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Medicare's benchmarking spinal DRGs have limited capacity in capturing the nuances of surgical invasiveness, hospital length of stay, discharge disposition, key quality metrics, and reimbursement costs for adult spinal deformity

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Key Words. Adult spinal deformity; thoracolumbar; Medicare; Diagnosis-Related Groups (DRGs); adverse events; 90-day outcomes; hospital length of stay; discharge disposition.

Key Points

- Medicare’s spinal-deformity-specific diagnosis-related groups (DRGs) relative to surgical invasiveness, key 90-day post-operative quality metrics, and reimbursement costs for adult spinal deformity (ASD) operations has been relatively unexplored.

- In this multi-center analysis of ASD patients who underwent thoracolumbar instrumented fusions, Medicare's 7 spinal-deformity DRG codes captured average trends in surgical/post-operative episodes of care for ASD patients, but not to an acceptable granularity, as each encompassed highly heterogeneous patients and associated surgical operations and reimbursement costs.

- While the 7 spinal-deformity DRGs varied significantly within and between a subset of 6 commonly performed surgical strategies, there were no differences in post-operative quality metrics.

- As these DRG codes were found to be unreliable gauges of patient/surgical complexity, early post-operative trajectories, and reimbursement costs, a more granular system is needed to more accurately capture the nuances of ASD operations and their associated quality metrics and reimbursements cost.

- A new system should ideally be informed by more comprehensive assessments of patient-level factors (i.e. social support, additional frailty indices), quantitative scoring systems for surgical invasiveness and associated objective measures of effort and risk, and tools that outline risk for specific complications and their related severity, extended hospital lengths of stay, and nonroutine discharges so that payment for care is appropriate and commiserate with the effort, risks, and costs of operative interventions for adult spinal deformity.

Abstract

Study Design. Retrospective cohort analysis.

Objective. Assess the distribution of Medicare's spinal-deformity-specific diagnosis-related group (DRGs) relative to surgical invasiveness, hospital length of stay (LOS), discharge disposition, 90-day post-operative quality metrics, and reimbursement costs for adult spinal deformity (ASD) operations.

Summary of Background Data. Heterogeneity of ASD call into question Medicare's DRGs to accurately capture nuances of ASD surgical episodes of care.

Methods. Adults who underwent thoracic to pelvis instrumentation with associated DRGs were identified from a multi-center database. Demographics, operative details, inpatient course, discharge disposition, 90-day adverse events, and reimbursement costs were compared between spinal deformity-specific DRG codes. Distribution of DRGs for a subset of these patients who fit into one of 6 commonly performed surgical strategies to address ASD were also assessed.

Results. Of the 314 patients included for analysis, the majority fell into +CC DRGs, while the minority had +MCC DRGs or no MCC/CC DRG. Within each DRG there was considerable heterogeneity in regard to patients' ages, ASA, CCI, frailty, surgical invasiveness, post-operative ICU/hospital LOS, discharge disposition, and complication profiles.
+MCC DRGs had significantly greater ASA and Edmonton Frailty Scores. While +MCC and +CC had relatively similar surgical invasiveness, +MCC had greater ICU admissions, in-hospital adverse events, and non-home discharges as well as longer ICU, hospital, and rehab LOS. While reimbursements were significantly higher for +MCC DRG compared to +CC DRGs and DRGs without MCC/CC, there were large ranges in reimbursement within all DRG subgroups.

The 7 DRGs varied significantly within and between the subset of 6 commonly performed surgical strategies, although there were no differences in regard to ICU admissions and LOS, hospital LOS, discharge disposition, and number of adverse events (in-hospital, 90-day).

Conclusions. While Medicare's spinal-deformity DRG codes capture average trends in surgical/post-operative episodes of care for ASD patients, each encompasses highly heterogeneous patients and associated surgical operations rendering them unreliable gauges of patient/surgical complexity, early post-operative trajectories, and reimbursement costs. A more granular system is needed to more accurately capture the nuances of ASD operations and their associated quality metrics and reimbursement costs.

Introduction

Adult spinal deformity (ASD) is a highly heterogeneous disorder that negatively impacts health related quality of life (HRQOL) [1,2]. Surgical intervention to address ASD has demonstrated to provide significant improvements in HRQOL scores but is fraught with numerous complications, and the episodes of care between ASD patients may vary significantly based on a variety of factors, including underlying comorbidities, social support, and surgical strategy [2]. Such complications lead to high costs that may be unsustainable for hospital systems, especially under bundled healthcare payment models where predetermined reimbursements are offered for a single episode of care.

