Staging in Circumferential Spinal Fusion for Adult Spinal Deformity: Systematic Review and Meta-Analysis

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Abstract

Background: Adult spinal deformity (ASD) is a prevalent condition often treated with circumferential spinal fusion (CF), which can be performed as Staged or Same-Day procedures. However, evidence guiding the choice between these approaches is lacking.

Objective: This systematic review and meta-analysis aimed to evaluate patient outcomes following Staged and Same-Day CF for ASD.

Methods: Following Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines, a comprehensive literature search was conducted in major databases. Eligible studies comparing Staged and Same-Day CF in adults with ASD were included. Data were extracted, and meta-analysis was performed for peri-operative outcomes and adverse events.

Results: Following exclusion criteria, seven studies were included for review. A total of 741 patients undergoing CF for ASD were included in the review (Staged: 331; Same-Day: 410). Four studies that had comparable outcomes were merged for the quantitative meta-analysis and split based on observed measures. Meta-analysis revealed significantly shorter operative time and hospital length of stay for Same-Day CF. Estimated blood loss and peri-operative adverse events trended towards significance favoring Same-Day CF. However, intra-operative and post-operative adverse event, reoperation, and readmission rates showed inconsistent findings between studies. Data quality assessment revealed a moderate degree of bias for all included studies.

Conclusions: Same-Day CF may offer advantages in terms of shorter operative time and hospital stay compared to Staged CF for ASD. However, there was marked heterogeneity in peri-operative outcomes reporting, and continuous variables were inconsistently presented. This underscored the need for standardized reporting of clinical variables and patient reported outcomes and higher evidence randomized controlled trials to elucidate the clinical superiority of either approach. Clinical Trial: In accordance with PRISMA-P guidelines, the protocol of the systematic review was registered on the International Prospective Register of Ongoing Systematic Reviews (PROSPERO) (CRD42022339764) and disseminated through the Journal of Medical Internet Research (JMIR) Research Protocols (International Registered Report Identifier (IRRID): PRR1-10.2196/4233)

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Review

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Adult spinal deformity (ASD) is a prevalent condition often treated with circumferential spinal fusion (CF), which can be performed as Staged or Same-Day procedures. However, evidence guiding the choice between these approaches is lacking. This systematic review and meta-analysis aimed to evaluate patient outcomes following Staged and Same-Day CF for ASD.

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Conclusion:

Same-Day CF may offer advantages in terms of shorter operative time and hospital stay compared to Staged CF for ASD. However, there was marked heterogeneity in peri-operative outcomes reporting, and continuous variables were inconsistently presented. This underscored the need for standardized reporting of clinical variables and patient reported outcomes and higher evidence randomized controlled trials to elucidate the clinical superiority of either approach.

Keywords: Adult; Circumferential Fusion; Humans; Scoliosis; Spinal Curvature; Spinal Fusion

1. INTRODUCTION

Adult spinal deformity (ASD) is defined as abnormal curvature of the spine and is becoming increasingly prevalent, affecting up to 68% of the elderly population.[1,2] ASD is a complex spectrum of spinal pathology, ranging from deformities such as lordosis, kyphosis, or scoliosis of the lumbar and thoracic spinal column. Although untreated adolescent ASD does occur, it typically presents in patients aged >60 due to factors such as age-related spinal degeneration or reduced bone density.[1,3]

Individuals with ASD can undergo expectant (observation-alone), non-operative, or operative therapies. At present, there is no high-quality evidence to support the decisions surgeons and patients face in treatment selection.[4] In past years, pain management and physical therapy were the preferred treatment options for ASD due to the high risk of adverse events, prolonged recovery time, and financial burden associated with surgical intervention.[1,5] If non-surgical approaches fail to improve patients' quality of life, surgical intervention is often considered. Multicenter retrospective cohort studies previously showed an improvement in patient reported outcomes following surgical management of ASD.[3,6] Indications for surgery include 1) progressive curvature of spine with sagittal or coronal imbalance 2) significant loss of pulmonary function caused by the misalignment and deformity, 3) loss of function due to pain associated with spinal curvature.[7-10] These are weighted against the patient co-morbidities and risks of operation.[11]

Long-segment surgical management by Circumferential Spinal Fusion (CF) has increased in popularity due to its added stability granted by both anterior and posterior fixation of the spinal column.[12] CF attempts to remedy the limitations of lateral approaches alone, such as the need for intra-operative patient repositioning, which increases operative time and puts the patient at risk for adverse events due to longer time under anesthesia.[13-15] ASD can be treated by CF in two primary ways: Staged and Same-Day. Staged fusions occur on two distinct operative days, while Same-Day are completed within a single session. Staging is largely determined by surgeon preference and case complexity, which can cause variability in clinical management of ASD. To our knowledge, there has not been a review of published literature on staging in CF. This systematic review and meta-analysis aim to assess and quantify the patient outcomes after Staged and Same-Day CF for ASD to guide operative decision-making and patient selection.

2. METHODS

Guidelines, Protocol, and Registration

The design and reporting of this study were supported by the following guidelines: the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) and Preferred Reporting Items for Systematic review and Meta-Analysis Protocols (PRISMA-P).[16,17] In accordance with PRISMA-P guidelines, the protocol of the systematic review was registered on the International Prospective Register of Ongoing Systematic Reviews (PROSPERO) (CRD42022339764) and disseminated through the Journal of Medical Internet Research (JMIR) Research Protocols (International Registered Report Identifier (IRRID): PRR1-10.2196/4233), with the protocol being published before any data was collected.[12]

Eligibility Criteria

The PICO (population, intervention, comparison, outcome) framework was used to formulate inclusion criteria:

- Population: adults with adult spinal deformity;
- Intervention: Staged CF surgery;
- Comparison: Same-Day CF surgery;
- Outcomes: peri-operative outcomes (estimated blood loss, operative time, length of hospital stay), adverse events, infection rates, and hospital readmissions/re-operations

Studies that do not differ in surgical timing (Staged vs. Same-Day), non-human or adolescent patient populations, reviews, conference abstracts, single case studies, or technical notes were excluded from analysis. Further, only studies originally published in English were considered.

Search Strategy

Databased explored included PubMed/Medline, Embase, Cochrane Central Register of Controlled Trials, Web of Science and Scopus. Literature search was conducted in accordance with the PRISMA guidelines on August 02, 2023. We utilized a complex search string that was modified and fitted to the unique search functions of each queried databases (**Supplement 1**). Additional searching through gray literature and reference lists was conducted to identify supplementary studies not initially captured by the database query.

Data Selection and Extraction

Articles and full text were screened, and data extracted utilizing Covidence.[18] Two reviewers

(FCO and ME) independently screened all articles, with a third reviewer (MMD) resolving any conflicts. The following data were extracted: authors, publication year, location, number of patients, age, study type, population details, surgery details, and results, including intra-operative adverse events, post-operative adverse events, post-operative infection, peri-operative adverse events, hospital length of stay (LOS), intensive care unit LOS, re-operation, re-admission and patient reported outcomes.

