

PROGNOSTIC CRITERIA FOR POST-OPERATIVE SUCCESS IN PATIENTS UNDERGOING SURGERY FOR ADULT SPINAL DEFORMITIES

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ABSTRACT

Objective: The current reported rate of revision after surgery for adult spinal deformities (ASDs) is up to 45%. The aim of this study was to analyze patients with ASD who underwent failed primary surgery and required revision surgeries, in order to identify the reasons for failure and revision, while assessing possible prognostic criteria.

Materials and Methods: Thirty-two patients (27 women, 5 men) with a mean age of 69.8 years and follow-up period of 44.6 months were included. Before first revision, patients had a mean sagittal vertical axis (SVA) of 94.2 mm, lumbar lordosis (LL) of 33.3°, thoracic kyphosis (TK) of 35.3°, pelvic incidence (PI) of 56.9°, pelvic tilt (PT) of 27.8°, PI-LL of 24.9°, and coronal Cobb angle of 22°. Mean duration from the initial surgery until the first revision was 34.8 months. Fusion levels extended from T1 to S2. Twenty patients received transforaminal lumbar interbody fusion and 9 received anterior lumbar interbody fusion cages. Five patients underwent corpectomy combined with anterior cage. Three patients underwent ponte-, and 7 underwent pedicle subtraction osteotomies.

Results: After the last revision surgery, patients' sagittal plane parameters were significantly corrected ($p < 0.001$ for mean SVA, LL, PT, PI-LL mismatch and coronal Cobb). The most frequent reason for revision was found as advanced sagittal malalignment (ASM) in 29 patients (90.6%) followed by proximal junctional kyphosis (PJK) in 13 patients (40.6%). The most common surgical planning mistakes leading to revision were detected as proximal short fusion extending to thoracolumbar junction and not to T10, thus avoiding the stabilizing effect of the rib cage in 18 patients (56.3%); followed by no bone cement [polymethylmethacrylate (PMMA)] augmented screw application despite documented osteoporosis in 17 patients (53.1%).

Conclusion: The present study concluded that ASM and PJK were the most common reasons for revision following ASD surgery, while short proximal level of instrumentation and not placing PMMA augmented pedicle screws in patients with documented osteoporosis were the most common surgical planning pitfalls leading to revision.

Keywords: Adult spinal deformity, spinal deformity correction surgery, revision surgery, causes of failure, prognostic criteria, pitfalls of surgical planning

Introduction

Adult spinal deformity (ASD), which might be the result of the developmental deformities at younger ages or might occur de novo in older ages as a result of degenerative changes in addition to tumors, infections or traumas as well as to a wide range of other etiologies, constitute a serious public health problem especially for geriatric population by causing physical limitations leading to remarkably diminished quality of life⁽¹⁻³⁾. With the increase of life expectancy, the ideal treatment of ASD was shifted towards surgical options, especially for patients over the age of 60, and in cases accompanied by the progression

of spinal deformity and neurological compression resulting in intractable pain and severe physical limitations yielding a remarkable decline in quality of life^(4,5). Hence, the often extensive surgical treatment for ASD was aimed to provide clinical amelioration by reducing the pain together with the deformity and allowing the patients to be freed from physical restrictions providing an improved quality of life^(6,7). Surgeries for ASD were reported to be prone to risks including neurologic and cardiovascular complications⁽⁸⁾. Despite modern instrumentation techniques, rates of revision surgeries after primary ASD surgeries were detected to be on the rise, ranging from 9% to 45%, with implant failure, pseudoarthrosis and



adjacent segment disease and infection has been reported frequently as common reasons^(9,10).

Revision ASD surgery is a more technically demanding procedure as compared to primary surgery for ASD with 20 to 50% rates of complications^(11,12). The aim of this study was to analyze the potential risk factors of patients who underwent failed surgery due to ASDs and required revision surgeries, and to assess possible pitfalls regarding surgical planning, which might be associated with a potential revision surgery, in addition to the evaluation of the sagittal parameters, clinical and functional outcomes together with the health related quality of life of patients revised after failed primary surgery for ASD.

Materials and Methods

After obtaining institutional review board approval (İstanbul University, İstanbul Faculty of Medicine, Department of Orthopedic Surgery and Traumatology, Nr: 2019/068), a retrospective analysis was undertaken to detect a consecutive group of patients, who had a primary diagnosis of ASD and was operated in a single institution between 2010-2015. Two hundred and eighteen consecutive patients were detected to be operated in the aforementioned time interval in a single institution for the management of ASD.