Medicare's specific spinal-deformity-specific diagnosis-related groups (DRGs) currently attempt to discern the heterogeneity of the treatment course within the ASD population and provide reimbursement to hospitals based on the specific assigned code [3-5]. The aim of this study is to assess the distribution of Medicare's DRGs with respect to surgical invasiveness, LOS, discharge disposition, and key quality metrics within 90-days following ASD operations.

Materials and Methods

Data Source

A prospective multi-center database of ASD operations was retrospectively queried. Database enrollment was performed at 14 institutional review board-approved sites across the United States. Records were obtained for patients from 2019-2023.

Inclusion and Exclusion Criteria

Eligibility criteria consisted of adult patients (all Medicare beneficiaries) with a diagnosis of ASD who underwent instrumentation from the thoracic spine [Upper Thoracic (UT): T1-T6; Lower Thoracic (LT): T6-T12) to the pelvis. Presence of associated DRGs and reimbursement costs were also used as an inclusion criterion. Excluded were those patients with incomplete data or those who underwent operations for trauma, infection, and/or tumor. Patients with unknown demographics, operative details, post-operative inpatient course, discharge disposition, and 90-day adverse events were also excluded.

Independent Variables

The independent variables included the spinal deformity-specific DRG codes (453,454,455,456,457,458,460) that were assigned to each patient following the patients' episodes of care. DRG codes 453, 454, and 455 corresponded to a combined anterior/posterior spinal fusion with major complication or comorbidity (MCC, DRG 453), with complication or comorbidity (CC, DRG 454, or without CC/MCC (DRG 455). DRG codes 456, 457, and 458 corresponded to spinal fusion (except cervical) with either spinal deformity or extensive fusions with MCC (DRG 456), with CC (DRG 457), or without CC/MCC (DRG 458). DRG code 460 corresponded to spinal fusion (except cervical) without MCC. For each patient, the reimbursement adjusted for inflation associated with the assigned DRG was also obtained. No data presented are related to charges or hospital prices.

Outcome Variables: Quality Metrics Associated with Episode of Care

Outcome variables included patient demographics, operative details, post-operative inpatient course, discharge disposition, and 90-day adverse events. Demographics obtained included age, body mass index (BMI), gender, American Society of Anesthesiologists (ASA) Score, Charleson Comorbidity Index (CCI), and Edmonton Frailty Score (EFS) [6]. The EFS is a tool used to assess frailty using the following nine domains: cognition, general health status, functional independence, social support, medication use, nutrition, mood, continence, and functional performance. It is a questionnaire-based assessment, with a total score ranging from 0 to 17, with higher scores indicating greater degree of frailty. Patients may be categorized based on the total score into one of the following 3 groups: "No Frailty" (≤5 points), "Apparently Vulnerable" (6-11 points), and "Severe Frailty" (12-17 points). The EFS has been shown to have good construct validity, good reliability, and acceptable internal consistency [6]. The EFS was collected by individual research coordinators at each participating institution at the time of enrollment.

Surgical treatment was described by the location of the upper instrumented vertebrae (UIV) [UT (T1-T6) or LT (T7-T12)], surgical approach (anterior and posterior, posterior alone), presence of interbody (yes or no), type of interbody (ALIF, TLIF), number of interbody cages placed, whether osteotomies were performed [3CO, pedicle subtraction osteotomy (PSO), vertebral column resection (VCR)], and whether blood transfusions were given (yes or no). Variable included in the postoperative inpatient course included ICU admission, number of days in the ICU, hospital LOS, discharge disposition (home vs rehab/SNF), and days spent in rehab. Postoperative adverse events were stratified by time course into in-hospital events, events within 30 days of surgery, and events within 30-90 days following surgery. Specific adverse events that were investigated were all-cause, cardiopulmonary, myocardial infarction (MI), venous thromboembolism (VTE)/deep venous thrombosis (DVT), cerebrovascular accident (CVA), delirium, infectious [any infection, *clostridium difficile*, sepsis, urinary tract infection (UTI)], renal failure, dural tear, surgical site infection [SSI, superficial or deep], new neurological deficit, and mortality. Individual complications were assessed by research coordinators at each participating institution and attributed to index procedures based on the aforementioned timing relative to the operation. No adjudication was needed.