Data Quality

The ROBINS-I tool was utilized to assess the risk of bias in the included non-randomized studies, covering bias due to confounding variables, patient selection, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes, and selection of reported results.[19] Two reviewers (FCO and JG) independently scored all domains, with a third reviewer (MMD) resolving any conflicts. Robvis was used for figure generation.[20]

Data Synthesis

Studies with comparable outcomes were merged for the quantitative meta-analysis and split based on observed measures. After conducting a qualitative evaluation, we determined that there was sufficient data to perform meta-analysis. RevMan 8.4 (Cochrane) using random-effects modeling was used for all quantitative analyses.[21] Standard differences in surgical time, blood loss, intra-operative adverse events, post-operative adverse events, post-operative infection, any adverse events, hospital LOS, intensive care unit LOS, reoperation and readmission were the endpoints of the meta-analysis.

3. RESULTS

Study Identification

In our search (**Fig. 1**), we identified 5199 unique articles by searching PubMed/Medline, Embase, Cochrane Central Register of Controlled Trials, Web of Science and Scopus, which were included for abstract screening, 64 of which were forwarded for full-text screening. After full text review seven original articles were included in the data extraction process and four of them in quantitative analysis.[22-28] Articles were excluded during full text review for the following reasons: wrong comparator (n=19), wrong patient population (n=19), pediatric population (n=11), wrong outcomes reported (n=5), wrong study design (n=4).

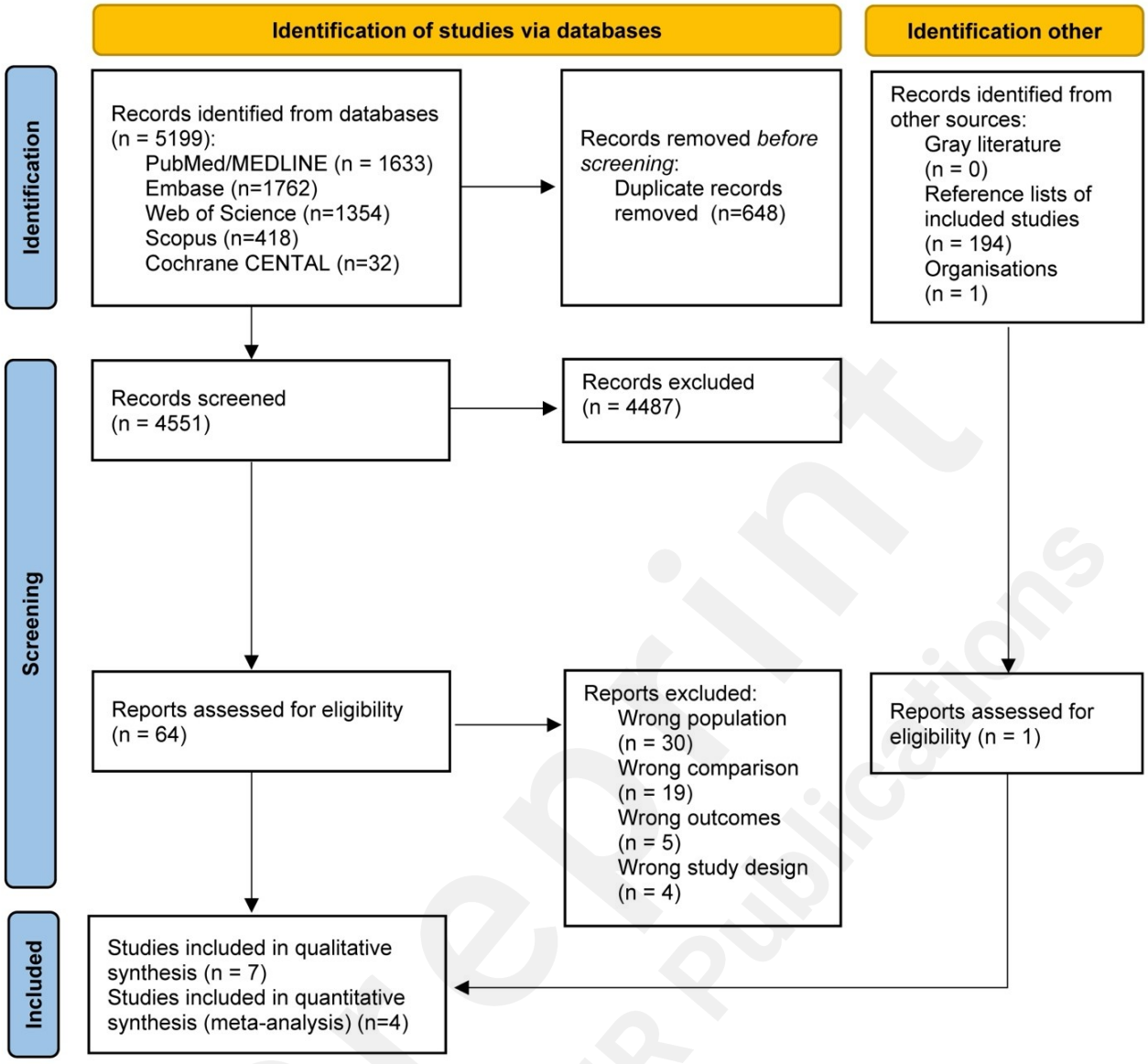

Figure 1. Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) flow diagram.

Baseline Parameters

Six of the studies included were conducted in the United States,[22-26,28] while one was conducted in Japan.[27] The included studies describe a total of 741 patients undergoing either Staged (n=331) or Same-Day (n=410) CF for ASD. 297 Patients underwent anterior lumbar interbody fusion (ALIF), 408 Patients underwent lateral interbody fusion (extreme lateral interbody fusion (XLIF), direct lateral interbody fusion (DLIF)/lateral lumbar interbody fusion (LLIF)), 54 Patients underwent either LLIF or transforaminal lumbar interbody fusion (TLIF) and all 741 patients underwent posterior spinal fixation (PSF). The average number of fused vertebrae across studies ranged from 4.4 to 10 (SD 3.9). The largest variation between groups within a study ranged from 7.3 (SD 3.1) in Same-Day vs. 10 (SD 3.9) in the Staged group. The follow-up period over all included studies ranged from 1 to >36 months, and the average age of patients ranged from 58.8 to 72.3 years. The patients included in

the article of Masuda et al. and Albayar et al. were inverse probability weighted (**Table 1.**).[22,27]

