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Early and Late Reoperation Rates With Various MIS Techniques for Adult Spinal Deformity Correction

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Abstract

Study Design: A multicenter retrospective review of an adult spinal deformity database.

Objective: We aimed to characterize reoperation rates and etiologies of adult spinal deformity surgery with circumferential minimally invasive surgery (cMIS) and hybrid (HYB) techniques.

Methods: Inclusion criteria were age $\geq$18 years, and one of the following: coronal Cobb >20°, sagittal vertical axis >5 cm, pelvic tilt >20°, and pelvic incidence-lumbar lordosis >10°. Patients with either cMIS or HYB surgery, $\geq$3 spinal levels treated with 2-year minimum follow-up were included.

Results: A total of 133 patients met inclusion for this study (65 HYB and 68 cMIS). Junctional failure (13.8%) was the most common reason for reoperation in the HYB group, while fixation failure was the most common reason in the cMIS group (14.7%). There was a higher incidence of proximal junctional failure (PJF) than distal junctional failure (DJF) within HYB (12.3% vs 3.1%), but no significant differences in PJF or DJF rates when compared to cMIS. Early (<30 days) reoperations were less common (cMIS = 1.5%; HYB = 6.1%) than late (>30 days) reoperations (cMIS = 26.5%; HYB = 27.7%), but early reoperations were more common in the HYB group after propensity matching, largely due to infection rates (10.8% vs 0%, $P = .04$).

Conclusions: Adult spinal deformity correction with cMIS and HYB techniques result in overall reoperation rates of 27.9% and 33.8%, respectively, at minimum 2-year follow-up. Junctional failures are more common after HYB approaches, while pseudarthrosis/fixation failures happen more often with cMIS techniques. Early reoperations were less common than later returns to the operating room in both groups, but cMIS demonstrated less risk of infection and early reoperation when compared with the HYB group.

Keywords
reoperation, minimally invasive surgery, adult spinal deformity

Introduction

Adult spinal deformity is a significant cause of disability and pain, resulting in substantial functional limitations.[1,2] Health-related quality of life measures are negatively affected by adult spinal deformity, and surgical correction has resulted in significant improvement in these measures.[3-6] Traditional open surgical techniques to correct adult spinal deformity have been associated with considerable morbidity, as well as high reoperation rates.[7-10]

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With the advancement of surgical technology and an interest in reducing the complication and morbidity profile of adult spinal deformity correction, minimally invasive techniques have been developed and applied. These less invasive techniques vary between circumferential (cMIS; minimally invasive surgery) and partially open (hybrid; HYB) approaches.[11] The cMIS techniques typically involve the application of interbody devices and posterior fixation entirely through soft tissue sparing methodology.[12] Alternatively, hybrid approaches combine less invasive interbody reconstruction, most often through lateral or mini-open anterior lumbar interbody fusion (ALIF) exposure, combined with open posterior fixation and reconstruction.

There is a growing body of evidence indicating that minimally invasive techniques for adult spinal deformity correction are associated with improvements over traditional open techniques, such as reduced blood loss, reduction in the need for care in the intensive care unit, and lower infection rates.[13,14] Complication rates have also been evaluated following the use of these techniques. However, few direct comparisons between cMIS and HYB techniques have been reported.[11,15-17] With the variance in surgical exposure required for each of them, cMIS and HYB approaches have theoretical advantages and disadvantages. One of the critical measures of success following surgery is the reoperation rate, as well as how quickly the reoperation is required relative to the index procedure. This is also a key determinant of the cost-effectiveness of adult spinal deformity surgical techniques. The purpose of the current study is to determine the early and late reoperation rates for both HYB and cMIS techniques for adult spinal deformity, as well as to characterize the indications for those reoperations.