Statistical Analysis

Patient demographics, operative details, post-operative inpatient course, discharge disposition, and 90-day adverse events were compared between the assigned spinal deformity-specific DRG codes (453,454,455,456,457,458,460). Also assessed was distribution of DRGs for a subset of these patients who fit into one of 6 commonly performed surgical strategies to address ASD: (1) primary lower thoracic (LT)-pelvis + TLIFs; (2) primary LT-pelvis + ALIFs; (3) primary upper thoracic (UT)-pelvis + TLIFs; (4) primary UT-pelvis + ALIFs; revision LT-pelvis +/- interbodies; (6) revision thoracic (T1-T12)-pelvis + 3 column osteotomy (3CO) +/- interbodies.

Statistical analyses consisted of ANOVA for continuous variables and Fisher Exact tests for categorical variables, with generation of p-values. A $p\text{-value}<0.05$ was deemed significant. All statistical tests were conducted using Microsoft Excel statistical package.

Results

DRG and Reimbursement Distribution (Table 1)

314 met inclusion criteria with complete DRG and reimbursement cost data. Most patients fell into +CC DRG groups (454 - 48.7%; 457 - 20.1%), while the minority had +MCC DRGs (453 - 12.7%; 456 - 5.7%) or no MCC/CC DRG (455 - 5.1%; 458 - 3.2%; 460 - 4.8%). Reimbursements were significantly higher for +MCC (453/456) DRG and significantly lower for DRGs without MCC/CC (455/458/460). Specifically, DRG 453 and DRG 456 had average reimbursements of $81,029 ± 17,838 (range, $65,283-137,325) and $76,331 ± 9,308 (range, 66,486-96,287), respectively, while DRG 455, 458, and 460 had average reimbursements of $37,936 ± 10,406 (range, $28,043-54,227), $45,936 ± 6,926 (range, $33,323-55,086), and $34,660 ± 12,784 (range, $11,401-60,402), respectively. Additionally, the +CC DRGs [454: $37,485 ± 12,254 (range, $35,095-121,089) and 457: $58,802 ± 11,615 (range, $44,539-103,161)] had relatively similar reimbursements to the no MCC/CC groups. Noteworthy is the considerable variation in reimbursement values per DRG, as evidenced by the wide ranges in values within each group.

Exploratory Data Analysis (Tables 1 & 2)

Within each DRG, there was considerable heterogeneity regarding patients' ages, ASA, CCI, frailty, surgical invasiveness, post-operative ICU and hospital lengths of stay, discharge disposition, and complication profiles (**Tables 1 & 2**). +MCC DRGs (453/456) had significantly higher Edmonton frailty and ASA scores (**Table 1**). +MCC (453/456) and +CC (454/457) had relatively similar surgical invasiveness regarding type of operation (primary vs revision) and 3-CO (**Table 1**). Despite the similarity, +MCC patients were admitted to the ICU more frequently and had longer ICU LOS, greater number of in-hospital adverse events, longer overall hospital

LOS, and greater percentage of discharges to rehabilitation centers with longer rehabilitation LOS (**Table 2**).

DRGs with no MCC/CC (455/458) had relatively lower surgical invasiveness (greater percentages of primary operations and LT UIVs and fewer 3-CO), less frequently received a blood transfusion, had fewer ICU admissions, shorter hospital LOS, greater percentage of discharges to home, and fewer in-hospital and 90-day adverse events compared to +MCC/+CC DRGs (**Tables 1 & 2**).

Surgical Strategy Subgroups (Tables 3 & 4)

196 patients had complete DRG and reimbursement cost data and fit into one of the aforementioned 6 surgical groups (Primary-LTp+TLIF – 53; Primary-LTp+ALIF – 26; Primary-UTp+TLIF – 18; Primary-UTp+ALIF – 19; Revision-LTp – 33; Revision+3CO - 47) (**Table 3**). Patients' ages, CCI scores, and Edmonton frailty scores differed significantly between the groups (**Table 3**). Post-operatively, there were no differences between the groups in regard to percentage of patients admitted to the ICU, ICU lengths of stays, overall hospital lengths of stays, discharge disposition (home vs. rehab/SNF), and number of in-hospital and 90-day adverse events (**Table 4**). However, DRGs varied significantly within and between each surgical group (**Table 3; Figures 1 & 2**). Reimbursements were significantly lower for Primary-LTp+TLIF ($55,234 ± 10,855) and Primary-LTp ($51,182 ± $19,971) compared to Primary UT operations and revision cohorts (all averages > $59,000) (**Table 3**).