Table 1: Patient demographics and significant results of included studies

Authors, Year Location	No. of Pts	Age (mean, range, median)	Study type	Population details and differences	Surgery details	Results
Albayar et al., 2023[22]	100	58.8 (9.0)	Retrospective cohort study, Inverse probability weighted	Patients >18 years at the time of surgery and diagnoses of ASD undergoing (ALIF), and open posterior lumbar or thoracolumbar (PSF)	Staged ALIF, and open posterior lumbar or thoracolumbar PSF, post. Vertebrae fused: 10 (SD 3.9)	Staged: (n=44), 1351.7ml (869), LOS 10.5d (5), IOAE n=6, POAE n=30, REOP n=10, POI n=5, READ n=10
United states		62.0 (11.9)			Same-Day ALIF, and open posterior lumbar or thoracolumbar PSF, post. Vertebrae fused: 7.3 (SD 3.1)	Same day: (n=56), EBL 1127.6ml (945.4), LOS 6.2d (3.1), IOAE n=2, POAE n=30, REOP n=8, POI n=1, READ n=8
Anand et al., 2014[23]	50	61 (20-85)	Retrospective cohort study	Patients with adult idiopathic scoliosis corrections undergoing cMISS, Cobb angle of greater than 30 but less than 75 degrees	Staged DLIF and L5-S1 XLIF followed by PSF; mean Vertebrae fused: 7 (range 4-15)	Staged: (n=37), EBL 763 ml (range: 25-2500), OR Time 482 min (range: 83-546)
United States					Same-Day DLIF and L5-S1 XLIF followed by PSF; mean Vertebrae fused: 7 (range 4-15)	Same day: (n=13), EBL 613ml (range: 150-1500), OR Time 351min (range: 176-510)
Anand et al., 2013[24]	71	64	Retrospective cohort study	Adults with scoliosis undergoing cMISS, 2 or more levels	Stage combination of DLIF and XLIF with PSF; mean Vertebrae fused: 4.4	Staged: (n=36), EBL 671ml, OR Time 426min
United States					Same-Day combination of DLIF and XLIF with PSF; mean Vertebrae fused: 4.4	Same day: (n=35), EBL 412ml, OR Time 291min
Arzeno et al., 2019[25]	92	68 (61-78)	Retrospective cohort study	Patients with ASD, undergoing anterior (including lateral and anterolateral approaches) and PSF of at least 5 levels	Staged circumferential spinal fusion (anterior, posterior), Ponte osteotomy n=39, Three- column osteotomy n=7, Decompression n=34 mean Vertebrae fused: 8 (95% CI 5-9)	Staged: (n=45), mean LOS 9d, REOP n=5, READ n=1, POI n=2, PEAE n=12
United States				Groups differ in: Approach, Ponte osteotomy, Three-column osteotomy, O-Arm, Neuromonitoring, Decompression, No. of posterior levels, fused; No. of osteotomy levels, mean; No. of decompression levels	Same-Day circumferential spinal fusion (anterior, posterior), Ponte osteotomy n=24, Three- column osteotomy n=1, Decompression n=16; mean Vertebrae fused: 9 (95% CI 9-9)	Same day: (n=47), mean LOS 6d, REOP n=7, READ n=6, POI n=3, PEAE n=7
Harris et al., 2021[26]	87	61 (11)	Retrospective cohort study	Patients with ASD who underwent long PSF (more than five levels fused, with fusion to the pelvis)	Staged circumferential -ALIF, PSF, mean Vertebrae fused: 8.7 (SD 0.48)	Staged: (n=41), ODI 45±17, SRS-22r 2.8±0.6
United				Groups differ in:	Same-Day circumferential - ALIF,	Same day: (n=46), ODI

States				Previous spine surgery, Scoliosis/kyphosis, Pseudarthrosis, Pelvic incidence	PSF, mean Vertebrae fused: 7.4 (SD 2.4)	48±15, SRS-22r 2.8±0.6
Masuda et al., 2023[27]	287	72.3	Retrospective cohort study, Propensity score weighted	Patients with ASD, ≥four fused levels and at least one level using LLIF, and presence of at least one spinal deformity marker: scoliosis Cobb angle≥20°, sagittal vertical axis≥5 cm, pelvic tilt≥25°, pelvic incidence minus lumbar lordosis angle≥10°, and/or thoracic kyphosis≥60°	Staged circumferential - LLIF, PSF, mean Vertebrae fused: 7.7 (SD 2.3)	Staged: (n=101), EBL 642.5ml (550.5), OR Time 541.3min (124.1), LOS 42d (25), IOAE n=11, POAE n=11, REOP n=11, POI n=4, AAE n=22
Japan					Same day circumferential - LLIF, PSF, mean Vertebrae fused: 6.2 (SD 2.4)	Same day: (n=186), EBL 722.2ml (612.6), OR Time 479.9min (128.5), LOS 34.1d (18.2), IOAE n=17, POAE n=23, REOP n=19, POI n=5, AAE n=40
Than et al., 2019[28]	54	67.3	Retrospective cohort study	Patients with ASD, coronal Cobb angle >20, SVA > 5 cm, PT> 20 , PI-LL> 10 , and/or thoracic kyphosis >60	Staged MIS LLIF and/or MIS TLIF with PSF, mean Vertebrae fused: 5.4	Staged: (n=27) REOP n=4, POI n=0, PEAE n=9
United States					Same-Day MIS LLIF and/or MIS TLIF with PSF, mean Vertebrae fused: 5.3	Staged: (n=27) REOP n=7, READ n=1, POI n=1, PEAE n=8

ALIF: Anterior Lumbar Interbody Fusion; CI: Confidence Interval; cMISS: Circumferential Minimally Invasive Spinal Surgery; DLIF: Direct Lateral Interbody Fusion; EBL: Estimated Blood Loss; IOAE: Intraoperative Adverse Events; LL: Lumbar Lordosis; LLIF: Lateral Lumbar Interbody Fusion; LOS: Length of Stay; MIS: Minimally Invasive Surgery; OR: Operating Room; ODI: Oswestry Disability Index; PEAE: Peri-operative Adverse Events; PI: Pelvic Incidence; POAE: Postoperative Adverse Events; POI: Post-operative Infection; PSF: Posterior Spinal Fusion; PT: Pelvic Tilt; Pts: Patients; READ: Readmission; REOP: Reoperation; SRS-22r: Scoliosis Research Society-22 revised; SD: Standard Deviation; SVA: Sagittal Vertical Axis; TLIF: Transforaminal Lumbar Interbody Fusion; XLIF: Extreme Lateral Interbody Fusion.

Quantitative Analysis

Of the included studies, four compared estimated blood loss (EBL) in the relevant groups, with three of them presenting a lower EBL (mean between 412-1127ml) in Same-Day surgery compared to Staged (mean between 642-1351ml).[22-25] Meta-analysis shows a nonsignificant advantage for Same-Day surgery **(Fig. 2A**). Only two studies that measured EBL were included in the quantitative analysis because of inconsistencies in reporting, where some did not report variables as measures of variance which made pooling in these instances not feasible. Three studies compared operative time between Staged and Same-Day CF, with all of them reporting a lower mean operative time for Same-Day CF (mean between 291-479min) compared to Staged CF (mean between 426-541min).[23-25] Just one group reported mean and standard deviation for OR Time, thus restricting the potential for a

quantitative analysis.

Three studies comparatively evaluated the hospital LOS.[22,23,26] All three studies consistently found that the mean LOS was less for Same-Day CF (mean between 6-34.1 days) in comparison to Staged CF (mean between 9-42days). Meta-analysis clearly presented a shorter LOS in patients undergoing Same-Day CF compared to Staged CF (**Fig. 2B**).