Materials and Methods

A retrospective multicenter, adult spinal deformity database approved by each site's institutional review board was queried. The database consists of 10 contributing sites and 12 participating surgeons and includes only patients who had undergone a minimally invasive procedure as part of their surgery. All sites are tertiary care centers with expertise in the surgical management of adult spinal deformity, and each contributing surgeon has expertise in spinal deformity as well as open and minimally invasive spine surgical techniques.

Inclusion criteria for the database are age ≥18 years, and at least one of the following: coronal Cobb >20°, sagittal vertical axis (SVA) >5 cm, pelvic tilt >20°, and pelvic incidence-lumbar lordosis mismatch >10°. All patients underwent surgery between October 2009 and September 2013 and had a minimum of 2 years of follow-up with AP and lateral 36-in. long-cassette films. Only patients with HYB or cMIS procedures with 3 or more levels treated were selected for this study. HYB patients included those who had an anterior or lateral interbody fusion (ALIF or LLIF, respectively) with an open posterior procedure, whereas cMIS was defined as ALIF or LLIF with posterior instrumentation placed percutaneously. ALIF was only performed via mini-open technique at L5-S1 for inclusion in this study. Open posterior procedures were performed with a midline skin and soft tissue exposure. Posterior column osteotomies and/or open decompressions were only performed in the HYB group, but not universally within that group. Traditional transpedicular screws were utilized for all patients, and were introduced either via percutaneous (cMIS) or open (HYB) technique. No cortical screws were employed for fixation. Patients with neuromuscular or congenital deformities were excluded, as were patients with Parkinson's disease. Postoperative rehabilitation and recovery was managed according to each site's standard routine.

Patient demographics, including age, sex, body mass index, and length of follow-up were evaluated. Surgical and clinical parameters were analyzed, including total hospital length of stay, estimated blood loss, total surgical time, and number of levels treated. Health-related quality of life outcomes collected in this study were Oswestry Disability Index (ODI) and Visual Analog Pain scale (VAS) back and leg.

All radiographic measurements were performed centrally (at the database repository) with standing full-length AP and lateral scoliosis radiographs that included the entire spine and both femoral heads. Radiographs were taken both before surgical correction and after surgical correction at 1 and 2 years after surgery. Measurements on the radiographs were performed using the surgical planning software Surgimap (Nemaris, Inc). Sagittal and coronal parameters measured included SVA, pelvic tilt, pelvic incidence, lumbar lordosis, pelvic incidence-lumbar lordosis, and maximum coronal Cobb angle. Clinical and radiographic parameters were compared between the HYB and cMIS. Within each surgical group, patients were further divided into those who did and did not need reoperation and all clinical and radiologic parameters compared again. Fixation failure via loosening or breakage was determined via plain radiographic analysis at all postoperative time points, as well as through operative report description in the case of revision.

Statistical analysis was performed using IBM SPSS Statistics, Version 23 (Armonk, NY). *T*-test was used to compare differences between groups when applicable, otherwise nonparametric Mann-Whitney *U* tests were applied. Chi-square test compared differences for categorical variables between the 2 groups. All statistical significance was set at $P < .05$.

In order to control for the variance in preoperative factors, patients were then propensity matched based on those covariates, including age, preoperative maximum Cobb angle, and preoperative SVA to create homogenous cohorts for a subgroup comparison. Patients were matched by assigning a propensity score using linear regression. Scores were ranked and binned into 3 groups with similar propensity scores. To create an equal sample size between cMIS and HYB groups, a random sample of each bin was selected by assigning a random uniform number. All statistical analyses were repeated on these propensity-matched subgroups.

Results

One hundred thirty-three patients met inclusion criteria from the multicenter database and had complete data available for

Table 1. Demographics and Radiographic Parameters.