Patients were enrolled in the present study on the basis of the following inclusion criteria: (1) Having a diagnosis of primary ASD; (2) being skeletally mature (>18 years of age); (3) having been revised after the primary operation for ASD for following reasons: Advanced sagittal imbalance, proximal junctional kyphosis (PJK), pseudoarthrosis, implant failure, infection, neurologic deficit; (4) having a minimum follow-up duration of 2 years; (3).

Exclusion criteria comprised: (1) Having a diagnosis other than primary ASD; (2) being skeletally immature (<18 years of age); (3) having only primary surgery for ASD with no revision; (4) having a minimum follow-up duration of less than 2 years; (5) having a diagnosis of acute trauma or tumor; (6) incomplete radiographic documentation; (7) being unwilling to participate in the study (Table 1).

As a result of the exclusion criteria 186 patients (143: Having only primary surgery for ASD with no revision; 18: Having a diagnosis of acute trauma-tumor; 11: Having a diagnosis other than primary ASD; 8: Incomplete radiographic documentation; 6: Unwilling to participate) were excluded from the study. The remaining 32 patients (27 women, 5 men) were included in the study (Table 2).

Radiographic Outcome Parameters (ROP)

Pre-operative and post-operative radiographic measurements were undertaken on standing whole spine posteroanterior and lateral X-rays. Computer tomography scans were utilized to evaluate implant placements and the stage of bony union; while magnetic resonance imaging was used to evaluate the current status of neural structures as well as the posterior ligamentous structures, if necessary and available.

The radiographic measurements regarding the sagittal parameters including sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), thoracic kyphosis (TK), lumbar lordosis (LL) and PI-LL mismatch together with coronal Cobb angle of the de novo scoliotic curves were undertaken by one independent senior spine surgeon with Surgimap software (Nemaris Inc., New York, NY, USA). X-Rays were taken pre-operatively, immediate postoperatively, at the 1st (first outpatient visit), 3rd and 6th month, annually and at the latest FU appointment.

Clinical Outcome Parameters

As patient reported outcome questionnaires including visual analogue scale (VAS) score for pain and Oswestry disability index (ODI) scores were applied to evaluate the clinical and functional outcomes pre-operatively and at the latest follow-up appointment. To assess the quality of life, SF-36 scores [mental component score (MCS) and physical component score (PCS)] were utilized.

Post-operative Rehabilitation Protocol

Patients were mobilized immediately after surgery and were allowed to return to daily activities after discharge, while return to sportive activities (including non-contact sports, swimming and light gym) were allowed after 6th post-operative month if they required to exercise.

Information of Informed Consent

All patients were taken informed consents, so that their pre-, intra- and post-operative data including the X-rays could be used for publication by hiding their identity.

Statistical Analysis

For the statistical analysis, SPSS software (Version 22.0; SPSS Inc, Chicago, IL, USA) was used. Data are expressed as mean +/- SD (standard deviation). The chi-square test and Fisher's exact test were used for the analysis of categorical variables and to compare different time points where appropriate. One-Way analysis of variance (ANOVA) was used to determine a significant difference at various time points. A p-value less than 0.05 was considered as statistically significant.

Results

Thirty-two patients (27 females, 5 males) with a mean age of 69.8 (range 60-84) and mean follow-up duration of 44.6 months (range 24-120) were included Table 3. Thirty-one patients were confirmed to have osteoporosis by using bone densitometry (96.9%).

Patients had primary diagnoses before the index surgery for ASD as: Isolated lumbar degenerative spondylolisthesis and sagittal malalignment in 2 patients (6.3%); degenerative spondylolisthesis and sagittal malalignment accompanied by neural compression due to disc herniation and/or spinal stenosis in 12 patients (37.5%); sagittal imbalance due to osteoporotic

vertebrae fractures (4 isolated lumbar, 1 lumbosacral junction, 1 multiple thoracic and lumbar) in 6 patients (18.7%); isolated coronal imbalance due to de novo scoliosis accompanied by lumbar disc herniation in 3 patients (9.4%); coronal imbalance due to combined sagittal imbalance and de novo scoliosis accompanied by lumbar disc herniation and/or spinal stenosis in 9 patients (28.1%) Table 3.

The rate of revision in the present study population was calculated as 14.7%. Patients had a mean time from the primary surgery to the first revision as 34.8 months (range 6-120), while 6 patients were revised more than 1 time (18.8%) (Table 3).