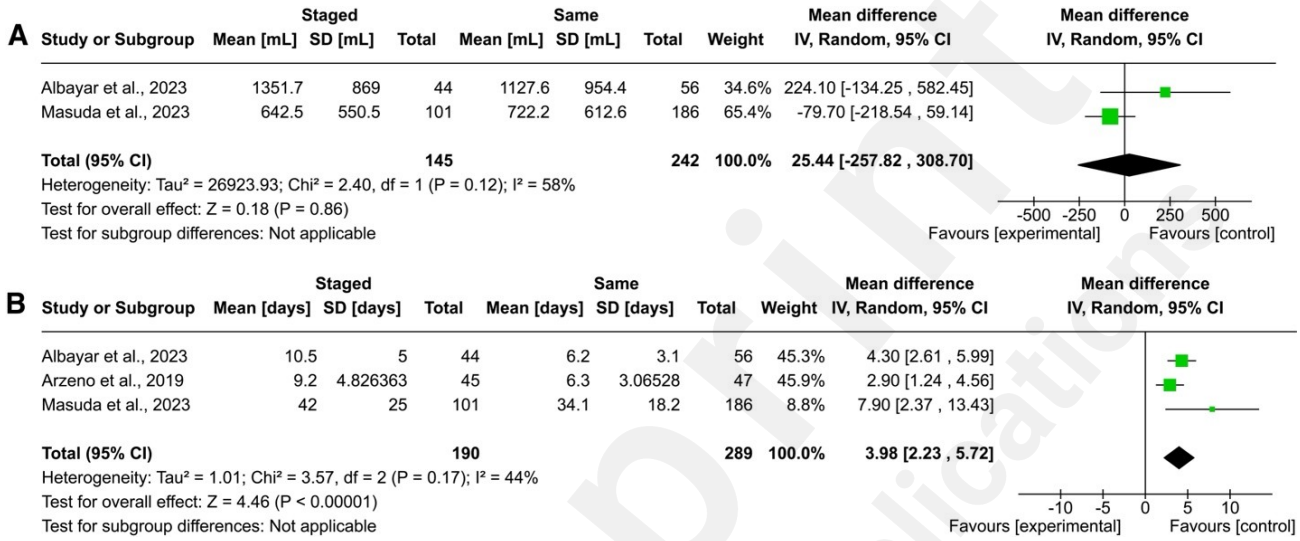

Figure 2. Forest plots comparing estimated blood loss (A) and hospital length of stay (B) between patients who underwent Staged or Same-Day circumferential spinal fusion for adult spinal deformity.

Two of the seven studies compared intra-operative and post-operative adverse events between Staged and Same-Day CF procedures.[22,27] Both Masuda et al. and Albayar et al. reported more intra-operative adverse events in Staged CF (10.9% and 13.6% respectively) compared to Same-Day CF (9.1% and 3.6% respectively); however, the meta-analysis failed to show a statistically significant difference between the groups **(Fig. 3A).** Masuda et al. reported less post-operative adverse events in Staged CF (10.9 vs 12.4%), while Albayar et al. presented a lower incidence in Same-Day CF (53.6 vs 68.2%), without a significant difference in the meta-analysis **(Fig. 3B)**.[22,27] Four studies measured any peri-operative adverse events.[22,23,27,28] The overarching analysis showed a higher incidence of adverse events in Staged CF over all studies; however, the meta-analysis did not show significance (**Fig. 3D**).

Four of the included studies compared re-operation and post-operative infection rates between patient groups.[22,23,27,28] Albayar et al. and Masuda et al. showed a slightly lower post-operative infection in Same-Day CF vs. Staged CF (4.4 vs 6.4% , 2.6 vs 4% and 1.7 vs 11.4% respectively),

while Than et al. showed a lower post-operative infection in Staged CF (0% vs 3.7%) **(Fig. 3C**). [22,23,27,28] While Arzeno et al. and Than et al. reported a lower re-operation in patients undergoing Staged CF (11.1 vs 14.9% and 14.8 vs 25.9% respectively,[25,28] Masuda et al. and Albayar et al. reported less re-operation in patients undergoing Same-Day CF vs. Staged CF (10.2 vs 10.9% and 14.2 vs 22.7% respectively).[22,27] However, none of these differences in re-operation reached statistical significance in either the original respective studies or our meta-analysis **(Fig. 3F).**

Re-admission rates reported by Arzeno et al. and Albayar et al. demonstrated diverging results. [22,25] Arzeno et al. found a lower re-admission for Staged CF vs. Same-Day CF (2.2 vs 12.8%), while Albayar et al. reported a higher re-admission in Staged CF vs. Same-Day CF (22.7 vs 14.3%). The meta-analysis did not indicate a conclusive result (**Fig. 3E**). Harris et al. is the only author reporting on either Oswestry Disability Index (ODI) or Scoliosis Research Society Score (SRS-22r), showing a better outcome measured by the ODI in Same-Day CF and no difference in SRS-22r.[26]

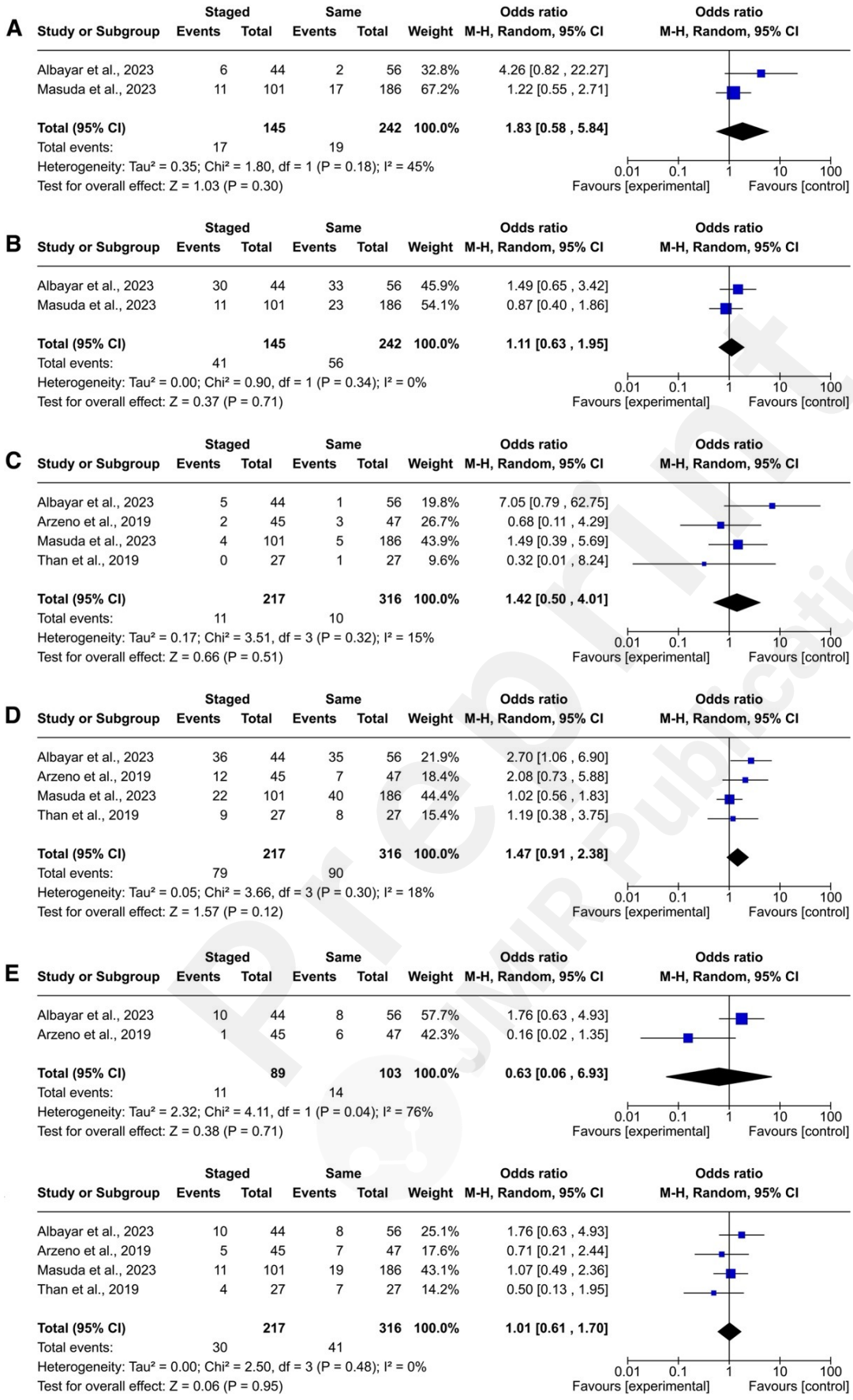

Figure 3. Forest plots comparing intra-operative adverse event (A), post-operative adverse event (B), post-operative infection (C), peri-operative adverse event (D), 30-day readmission (E), and re-operation (F) rates between patients who underwent Staged or Same-Day circumferential spinal fusion for adult spinal deformity.

