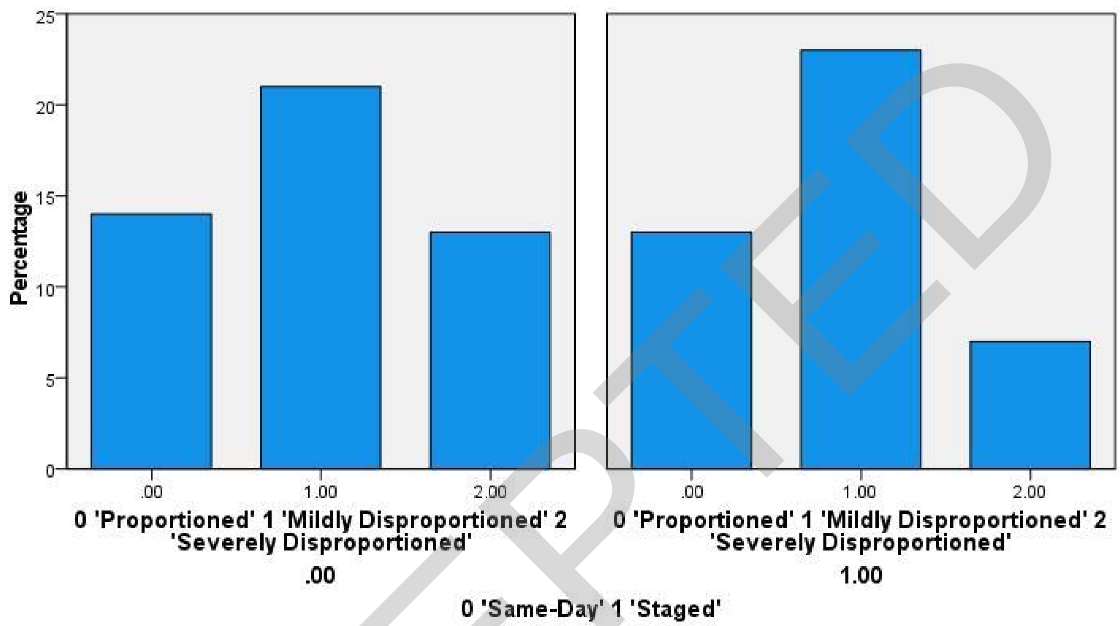

Figure 2: Baseline to 2 Year Radiographs: A 65 year old female with a BMI of 30.8 kg/m^2 underwent a staged anterior-posterior 14 level fusion to the pelvis. At baseline, patient presented with a PT of 30.8°, PI-LL of 18.9°, and SVA of 74.5 mm. At two years patient presented with a PT of 24.8°, PI-LL of 4.1°, and SVA of 8.7 mm.