Main reasons for revision were detected as: Advanced sagittal imbalance in 29 patients (90.6%); PJK in 13 patients (40.6%); pseudoarthrosis (L5-S1:7, L4-L5:2, L3-L4:2) in 11 patients (34.4%); coronal imbalance due to de novo scoliosis in 8 patients (25%); implant failure (screw pull-out) in 7 patients (21.9%). In some patients, more than one pre-revision diagnosis was present at the same time (Table 4).

Main mistakes regarding the surgical planning leading to revision were detected as: Short proximal fusion extending to thoracolumbar junction and not to T10, thus avoiding the stabilizing effect of the rib cage in 18 patients (56.3%); no bone cement polymethyl methacrylate (PMMA) augmented screw application despite documented osteoporosis in 17 patients (53.1%); continuing sagittal imbalance as a result of the failed primary surgery and/or failed previous revision surgery in 15 patients (46.9%); avoiding to perform transforaminal lumbar interbody fusion (with cage) despite the instrumentation of L5-S1 in 7 patients (21.9%); problems regarding the design of the constructs leading to biomechanical failure in 5 patients (15.6%); application of kyphoplasty only without further correction of sagittal imbalance in 2 patients (6.3%). In some patients, more than one pre-revision surgical planning mistake was present at the same time (Table 4).

Revision procedures together with types of osteotomies, applied to the study population, were summarized in Table 5, Figure 1.

Patients' pre-operative mean VAS-back score of 7.4 (range 6-8) and VAS-leg score of 6.1 (range 5-7) were improved to 2.6 (range 2-4) and 2.8 (range 1-4), respectively at latest follow-up with high statistical significance ($p < 0.001$ for both). Pre-operative ODI scores of 68.4 (range 61-73) were detected to be improved to 21.3 (range 17-28) at latest follow-up with high statistical significance as well ($p < 0.001$). Pre-operative SF-36 MCS of 46.2 (range 45.8-49.7) and PCS of 45.1 (42.6-48.3) indicating health related quality of life were detected to be improved to 54.8 (range 52.6-57.2) and 55.7 (54.3-57.2) respectively at the latest follow-up with high statistical significance ($p < 0.001$ for both) (Table 6).

Sagittal parameters including SVA, PT and PI-LL mismatches were detected to be improved with high statistical significance at the last follow-up ($p < 0.001$ for all), together with the remarkable improvement of LL ($p < 0.001$), while the TK and PI at the last follow-up remained similar to pre-operative values ($p > 0.05$) (Table 7).

No intraoperative complications were acquired. All patients were neurologically intact early post-op and at the latest follow-up visit. Three patients at developed radicular pain with

Table 2. Flowchart of the study population

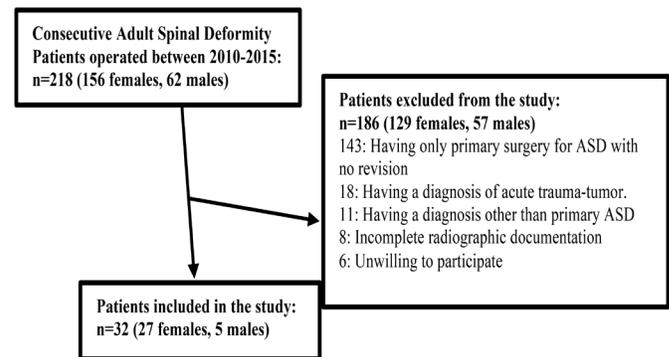


Table 1. Inclusion and exclusion criteria	
Inclusion Criteria	Exclusion Criteria
Having a diagnosis of primary adult spinal deformity (ASD)	Having a diagnosis other than primary adult spinal deformity (ASD)
Being skeletally mature (>18 years of age)	Being skeletally immature (<18 years of age)
Having been revised after the primary operation for ASD for following reasons: -Advanced sagittal imbalance -Proximal junctional kyphosis (PJK) -Pseudoarthrosis -Implant failure -Infection -Neurological deficit	Having only primary surgery for ASD with no revision
Having a minimum follow-up duration of 2 years	Having a follow-up duration of less than 2 years Having a diagnosis of acute trauma or tumor Incomplete radiographic documentation Being unwilling to participate in the study

no motor deficit early postoperative and were managed with conservative therapy. Two patients early post-operatively had superficial wound problems resolved with local wound care

and appropriate dressings. No major complications including implant failure or pseudoarthrosis were encountered at the latest follow-up visit.