Risk of Bias Analysis

There was a moderate degree of bias for all included studies (**Fig. 4**).

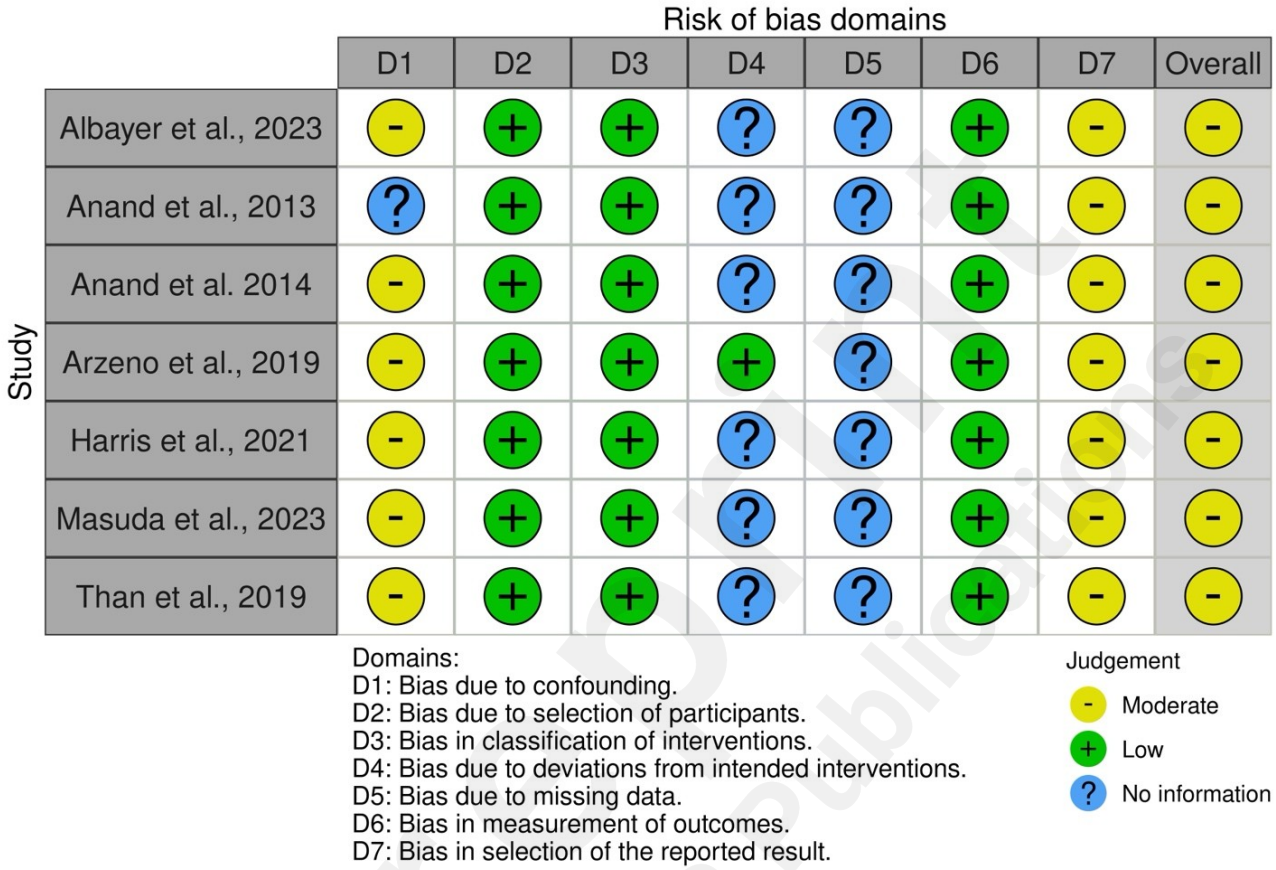

Figure 4. Robins-I traffic light plot of included studies.

4. DISCUSSION

In the present systematic review and meta-analysis, we compared differences in clinical variables and patient outcomes for individuals undergoing Staged or Same-Day CF in seven included studies. There was marked differences between patient populations and the clinical outcomes that were reported in each. Our quantitative results are paradoxical as there were inconsistencies between studies in the Staged and Same-Day subgroups for certain reported outcomes, while other findings had stronger conclusive evidence. Due to the apparent differences in consensus, the research included in the following discussion is organized according to the consistency of results.

4.1 Mixed Findings

Heterogeneity in meta-analyses grants the opportunity to examine variable factors that may be leading to the results. There were several reported outcomes that yielded inconclusive evidence in this study. Adverse event rates were reported by authors in several ways, with some splitting between intra-operative or post-operative adverse events, while others reported any adverse event throughout the peri-operative course. Two studies reported more intra-operative adverse events in Staged CF, but the meta-analysis failed to show a statistically significant difference. Further, one study presented a lower post-operative adverse events rate during Staged CF, while a different group found a higher rate in Staged. When all peri-operative adverse events were instead considered, every study reported a higher incidence in Staged CF, and this result trended toward significance. Vastly different conclusions depending on the stage of surgery which the adverse events are considered illuminates the need for greater consistency in reporting outcomes.

The Centers for Medicare & Medicaid Services (CMS) targeted 30-day re-admission rates as a source of unnecessary costs.[29] A study conducted by McCarthy et al. found the total hospital costs to surgically treat ASD averaged $120,394, with primary surgery averaging $103,143, and total readmission costs of $67,262 for their cohort.[30] The high costs associated with spine surgery make patient re-admission and re-operation lucrative targets. There is profound heterogeneity in re-operation and re-admission rates that depend on several factors, such as patient demographics, procedure types, and institutional factors. A recent systematic review found the 30-day re-admission rate in spine surgery to be 4.2% and 7.4%.[31] In the present review, 2 studies reported re-admission with diverging results. Arzeno et al. found a lower re-admission for Staged CF, while Albayar et al. reported a higher re-admission for Same-Day CF.[22,25] Likewise, four studies reported re-operation with a split in consensus.[22,25,27,28] Given the small number of studies that measured re-operation and re-admission, the results from our meta-analysis were inconclusive. The limited ability to pool data speaks to the lack of reporting for these metrics in the literature.