	HYB	cMIS	*P*
N	65	68	
Age (years)	56.2	63.1	**.006***
Gender (female)	55 (84.6%)	52 (76.5%)	.236
BMI	26.5	28.3	.096
Preoperative ODI	55.5	49	**.033***
Postoperative ODI	36.6	29.2	.053
Preoperative VAS back	6.9	6.7	.246
Postoperative VAS back	4.4	3.4	**.028***
Preoperative VAS leg	5.1	5.8	.334
Postoperative VAS leg	3.1	2.1	.062
Preoperative SVA (mm)	59.8	40.9	**.0182***
Postoperative SVA (mm)	45.3	43.4	.675
Preoperative maximum Cobb (°)	45	34	**<.001***
Postoperative maximum Cobb (°)	20.8	10.6	.057
Preoperative PI-LL (°)	18.1	17.1	.954
Postoperative PI-LL (°)	9.1	13.2	.107
Preoperative LL (°)	37.3	36.8	.353
Postoperative LL (°)	46.9	40.8	**.009***
OR time (minutes)	682.9	475.1	**<.001***
Staged	44 (67.7%)	45 (66.2%)	.853
EBL (mL)	1567.8	646.3	**<.001***
Total LOS (days)	9.7	7.9	**.005***

Abbreviations: HYB, hybrid technique; cMIS, circumferential minimally invasive surgery; BMI, body mass index; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale; SVA, sagittal vertical axis; PI, pelvic incidence; LL, lumbar lordosis; OR, operating room; EBL, estimated blood loss; LOS, length of stay.
*$P < .05$ (significant).

analysis with 2-year follow-up. Two groups (65 HYB and 68 cMIS) were identified for initial comparison. After propensity matching, there were 37 patients in each subgroup that were reanalyzed. The patients in the cMIS group were older on average (63.1 years vs 56.2 years, $P = .006$) than those in the HYB group. A majority of the patients were female in both groups (HYB = 85%; cMIS = 76%). Average follow-up after surgery was also similar (HYB = 32.2 months; cMIS = 35.5 months). The HYB group had more levels treated on average (9.7 levels) than the cMIS group (7.9 levels; $P = .005$). Demographic, blood loss, operating room time, and length of stay data is summarized in Tables 1 and 2. The percentage of patients who smoke were similar between groups (HYB 6 [16.2%]; cMIS 4 [10.8%]; $P = .496$).

The HYB group had larger coronal deformities based on higher preoperative Cobb angles, as well as more sagittal malalignment (Tables 3 and 4). They also had slightly higher preoperative ODI and VAS back scores, but there were no differences in postoperative radiographic parameters or outcome measures between HYB and cMIS groups.

Reoperation rates were similar when comparing HYB and cMIS groups, and the acute reoperations were much less common than later (>30 days) reoperations for both groups. For reoperations, the HYB group more frequently required additional levels of fusion. There were no significant differences in sources of reoperation when comparing the groups (Tables 3 and 4). Notably, the most common general indication for reoperation in the HYB group was related to junctional failure, with a predominance of proximal junctional kyphosis (PJK) versus distal junctional kyphosis (DJK) (Figure 1). The more common indication for reoperation in the cMIS group,

Table 2. Propensity-Matched Cohorts: Demographics and Radiographic Parameters.

	HYB	cMIS	*P*
N	37	37	
Age (years)	61.8	61.7	.991
Gender (female)	32 (86.5%)	28 (75.7%)	.235
BMI	27.3	28.5	.335
Preoperative ODI	53.6	49.1	.242
Postoperative ODI	35.6	30.7	.325
Preoperative VAS back	6.8	6.5	.252
Postoperative VAS back	4.4	3.4	.113
Preoperative VAS leg	5.2	5.4	.965
Postoperative VAS leg	3.3	2.1	.141
Preoperative SVA (mm)	53.4	49.8	.944
Postoperative SVA (mm)	50.6	52.6	.869
Preoperative maximum Cobb (°)	40.5	36.4	.302
Postoperative maximum Cobb (°)	21.7	9.5	.036
Preoperative PI-LL (°)	18.4	16.5	.681
Postoperative PI-LL (°)	12.1	12.4	.835
Preoperative LL (°)	38.5	36.5	.396
Postoperative LL (°)	45.9	41.4	.161
OR time (minutes)	680.3	498.9	**.001***
Staged	26 (47.3%)	29 (52.7%)	.0425
EBL (mL)	1579.7	766.2	**.001***
Total LOS (days)	9.6	7.4	**.014***