Table 3. Data regarding the patients' characteristics

Number of patients	32 (27 females, 5 males)
Mean age of patients	69.8 (range 60-84)
Average duration of follow-up	44.6 (range 24-120)
Primary diagnoses of patients before the index surgery for ASD	12 Patients: degenerative spondylolisthesis and sagittal malalignment accompanied by neural compression due to disc herniation and/or spinal stenosis 9 Patients: Coronal imbalance due to combined sagittal imbalance and de novo scoliosis accompanied by lumbar disc herniation and/or spinal stenosis 6 Patients: sagittal imbalance due to osteoporotic vertebrae fractures (4 isolated lumbar, 1 lumbosacral junction, 1 multiple thoracic and lumbar) 3 Patients: Isolated coronal imbalance due to de novo scoliosis accompanied by lumbar disc herniation. 2 Patients: Isolated lumbar degenerative spondylolisthesis and sagittal malalignment
Rate of revision	14.7%
Mean time from the primary surgery to the first revision	34.8 months (range 6-120)
Patients revised more than one time	6 (18.8%)

Table 4. Reasons for revision-surgical planning mistakes leading to revision

Main reasons for revision	29 Patients (90.6%): Advanced sagittal imbalance 13 Patients (40.6%): Proximal junctional kyphosis (PJK) 11 Patients (34.4%): Pseudoarthrosis (L5-S1:7, L4-L5:2, L3-L4:2) 8 Patients (25%): Coronal imbalance due to de novo scoliosis 7 Patients (21.9%): Implant failure (screw pull-out)
Main mistakes regarding surgical planning leading to revision	18 Patients (56.3%): Short proximal fusion extending to thoracolumbar junction and not to T10, thus avoiding the stabilizing effect of the rib cage 17 Patients (53.1%): No bone cement (PMMA) augmented screw application despite documented osteoporosis 15 Patients (46.9%): Continuing sagittal imbalance as a result of the failed primary surgery and/or failed previous revision surgery 7 Patients (21.9%): Avoiding to perform TLIF (with cage) despite the instrumentation of L5-S1 5 Patients (15.6%): Problems regarding the design of the constructs leading to biomechanical failure 2 Patients (6.3%): Application of kyphoplasty only without further correction of sagittal imbalance in 2 patients

TLIF: Transforaminal lumbar interbody fusion, PMMA: Polymethyl methacrylate

Table 5. Revision procedures

Number of patients	Revision procedure
32 (100%)	Elongation of posterior fusion levels (between T1-S2)
12 (37.5%)	Extension of distal fusion level to S2 and performing spinopelvic fixation by using S2-iliac-alar screws
20 (62.5%)	Posterior interbody fusion by using TLIF with autograft filled cages (between L1-S1 at various levels)
9 (28.1%)	Anterior interbody fusion by using ALIF with autograft filled cages (at L5-S1 only)
5 (15.6%)	Total -/ hemicorpectomy + insertion of an autograft filled expandable cage (2: L1 hemicorpectomy, 1 T11 hemi-, T12 total, L1 hemicorpectomy, 1 L2-3 hemicorpectomy, 1 T12 hemi-, L1 total corpectomy)
24 (75%)	Bone cement (PMMA) augmented, fenestrated pedicle screws
3 (9.3%)	Ponte osteotomy (1 one level, 1 two levels)
7 (21.9%)	Pedicle subtraction osteotomy (PSO) (6 L3, 1 L3 and L4)

PMMA: Polymethyl methacrylate, ALIF: Anterior lumbar interbody fusion

Discussion

Revision procedures following primary surgeries or previous revisions of patients with ASD could be considered as one of the most challenging procedures among all operations in context of spine surgery, because these particular operations were reported to be prone to many complications and further revisions as a result of individual patients' characteristics, comorbidities and technical problems related to prior surgeries; thus they must be individualized in order to obtain optimal