It was also uncommon for the included studies to report specific reasons that re-operation or re-admission occurred. As re-admission depends on a many variables including on patient comorbidities, initial risk, or operative adverse events, it is crucial for authors to include these measures in future comparative studies for stronger subgroup analyses. Post-operative infection is also a driver leading to re-operation or re-admission, and it is also with additional healthcare costs.[32] A recent meta-analysis found the pooled incidence of surgical site infection in 22,475 patients to be 3.1%.[33] Our included studies also reported a low incidence of post-operative infection;

however, there were inconsistencies as three out of the four groups found a lower post-operative infection in Same-Day CF.[22,25,27,28] There are several risk factors for post-operative infection that may lead to the heterogeneity. Farshad et al. found that intra-operative EBL was a risk factor in post-operative infection.[34] Some studies found BMI to be predictors of post-operative infection, although this result remains controversial.[35-37] The discrepancies seen in this review may stem from variations in surgical techniques, peri-operative antibiotic prophylaxis, and patient-specific risk factors. Therefore, a comprehensive understanding of the determinants of post-operative infection is essential for optimizing patient outcomes.

4.2 Associations of Operative Variables in CF Staging

For highly invasive spine surgeries, such as long-segmented CF for ASD, patients may require extended resource utilization.[38] Surgical operative time and LOS are critical metrics in evaluating the efficiency and resource utilization of staging in CF. Shorter surgical times are generally associated with reduced intra-operative adverse events, lower anesthesia-related risks, and decreased blood loss, thus contributing to improved patient safety and outcomes.[15,39] Peng et al. conducted a meta-analysis on correlations between operative time and post-operative infection, and they concluded that there was a four-fold increase in post-operative infection risk for operations greater than 3 hours.[40] The studies included in our review all found a lower mean operative time for Same-Day CF.

Shorter LOS is also desirable as it minimizes healthcare resource utilization and lowers costs.[41] Further, early mobilization and discharge are associated with improved patient satisfaction and reduced psychological stress.[42] However, reducing LOS has also been associated with an increasing re-admission rate at the population level.[43] Our meta-analysis found a significantly lower LOS for Same-Day CF compared to Staged CF. This difference in LOS may be attributed to the cumulative effect of multiple hospital admissions, prolonged recovery periods between surgeries, and the need for additional preoperative preparation in Staged CF. While the lower operative time and LOS results in patients undergoing Same-Day CF seem intuitive, it is important to interpret them cautiously, considering potential factors such as patient selection, discharge criteria, and institutional practices that may differ between studies. Moreover, while shorter operative time and LOS may reduce healthcare costs and improve resource allocation, it should not compromise patient safety or post-operative care quality.

4.3 Study Limitations

There are several limitations to the present study and the articles included in this review. First, the limited literature comparing Staged and Same-Day CF resulted in only seven articles being included, which reduced the statistical power of the meta-analysis as only four qualified for quantitative analysis. All the included articles are retrospective cohort studies with a level of evidence of III or II, and only two used inverse probability weighting to control for between-patient differences. Consequently, there was a moderate potential for bias which limited our ability to reach generalizable conclusions. To elucidate the differences in surgical treatment options for CF, it will be necessary to investigate staging in level I or II randomized controlled trials. Without randomized control trials, it is difficult to adjust for surgeon preference bias. Each study also demonstrated heterogeneity with respect to the patient outcomes reported, further limiting the ability for robust statistical analysis. Continuous variables were generally poorly reported, since many did not report measures of variance such as mean and standard deviation, but rather mean/median and range (min-max or interquartile range). This made pooling in those instances not feasible, limiting the generalizability of results. Further, only one group presented patient reported outcomes, such as ODI, which are a standardized clinical variable that can be useful to measure subjective pain and disability. Novel studies should aim to standardize the variables being reported, so future meta-analyses will have wider samples to yield more conclusive evidence for staging differences in CF. In doing so, the mixed results presented in this study can be further assessed to support wider implementation of either Staged or Same-Day CF.

4.3 Conclusion

Here, we present the first systematic review and quantitative meta-analysis on staging in CF to treat patients with ASD. Operative time and hospital LOS were significantly lower in Same-Day CF surgery, with EBL and peri-operative adverse events also trending towards significance. However, there was heterogeneity in additional operative measures, such as intra/post-operative adverse event rates, re-operation, and re-admission, and no differences were found in our meta-analysis. Based on our results, it is suggested that Same-Day CF is advantageous as a potential time-save with patients spending less time in the operating room and hospital, potential saving costs. However, it is still unclear whether either Same-Day or Staged CF provides a clinical advantage for patient outcomes. Additional level I and II RCTs should be conducted to elucidate the associations between these variables and provide stronger evidence in favor of either approach.

Authors' Contributions

WCW is the guarantor of the study. MMD and WCW led conceptualization, data acquisition, analysis, drafting and revision of the manuscript. RWT, JG, GS, DC, HSA, CAW, TG, JDA, JLG, and BJG contributed to data acquisition, analysis, and drafting. Independent review was performed by FCO, ME, and MMD. All authors contributed to analysis, interpretation, and drafting. JHS, JWY, AKO, and WCW contributed critical guidance at all stages of the study. The manuscript was reviewed, edited, and its final version approved by all authors.

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Conflicts of Interest

In the past 36 months, AKO has received consulting fees from Medacta and Johnson and Johnson, and has served as an E2M ad-hoc reviewer for the Journal of Neurosurgery Publishing Group (JNS PG), with no relation to this work. Additionally, within the same period, JWY has received a grant from Johnson and Johnson; consulting fees from Medyssey, TrackX, Richard Wolf, and Johnson and Johnson; holds patents planned, issued, or pending with Kinesiometrics and MedCyclops; and has served in a leadership role on the Scientific Program Committee of the AANS/CNS Joint Section on Disorders of the Spine and Peripheral Nerves, with no relation to this work. All other authors report no conflict of interest.

Data Availability

All data generated or analyzed during this study are included in this published article

Abbreviations

ALIF: Anterior Lumbar Interbody Fusion
ASD: Adult Spinal Deformity
CF: Circumferential Fusion
CMS: Centers for Medicare & Medicaid Services
DLIF: Direct Lateral Interbody Fusion
EBL: Estimated Blood Loss
ICU: Intensive Care Unit
IRRID: International Registered Report Identifier

JMIR: Journal of Medical Internet Research

LLIF: Lateral Lumbar Interbody Fusion

LOS: Length of Stay

ODI: Oswestry Disability Index

PICO: Population, Intervention, Comparison, Outcome

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PROSPERO: International Prospective Register of Ongoing Systematic Reviews