Abbreviations: HYB, hybrid technique; cMIS, circumferential minimally invasive surgery; BMI, body mass index; ODI, Oswestry Disability Index; VAS, Visual Analogue Scale; SVA, sagittal vertical axis; PI, pelvic incidence; LL, lumbar lordosis; OR, operating room; EBL, estimated blood loss; LOS, length of stay.
*$P < .05$ (significant).

Table 3. Reoperation Timing and Indications for HYB and cMIS Approaches[a].

	HYB	cMIS	*P*
N	65	68	
Reoperation	22 (33.8%)	19 (27.9%)	.461
Acute	4 (6.1%)	1 (1.5%)	.156
Late	18 (27.7%)	18 (26.5%)	.874
Indications			
Infection	4 (6.1%)	1 (1.5%)	.156
Neurologic	4 (6.1%)	2 (2.9%)	.372
Fixation failure/pseudathrosis	4 (6.2%)	10 (14.7%)	.169
Fixation failure	4 (6.1%)	6 (8.8%)	.559
Pseudo	1 (1.5%)	4 (5.9%)	.188
Junctional failure	9 (13.8%)	7 (10.3%)	.529
DJF (distal junctional failure)	2 (3.1%)	4 (5.9%)	.436
PJF (proximal junctional failure)	8 (12.3%)	3 (4.4%)	.098
CSF leak	2 (3.1%)	0 (0.0%)	.145
Bowel/bladder	1 (1.5%)	0 (0.0%)	.305

Abbreviations: HYB, hybrid technique; cMIS, circumferential minimally invasive surgery; CSF, cerebrospinal fluid.
[a]Numbers represent count of patients, complications are not mutually exclusive as patients may suffer from more than one complication.

Table 4. Propensity-Matched Cohorts: Reoperation Timing and Indications.

	HYB	cMIS	P
N	37	37	
Reoperation	12 (32.4%)	10 (27.0%)	.611
Acute	4 (10.8%)	0 (0.0%)	**.04***
Late	8 (21.6%)	10 (27.0%)	.588
Indications			
Infection	4 (10.8%)	0 (0.0%)	**.04***
Neurologic	3 (8.1%)	1 (2.7%)	.304
Fixation failure/pseudathrosis	3 (8.1%)	4 (10.8%)	.691
Fixation failure	3 (8.1%)	3 (8.1%)	.999
Pseudo	0 (0.0%)	1 (1.4%)	.314
Junctional failure	3 (8.1%)	5 (6.8%)	.454
DJF (distal junctional failure)	0 (0.0%)	3 (8.1%)	.077
PJF (proximal junctional failure)	3 (8.1%)	2 (2.7%)	.643
CSF leak	2 (2.7%)	0 (0.0%)	.152
Bowel/bladder	0 (0.0%)	0 (0.0%)	

Abbreviations: HYB, hybrid technique; cMIS, circumferential minimally invasive surgery; CSF, cerebrospinal fluid.

[a]Numbers represent count of patients, complications are not mutually exclusive as patients may suffer from more than one complication.

*$P < .05$ (significant).

Figure 1. Preoperative and postoperative lateral radiographs of a patient from the HYB group who underwent T9-S1/pelvis reconstruction and incurred PJK.

however, was fixation failure/pseudarthrosis (Figure 2). Neurologic rationale for reoperation included 2 patients with motor and sensory deficit and 1 patient solely with radiculopathy in the HYB group, while there was only 1 patient with radiculopathy in the cMIS group.