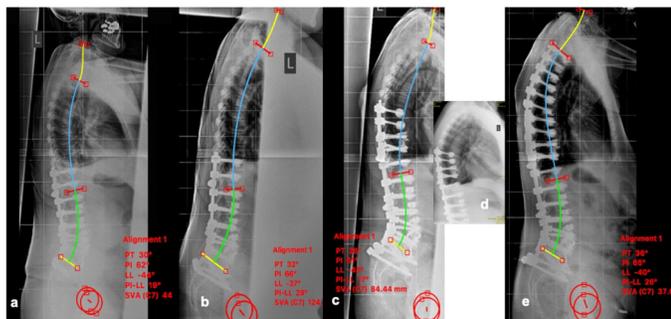


Figure 1. A 77-year old female patient primarily operated for ASD **a:** Standing early post-op lateral X-ray showing good global sagittal balance. **b:** 1st year postoperative. Advanced positive sagittal imbalance due to implant failure. Revision planned: Extension of the instrumentation to: T8-S2. S2-alar-iliac instrumentation. Spinopelvic fixation. PMMA augmented, fenestrated pedicle screw application. **c:** Standing early postoperative lateral X-ray showing restored global sagittal balance (1st revision). **d:** PJK detected 6 months after the first revision. 2nd revision planned: Proximal extension of the construct to T1. **e:** 1st year after the second revision. Global sagittal balance is restored ASD: Adult spinal deformity, PMMA: Polymethyl methacrylate, PJK: Proximal junctional kyphosis

results with the aim to reduce further revisions^(3,13).

The present study reported a rate of revision of 14.7%, which was in conjunction with the current literature reporting a wide spectrum of rates of revision ranging from 9% to 45%^(2,10). Hence, that particular wide range of rates of revision procedures were attributed by previous studies to individual patients characteristics including age, comorbidities, status of osteoporosis, as well as types of previously applied procedures, length of follow-up and advancements in surgical strategies^(1,2,9). Nevertheless it is an inevitable fact, that despite the surgical advancements including the application of modern instrumentation methods and advanced methods to treat osteoporosis, and osteobiotics, rates of revisions for ASD surgery were not detected to be improving in recent years^(11,13,14). The most common reason for revision was reported as implant failure by many studies. The results of the present study were also in conjunction with the current literature, with advanced sagittal imbalance due to implant failure was reported a common reason for revision. Implant failure was reported by Poorman et al.⁽¹⁵⁾ (43.1%), Pitter et al.⁽²⁾ (38.2%) and Martini et al.⁽³⁾ (36%) as the most common reason for revision. The present study reported an implant failure rate of 21.9% resulted in revision surgery especially attributed to screw pull-out in the fusion construct. In addition to that, in line with the numbers in the recent literature, among patients with advanced sagittal imbalance, 12 cases with a rate of 37.5% were found out to have implant failure as well. To overcome implant failure, proximal and distal extension of the construct with various rod combinations has been advised. While Kelly et al.⁽¹⁰⁾ reported to extend the construct to ilium as standard of care in revision

Table 6. Clinical and functional outcomes

	Pre-operative	At the last follow-up	p-value
Mean VAS-back	7.4 (range 6-8)	2.6 (range 2-4)	<0.001
Mean VAS-leg	6.1 (range 5-7)	2.8 (range 1-4)	<0.001
Mean ODI score	68.4 (range 61-73)	21.3 (range 17-28)	<0.001
Mean SF-36 MCS	46.2 (range 45.8-49.7)	54.8 (range 52.6-57.2)	<0.001
Mean SF-36 PCS	45.1 (range 42.6-48.3)	55.7 (range 54.3-57.2)	<0.001

VAS: Visual analogue scale, ODI: Oswestry disability index, MCS: Mental component score, PCS: Physical component score

Table 7. Radiographic outcomes

	Pre-operative	At the last follow-up	p-value
Mean SVA (mm)	94.2 (range -14.2-226.7)	46.5 (range 2-122.8)	<0.001
Mean coronal malalignment (mm)	81.4 (range 47.1/-121.9)	12.1 (range 3.5-62.1)	<0.001
Mean thoracic kyphosis (°)	35.3 (range 2-47)	37.9 (range 21-49)	0.37
Mean lumbar lordosis (°)	33.3 (range 3-54)	46.2 (range 20-71)	<0.001
Mean pelvic incidence (PI) (°)	56.9 (range 35-82)	57.3 (range 39-88)	0.42
Mean pelvic tilt (PT) (°)	27.8 (range 12-49)	24.4 (range 10-48)	<0.001
Mean PI-LL mismatch	24.9 (range 1-48)	13.4 (range 0-39)	<0.001
Mean coronal cobb angle (°)	22 (range 9-35)	3 (range 2-4)	<0.001

SVA: Sagittal vertical axis

surgery, Martini et al.⁽⁵⁾ recommended the application of delta-rod, tie-rod and kickstand rod configurations. We preferred to expand the construct to S2 and to apply S2-alar-iliac screws resulting in spinopelvic fixation in conjunction with the literature.