PSF: Posterior Spinal Fixation

RevMan: Review Manager

ROBINS-I: Risk Of Bias In Non-randomized Studies - of Interventions

SRS-22r: Scoliosis Research Society-22r

TLIF: Transforaminal Lumbar Interbody Fusion

XLIF: Extreme Lateral Interbody Fusion

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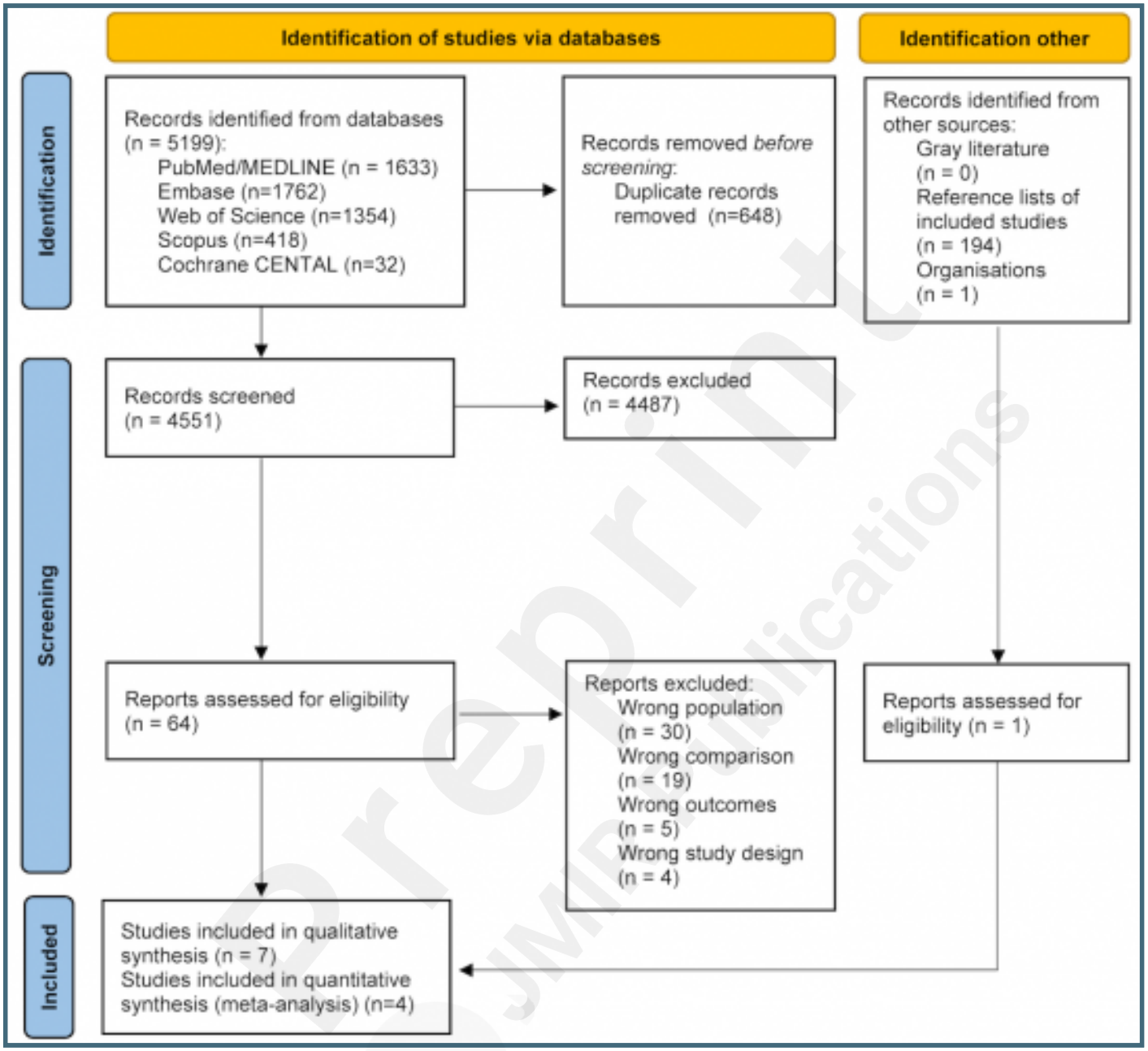
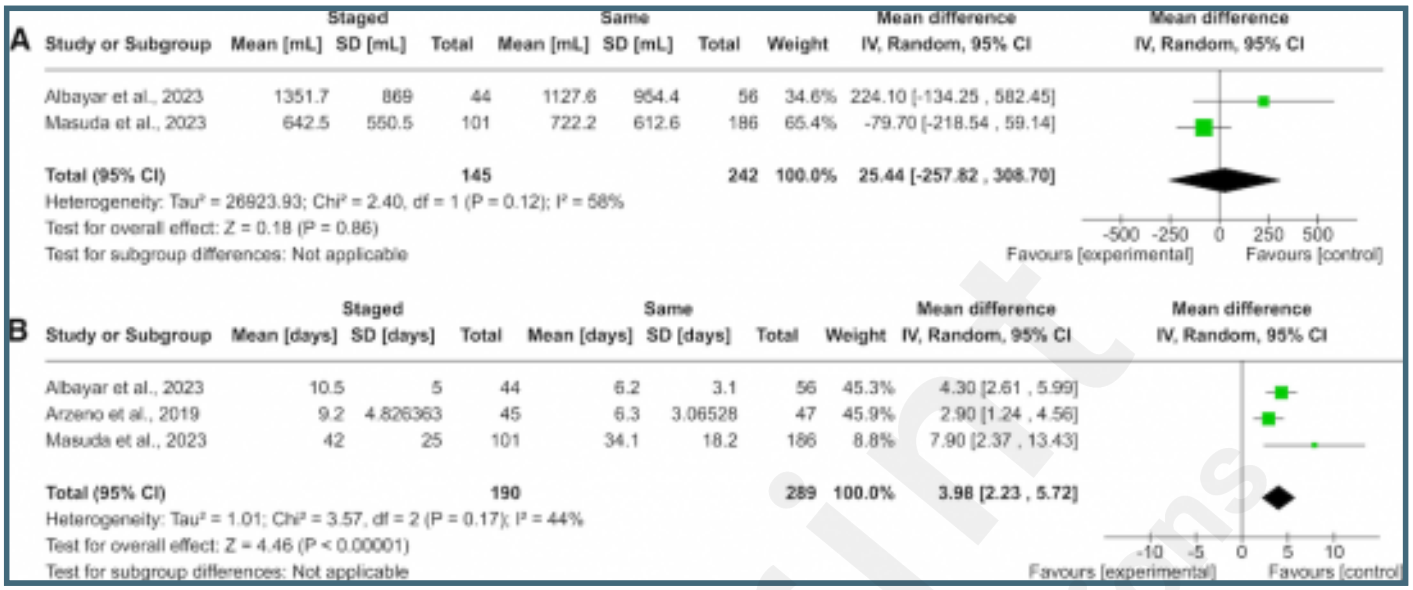
Supplementary Files