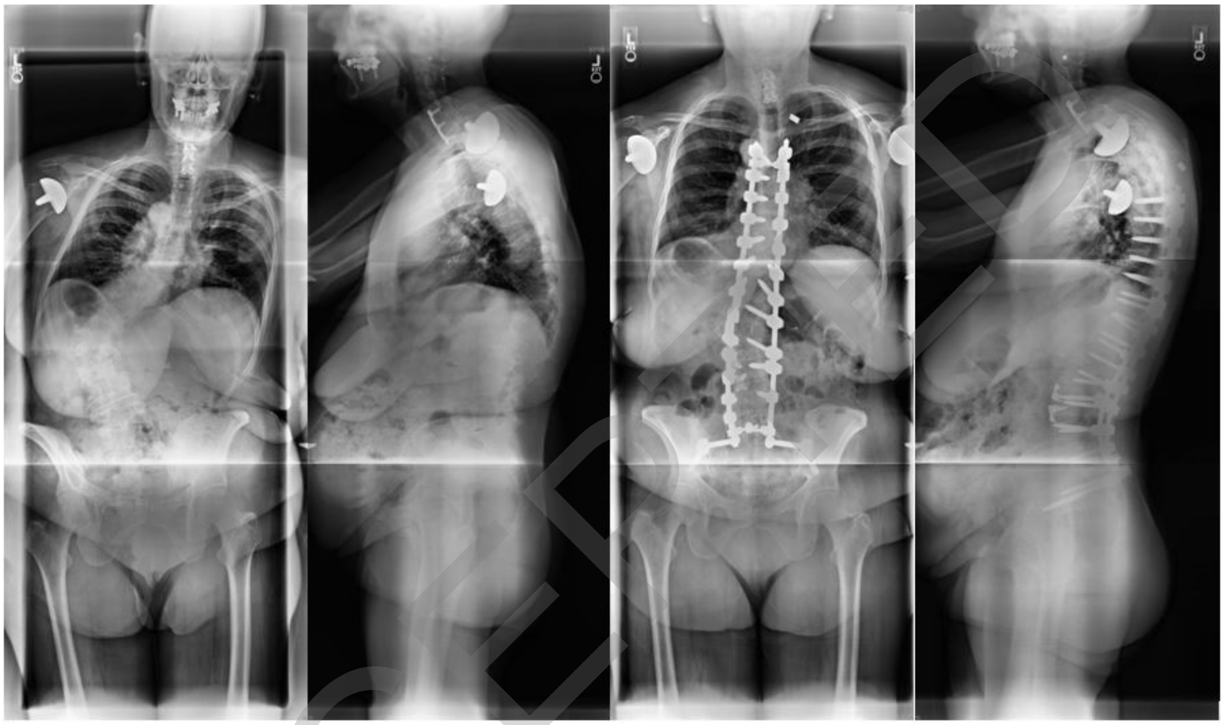

Figure 3: Baseline to 2 Year Radiographs: A 57 year old female with a BMI of 29.8 kg/m^2 underwent a staged anterior-posterior 15 level fusion to the pelvis. At baseline, patient presented with a PT of 34.2°, PI-LL of 49.2°, and SVA of 149.6 mm. At two years patient presented with a PT of 26.6°, PI-LL of 12.3°, and SVA of 18.0 mm.

Table 1. Aggregate Baseline Demographic and Surgical Details of Total Cohort

Baseline Factor	
Age	63.0±10.1
Female	78%
Body Mass Index (BMI)	28.7±5.4, kg/m2
CCI	1.9±1.6
ASD-FI	3.9±1.5
Surgical Descriptors	
Levels Fused	12.3±3.8
Operative Time	557±552 minutes
Estimated Blood Loss	1956±1484 mL
Osteotomy	47%
Decompression	47%

Table 2. Operative and Complication Differences

	Staged Anterior-Posterior Fusion	Same-Day Anterior-Posterior Fusion	P Value
Rate of Intensive Care Unit Admissions Post-Operatively	76.6%	100%	p<0.001
Neurological Complications	6.8%	19.3%	P=0.014
Infection	6.8%	14.8%	P=0.089

Table 3. Differences in baseline and perioperative variables between Same-Day and Staged patients

Baseline and Perioperative Differences		Mean ± Std. Deviation	p value
Age	Same Day	61.9 ± 9.8	0.279
	Staged	63.5 ± 10.5	
Body Mass Index	Same Day	28.6 ± 5.4	0.819
	Staged	28.8 ± 5.4	
Charlson Comorbidity Index	Same Day	2.1 ± 1.8	0.540
	Staged	1.9 ± 1.4	
Estimated Blood Loss	Same Day	1842.2 ± 1421.6	0.306
	Staged	2071.8 ± 1544.5	
Operative Time	Same Day	505.1 ± 131.6	0.000
	Staged	649.2 ± 211.5	
Length of Stay	Same Day	9.9 ± 10.8	0.195
	Staged	11.6 ± 5.2	
Levels Fused	Same Day	12.3 ± 3.7	0.920
	Staged	12.3 ± 3.8	