Iliac fixation had been utilized in 36 (55.4%) of the HYB group and 30 (44.1%) of the cMIS group ($P = .194$). There were more reoperations required in the HYB group with iliac fixation (77.3%) than those without it (44.2%; $P = .011$). However, such a difference in reoperation rates was not found in relation to iliac fixation in the cMIS patients (42.9% and 47.4%, $P = .737$).

When evaluating those patients requiring reoperation from either group, they had postoperative pelvic incidence-lumbar lordosis similar to those patients not requiring reoperation (16.4° vs 12.1°, $P = .182$). However, there was a higher postoperative SVA in patients requiring reoperation (66.5 mm vs 35.0 mm, $P = .047$). Additionally, those requiring reoperation had a higher postoperative coronal deformity (18.8° vs 7.0°, $P = .033$).

With propensity matching and further analyzing the subgroups, there is a notable finding of significantly greater risk of early reoperation in the HYB group when compared to the cMIS group (Table 1). This is primarily explained by the greater risk of infection after the HYB approach (10.8% HYB vs 0% cMIS, $P = .04$). After propensity matching, there were no radiographic differences, but operating room time, estimated blood loss, and length of stay all were significantly lower within the cMIS group (Table 4).

Discussion

Adult spinal deformity is a complex disease process that is increasing in prevalence as the population ages, and as a result there is an escalating rate of corrective surgeries being performed. The challenging morbidity of traditional open correction of these deformities, as well as advancing technology, have led to the development of less invasive techniques. Studies have shown that MIS techniques can provide similar correction when compared to open techniques in certain cohorts of patients with spinal deformities.[18-20]

Correction of adult spinal deformity through traditional open techniques has historically been associated with both a high rate of complications and reoperation.[9,10,21,22] The application of MIS techniques in correcting adult spinal deformity has been shown to reduce overall complication rates; however, reoperation rates following the use of these techniques have not been previously established.[13,16,23] Furthermore, the factors leading to reoperation after adult spinal deformity correction may vary depending on the technique utilized. Given the impact of reoperation on cost-effectiveness and durability of adult spinal deformity surgery, a better understanding of the causes and rates of reoperation remains critical to improving outcomes following adult spinal deformity surgery.

This study reports on the reoperation rates and indications following MIS surgery for adult spinal deformity. We found that both cMIS and HYB approaches carried considerable reoperation rate risk, similar to those seen in traditional open surgery. In long-term follow-up, reoperation rates were 33.8% and 27.9% for HYB and cMIS groups, respectively, with most of these occurring later in recovery (>30 days postoperatively).