Figures

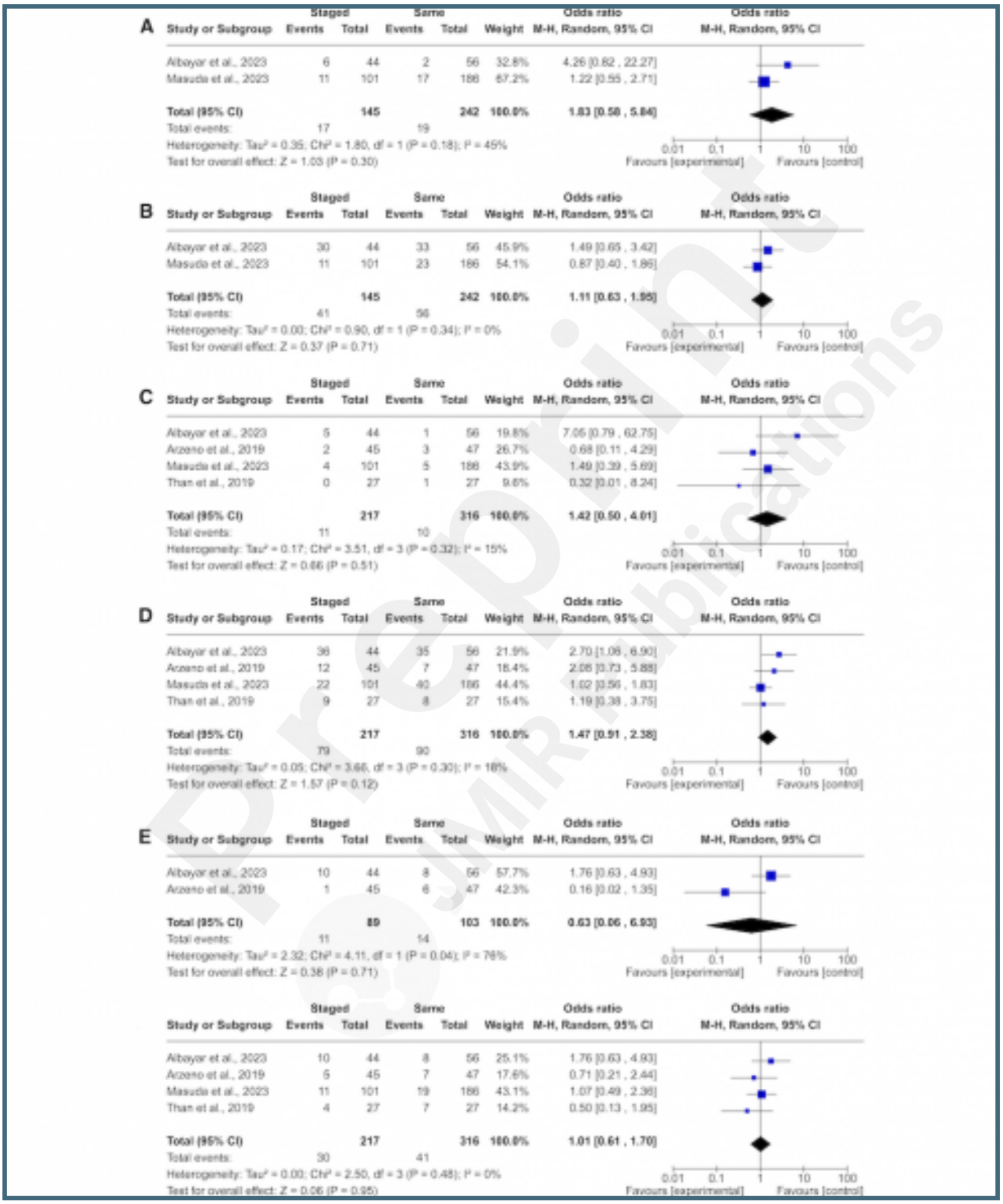
Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) flow diagram.



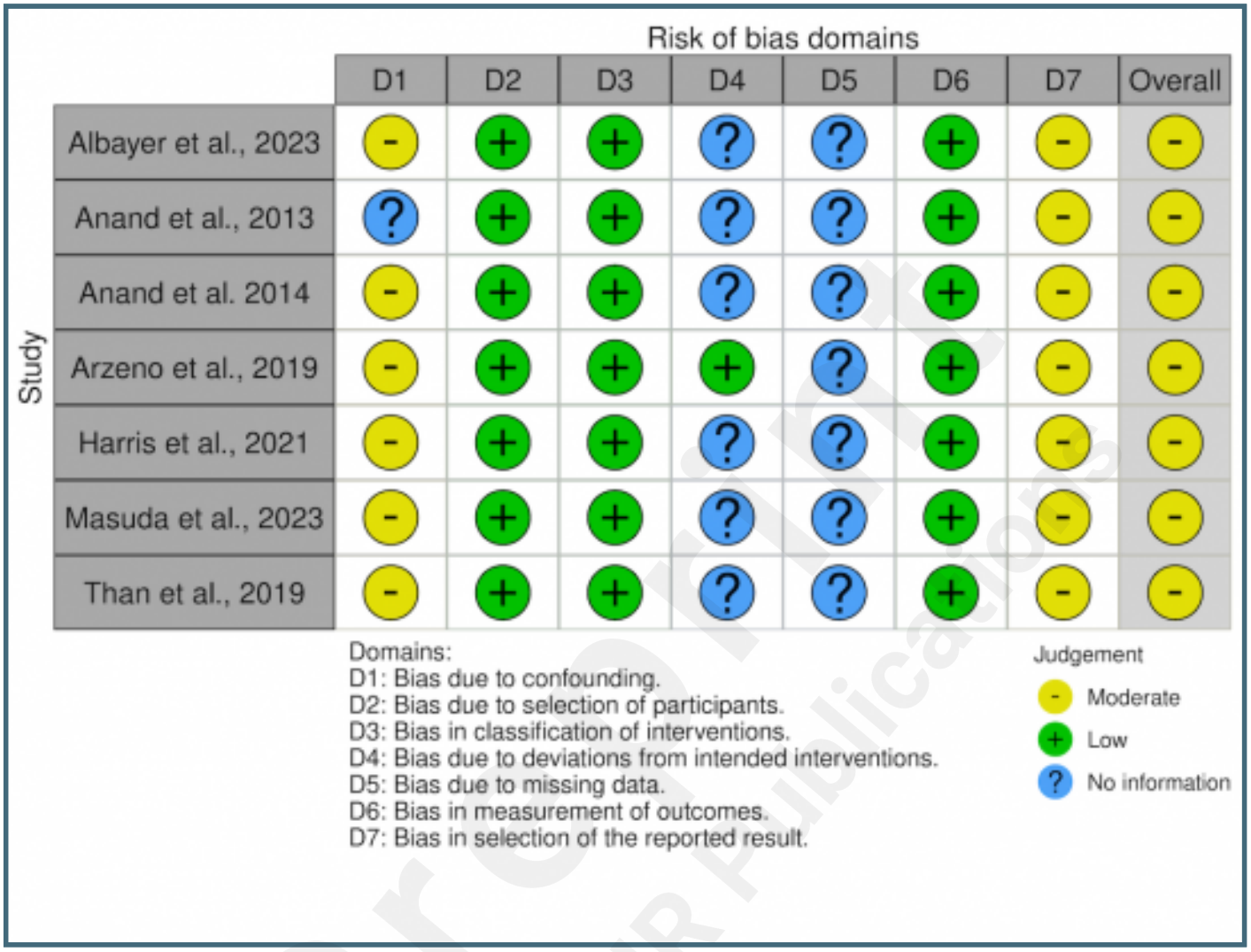
Forest plots comparing estimated blood loss (A) and hospital length of stay (B) between patients who underwent Staged or Same-Day circumferential spinal fusion for adult spinal deformity.



Forest plots comparing intra-operative adverse event (A), post-operative adverse event (B), post-operative infection (C), peri-operative adverse event (D), 30-day readmission (E), and re-operation (F) rates between patients who underwent Staged or Same-Day circumferential spinal fusion for adult spinal deformity.



Robins-I traffic light plot of included studies.



Multimedia Appendixes

Supplemental search strings for query.
URL: http://asset.jmir.pub/assets/9b85a6e7d8b84810a7133f927d7aeabe.docx

CONSORT (or other) checklists

PRISMA checklist.
URL: http://asset.jmir.pub/assets/90edf88709226057e4f415ce39254f7b.pdf