Discussion

The goal of this study was to determine whether Medicare's ASD-related DRG codes accurately captured the heterogeneity in patient demographics, surgical invasiveness, LOS, discharge disposition, and complication profile within the 90-day postoperative period following surgical treatment for ASD. Variables that significantly varied between DRG groups included demographic variables (reimbursement, BMI, ASA, frailty score), select operative variables (revision surgery, surgical approach, number of interbodies placed, blood transfusions), certain postoperative complications (ICU admissions, days in ICU, LOS, days in rehab), and in-hospital postoperative adverse events. Aspects of the patient's episode of care that did not significantly differ between DRG groups were age, gender, CCI, UIV level, discharge disposition, postoperative adverse events within 30 days following surgery, and postoperative adverse events within 30-90 days following surgery.

The limited available literature is concordant with the findings presented in this study. Previous retrospective studies have found that a combined anterior and posterior approach, longer hospital stays (3-8 days), and presence of complications and comorbidities are reflected in the DRG classification and result in increased reimbursement [5]. While DRG codes may capture these simple average trends, they are an imperfect way of capturing the true heterogeneity of the patient's episode of care. In a related study on a cervical fusion cohort, *Malik et al* found that the DRG system was unable to control for cost variation seen among cervical fusions [7]. The study determined that providers were reimbursed the same amount for cervical fusions regardless of surgical approach, number of levels fused, use of adjunct procedures (i.e. decompressions), and the surgical indication (i.e. degenerative pathology vs fracture) [7]. *Yeramaneni et al.'s* study of 330 ASD surgical patients found similarly found that Medicare-based payments for complex spinal deformity fusions were driven primarily by the relative weight of the DRG and the hospital's base rate, while patient and procedural factors were completely unaccounted for [5].

The DRG's inability to distinguish between each patient's episode of care results in catastrophic costs for hospital systems and creates barriers for future access to spine deformity care. In our study, the DRG codes failed to capture the heterogeneity in age, gender, CCI, surgical invasiveness (i.e. UIV level), discharge disposition, and postoperative adverse within 30 and 30-90 days. For example, patients with age>60 have been clearly implicated with higher risk of complications and needing rehabilitation discharge [8,9]. A higher surgical invasiveness has been broadly associated with SSIs, greater operative time, perioperative complications, and higher LOS, all of which increase cost of care [10-12]. Discharge disposition along with LOS are often interdependent, as patients with extended LOS may require rehabilitation to facilitate functional return, while patients requiring discharge to rehabilitation may require longer LOS due to the referral process and administrative delay [13-15]. Therefore, it is concerning that the DRG codes investigated in this study failed to capture the heterogeneity in discharge disposition, especially since discharge location is an extremely strong predictor of increased costs [16]. The inability for DRG codes to also capture differences in postoperative adverse events within 30 and 30-90 days is especially notable. Deformity patients have the highest postoperative medical complication rates, with estimates greater than 45% [17]. Such events within the 30-day and 90-day period may require readmission or reoperation, with significant impact on patient quality of life. Moreover, complications to the cardiac, hematologic, gastrointestinal, and/or neurologic systems may necessitate a multidisciplinary approach that adds significant resource allocation [18]. In essence, each factor within the patient's episode of care incurs a vastly different resource utilization by the patient care team. The inability of DRG codes to accurately capture such heterogeneity may create financial barriers for hospitals to continue providing accessible, high-quality spinal care.