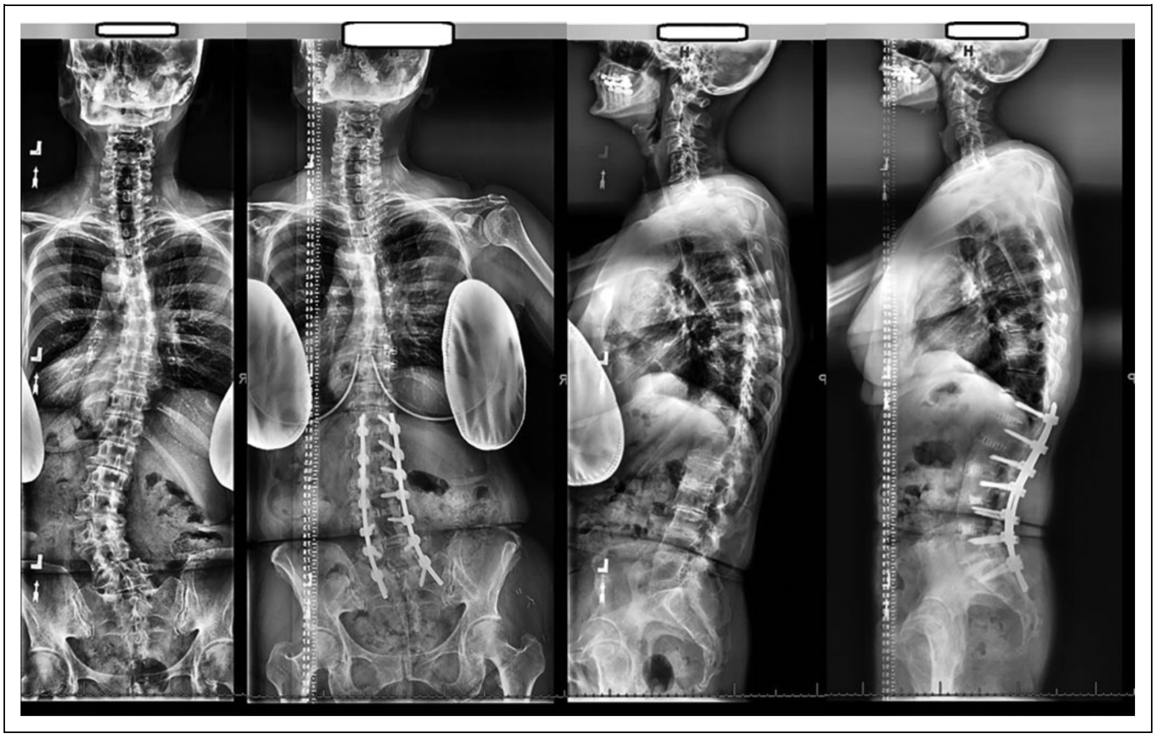

Figure 2. Preoperative and postoperative PA and lateral radiographs of a patient corrected with cMIS and demonstrating lucency of the S1 screws and possible pseudarthrosis at L5-S1.

After open adult spinal deformity surgery, reoperation rates have been reported in the literature ranging from 9% to 58%.[9,10,22,24-26] Mok et al reported a reoperation rate of 25.8% following traditional open adult deformity correction utilizing 2-year follow-up.[9] Scheer et al reported a reoperation rate of only 17%; however, follow-up was less than 2 years in their study.[27] Hamilton et al found a 12% reoperation rate after traditional open surgery; however, when less invasive procedures were employed, the rate climbed to 27% in the HYB group, while it dropped to 11.1% in the cMIS group.[11] In general, reoperation rates increase as follow-up increases, likely influenced by failures such as rod breakage, pseudarthrosis, or adjacent segment disease that may occur or become symptomatic several years after surgery. Hence, longer-term follow-up is critical in evaluating the various options for adult deformity surgery.

Given that the HYB technique for adult spinal deformity correction relies on an open posterior surgical approach, there may be specific mechanisms of failure or complications that lead to reoperations when comparing to cMIS approaches that preserve the posterior soft tissue and muscular envelope. These soft tissues are secondary stabilizers of the spine, whose function as a posterior tension band likely contributes to reducing adjacent segment stress. Despite the expected differences in indications for reoperation on the basis of these approach factors, we did not demonstrate any difference in the etiologies of reoperation when comparing HYB and cMIS groups. However, the finding of predominant reoperation indications being junctional failure in the HYB group versus fixation failure/pseudarthrosis in the cMIS group suggest the specific approaches likely have important implications for the type of failure and/or need for revision surgery.

It has been hypothesized that utilizing posterior MIS techniques for adult spinal deformity correction can potentially reduce the rate of proximal junctional failure, which has been historically high with open deformity correction.[16,28] We were unable to confirm this hypothesis, as both HYB and cMIS groups had statistically similar rates of proximal junctional failure. This is consistent with prior comparisons of PJK rates after undergoing HYB or cMIS adult spinal deformity correction,[29] but the limited numbers in our patient population may not have been adequately powered to detect differences that may actually exist. This same limitation affects our detection of potential differences in pseudarthrosis and fixation failure rates between HYB and cMIS groups. Furthermore, the trend toward higher pseudarthrosis rate in the cMIS group is an interesting finding that may reflect the lack of bony surface area available for arthrodesis that is otherwise achieved with open posterior approaches. Minimally invasive posterior approaches may intentionally be focused on delivering fixation alone, in which case, posterior arthrodesis is not formally attempted. In alternative versions of posterior MIS approaches, and with an intent to limit soft tissue damage, the extent of posterior exposure may limit the relative effectiveness of any attempt at posterior arthrodesis.