PJK was reported by many studies as the second most common (after implant failure) reason for revision after ASD surgery^(3,10), while Kim et al.⁽¹⁶⁾ reported PJK as the most common cause of revision surgery after primary surgery for ASD. The present study, in conjunction with the majority of the current literature also reported PJK as the second most common cause of revision surgery following primary surgery for ASD. To overcome PJK, more proximal extension of the instrumentation in addition to less constrained instrumentation at the transition zone and application of prophylactic vertebroplasty to adjacent level while augmenting those levels with bone cement has been suggested and reported varying rates of success regarding the prevention of PJK⁽¹⁷⁻²⁰⁾. In the present study, to prevent further PJK, proximal extension of the instrumentation while keeping it less constrained at the transition zone together with protection of the integrity of posterior ligamentous structures at the most proximal level of the construct was undertaken.

Pseudoarthrosis was reported to be one of the main causes for revision surgery after primary interventions for ASD^(2,15). Kelly et al.⁽¹⁰⁾ underlined, that pseudoarthrosis was the most common reason for the index revision surgery regarding patients with ASD. A repeat surgery rate of 10% was reported by some literature to underline pseudoarthrosis, which if multiple was likely to provide subsequent pseudoarthrosis especially at transitional areas (thoracolumbar and lumbosacral junctions) necessitating multiple revision surgeries^(21,22). To overcome pseudoarthrosis, the importance of anterior and posterior interbody fusion by using interbody cages filled with autografts was underlined^(3,14,21). It was also suggested, that the usage of bone morphogenetic protein might be helpful to achieve fusion with better quality^(15,23). In line with the current literature, the present study also utilized anterior and posterior interbody fusion by using autograft filled interbody cages especially at the level of L5-S1 as a routine in revisions for ASD, while L5-S1 pseudoarthrosis was also reported frequently necessitating L5-S1 interbody fusion and spinopelvic fixation^(24,25).

The usage of major osteotomies by aiming optimal correction in both coronal and sagittal planes has been accepted as a current standart of care in terms of primary and revision surgeries for ASD^(3,6,26). Among the high variety of osteotomies, pedicle subtraction osteotomy (PSO) has especially been used more frequently because of the high angular correctional efficacy up to 30°^(27,28). In the present study, in conjunction with the literature 7 PSOs and 3 ponte osteotomies were utilized.

Restoration of global sagittal alignment was reported to be of crucial importance by yielding improved clinical outcomes, while the magnitude of kyphosis -sagittal imbalance- was positively correlated with the worsening of quality of life^(6,13). Martini et al.⁽⁵⁾ showed a successful restoration of the global

sagittal balance with improved PT and PI-LL values, correlated with the improvement of clinical and functional scores (including VAS, ODI, SF-36), as did Hu and Lieberman⁽⁷⁾. The present study, in conjunction with the literature reported, that restoration of sagittal balance was accompanied with significantly improved VAS led/back, ODI and SF-36 MCS/PCS scores underlining the excellent clinical-functional outcomes together with remarkable improvements regarding the health related quality of life.

Study Limitations

One of the limitations of the present study is its retrospective nature. Another limitation is the relatively limited number of patients, which is owed to the strict inclusion criteria that were defined to obtain a homogenous group of patients.

Conclusion

The present study concluded, that 14.7% of patients who had a primary surgery for ASD required one or more revision surgeries. Advanced sagittal malalignment followed by PJK were the most frequent reasons for revision following ASD surgery, in addition to short proximal level of instrumentation and not placing PMMA augmented pedicle screws in cases with documented osteoporosis, which were detected as the most frequent surgical planning pitfalls leading to revision following primary ASD surgery. It was concluded, that with individualized surgical planning, the global sagittal alignment could be restored and excellent clinical and functional scores could be obtained.

Ethics

Ethics Committee Approval: Institutional review board approval was taken from İstanbul University, İstanbul Faculty of Medicine, Department of Orthopedic Surgery and Traumatology (Nr: 2019/068).

Informed Consent: A retrospective analysis was undertaken to detect a consecutive group of patients, who had a primary diagnosis of ASD.

Peer-reviewed: Internally peer-reviewed.

Authorship Contributions

Concept: T.P., Design: T.P., U.T., Data Collection or Processing: T.P., T.A., S.B., K.S., F.D., U.T., Analysis or Interpretation: T.P., U.T., Literature Search: T.P., T.A., S.B., K.S., F.D., U.T., Writing: T.P.

Conflict of Interest: The authors declare that they have no conflict of interest.

Financial Disclosure: The authors declared that this study received no financial support.

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