Table 4. Baseline and two years postoperative radiographic alignment differences between Same-Day and Staged patients

Baseline Radiographic Parameters		Mean ± Std. Deviation	p value
SS	Same Day	28.6 ± 11.9	0.126
	Staged	31.4 ± 11.7	
PT	Same Day	27.1 ± 10.3	0.569
	Staged	26.2 ± 10	
PI	Same Day	55.7 ± 12.5	0.323
	Staged	57.6 ± 12.4	
PI-LL	Same Day	24.1 ± 20.5	0.878
	Staged	24.6 ± 18.3	
T2-T12	Same Day	-36 ± 18.6	0.212
	Staged	-32.5 ± 18.9	
T1SS	Same Day	34.1 ± 15.2	0.184
	Staged	31.1 ± 14.2	
TS-CL	Same Day	18.1 ± 11.4	0.344
	Staged	16.2 ± 13.9	
C2-C7	Same Day	14.4 ± 18.4	0.718
	Staged	13.5 ± 15.5	
SVA C2-C7	Same Day	30 ± 14.3	0.437
	Staged	28.3 ± 13.1	
C2SS	Same Day	16.4 ± 11.1	0.387
	Staged	14.6 ± 14.2	
SVA C7 S1	Same Day	103.9 ± 88.9	0.567
	Staged	97 ± 69.6	
T1PA	Same Day	29 ± 14.5	0.489
	Staged	27.6 ± 11.6	

Two Year Radiographic Parameters		Mean ± Std. Deviation	p value
SS	Same Day	31.51 ± 7.74	0.042
	Staged	35.3 ± 9.92	
PT	Same Day	22.16 ± 10.22	0.53
	Staged	20.91 ± 8.66	
PI	Same Day	53.67 ± 11.48	0.313
	Staged	56.22 ± 12.75	
PI-LL	Same Day	-0.82 ± 13.45	0.491
	Staged	1.13 ± 13.72	
T2-T12	Same Day	-59.64 ± 17.42	0.07
	Staged	-53.13 ± 16.78	
T1SS	Same Day	36.48 ± 13.35	0.271
	Staged	33.59 ± 11.6	
TS-CL	Same Day	20.27 ± 9.67	0.046
	Staged	24.68 ± 10.99	
C2-C7	Same Day	16.16 ± 15.73	0.014
	Staged	8.43 ± 13.27	
SVA C2-C7	Same Day	30.37 ± 14.17	0.146
	Staged	34.55 ± 12.6	
C2SS	Same Day	17.71 ± 9.79	0.032
	Staged	22.5 ± 11.07	
SVA C7 S1	Same Day	24.32 ± 55.53	0.747
	Staged	27.76 ± 45.89	
T1PA	Same Day	17.25 ± 11.46	0.839
	Staged	16.8 ± 9.45	

Table 5. Gross two-year postoperative patient-reported differences between Same-Day and Staged patients

2Y Patient-Reported Parameters		**Mean ± Std. Deviation**	**p value**
ODI	Same Day	26.47 ± 19.56	0.499
	Staged	29.32 ± 21.4	
PCS	Same Day	40.42 ± 12.06	0.795
	Staged	39.8 ± 11.03	
SRS-ACTIVITY	Same Day	3.53 ± 0.92	0.436
	Staged	3.38 ± 0.92	
SRS-PAIN	Same Day	3.41 ± 1.13	0.871
	Staged	3.37 ± 1.16	
SRS-APPEARANCE	Same Day	3.62 ± 0.86	0.493
	Staged	3.61 ± 0.97	
SRS-MENTAL	Same Day	3.94 ± 0.73	0.171
	Staged	3.77 ± 0.98	
SRS-SATISFACTION	Same Day	4.09 ± 1	0.135
	Staged	4.31 ± 0.94	
SRS-TOTAL	Same Day	3.67 ± 0.78	0.355
	Staged	3.61 ± 0.82	