Another area of expected difference between these 2 groups may exist in the need for acute reoperation. HYB techniques employ direct decompression of neural elements, with a commensurate risk of dural injury and cerebrospinal fluid leakage, as well as greater muscle stripping and retraction, which increases the risk of infection. These types of complications tend to lead to early reoperations, and would theoretically specifically increase the rates differentially in the HYB group, as demonstrated with the propensity-matched subgroup analysis.

Neurologic complications after adult deformity surgery occur with significant and somewhat variable frequency.[6,30,31,32] Smith et al reported neurological complications rate of 27.8% at 2 years post adult spinal deformity correction surgery,[31] while Lenke et al reported rates of 10.8%.[6] In the prior study by Hamilton et al, the need for reoperation on the basis of neurologic complications occurred at a rate of 7.9% after open deformity correction, 11.1% in a HYB group and in 1.6% in a cMIS group.[11] Our findings were largely consistent with these reports, with the caveat that our study may be underpowered to demonstrate differences between groups with the relatively small number of patients.

As expected, there were fewer infections that resulted in reoperation in the cMIS group, when correcting for confounders via propensity matching. Higher postoperative infection risks (posterior infections) point to the open posterior approach utilized in the HYB group, and this difference is consistent with prior studies that have shown a lower infection rate when utilizing posterior MIS techniques for adult spinal deformity correction.[13,16,23] Blood loss, operative time, and length of hospital stay were also significantly lower in the cMIS group, despite no difference in the percentage of staged procedures in each subgroup. Length of stay analysis included those patients undergoing staged procedures occurring on different days. As scheduling of staged interventions is often primarily influenced by operating room and surgeon availability, rather than a standard or set time between stages, the length of stay for both groups might be variably influenced by factors not intrinsic to the surgical recovery.

Reoperation rates after surgery are of specific importance due to the high cost and morbidity of adult deformity procedures. Furthermore, the cost-effectiveness of the index operation is undermined substantially by the need for reoperation. On average primary adult spinal deformity surgery and hospitalization costs approximate $100 000, while readmission hospitalization and reoperation costs approximate $70 000.[30] Because of the relatively high reoperation rates following correction of adult spinal deformity, which have historically approximated 25%, and the costs associated with revisions, there is a critical need to identify the etiologies of reoperation need, as well as prevention strategies.[9,10,21,28] Reducing reoperation rates will be critical to successfully improving the cost-effectiveness of correcting adult spinal deformity with surgery.

Limitations of the Study

This is a retrospective study, and as such, it carries with it the inherent limitations in data collection for all such retrospective reviews; future prospective studies will be needed to optimize the data reliability and integrity and are ongoing in our group. Randomization of subjects into a prospective study may be considered, as well, but this consideration is challenged by the need to acknowledge the skill set of participating surgeons, as well as the difficulty in achieving the equipoise necessary to ethically conduct such a study.

Conclusion

In this comparative study, reoperation rates were similar between cMIS and HYB approaches in the treatment of adult spinal deformity. Notably, most reoperations occurred after 30 days (late) following adult spinal deformity surgical correction, regardless of the surgical invasiveness employed. The most common cause for reoperation was fixation failure and pseudarthrosis in the cMIS group, whereas proximal junctional failure was the most frequent etiology in the HYB group. When propensity matched, infection risk was greater among the HYB group as well, leading to higher rates of early reoperation. Prospective analyses are currently underway to further help delineate and characterize these risks and others as it relates to adult spinal deformity corrective surgery and reoperation.

Declaration of Conflicting Interests

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