Accurate assessment of the patient's episode of care has clinical utility and can enable cost effectiveness for hospital systems. The average cost for a long-segment fusion for deformity between 2013-2018 was $72,000, with reimbursement rates often failing to cover total costs [19-21]. Especially under bundled healthcare payment models, where predetermined reimbursements are offered for a single episode of care, costs beyond the reimbursement amounts are unsustainable for hospitals in the long-term [22]. While DRG codes that accurately capture the heterogeneity within each patient's episode of care are an essential component to ensure the sustainability of spinal deformity care, target pricing in the Bundled Payment for Care Improvement (BPCI) and BPCI-advanced are based on each hospital's own historical cases (i.e. reference prices are based on the type of patients for whom the hospital already cares, with each hospital serving as its own baseline). While some patients have more complexity and higher cost than average, others are significantly lower. These ideally average out in a bundle payment model. Because target prices for each DRG is hospital-specific, financial risk increases if the distribution of ASD patients suddenly increases compared to historical levels. In addition, to date, all existing bundled payment models are subject to stop-less/gain provisions, which caps potential financial losses.

The strengths of this study include highly granular multicenter patient data, rigorous application of inclusion and exclusion criteria, availability of assigned DRG codes with reimbursement data, and access to postoperative complications within the 90-day period. Data derived from a multicenter center enabled good study generalizability. Access to operative data enabled a detailed comparison of surgical invasiveness, with additional granularity by having access to variables such as UIV, surgical approach, type of osteotomies performed, and the type and number of interbody fusions. Variables that significantly differed between DRG groups had excellent face validity. For example, +MCC DRGs (453/456) had significantly greater ASA and Edmonton frailty scores, higher frequency of ICU admissions, greater ICU LOS, more in-hospital adverse events, and longer hospital LOS. As expected, DRGs with no MCC/CC (455/458) had significantly lower percentages of primary operations, fewer 3-CO, received fewer blood transfusions, had fewer ICU admissions, shorter hospital LOS, and fewer in-hospital adverse events compared to +MCC/+CC DRGs. While these data may lend credence to the notion that the DRG designations appropriately capture higher cost patients with more complexity, they do not differentiate patients to the accuracy needed, as they each still encompass highly heterogeneous patients and associated surgical operations. Among the current literature analyzing the heterogeneity of key patient outcomes within Medicare ASD DRG codes, this is the first to simultaneously assess variables such as surgical invasiveness, ICU admissions, LOS, discharge disposition, time in rehabilitation, and postoperative adverse events stratified by time course.

The study should also be interpreted in the context of its limitations. Despite an overall cohort size of over 300 patients, the relatively small cohort sizes of each DRG subgroup may jeopardize the power of the study and its ability to make meaningful inferences about differences in complication rates by DRG or subgroups. As hospitals are paid based on several factors, including DRGs, a defined fee for each night in the hospital, and local modifiers (i.e. local wage index, adoption of certain technologies, additive payments for teaching cases, surgical assistants, and/or designation as critical access or rural hospitals) [4], the observed variations in reimbursement cost by DRG groups in this study may be related to other factors given this is a multi-center study. We are not able to comment on whether variations within the DRG subgroups are attributed to differences between hospitals given individual patient data in our database are not linked to individual institutions per IRB regulations to ensure patient anonymity and minimize risk of loss of protected health information. As such, our study's inability to differentiate between institutions, as well lack of geographical information, is a limitation and presents a promising avenue for future study. Another limitation is our study's lack of incorporation of socioeconomic variables (i.e. housing status and income), which may influence degree and type of support required throughout the continuum of care. Important to also note is that Medicare revised the lumbar fusion DRG's in 2025 to better distinguish combined anterior-posterior and multilevel fusions, so the analysis presented in this manuscript is slightly less specific to the DRG's in current use.

Conclusions

While Medicare's spinal-deformity DRG codes capture average trends in surgical and post-operative episodes of care for ASD patients, each encompasses highly heterogeneous patients and associated surgical operations rendering them unreliable gauges of patient and surgical complexity, early post-operative trajectories, and associated reimbursement costs for care. These underestimations lead to inaccurate billing and underpayment to physicians and the healthcare system. As such, a more granular grading system is needed to more accurately capture the nuances of ASD operations and their associated quality metrics and associated reimbursement costs for care. A new system should ideally be informed by more comprehensive assessments of patient-level factors (i.e. social support, additional frailty indices), quantitative scoring systems for surgical invasiveness and associated objective measures of effort and risk, and tools that outline risk for specific complications and their related severity, extended hospital lengths of stay, and nonroutine discharges so that payment for care is appropriate and commiserate with the effort, risks, and costs of operative interventions for adult spinal deformity.

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Figure 1. Graphical representation of significant variation in spinal deformity-specific DRGs *between* 6 commonly performed surgical strategies to address adult spinal deformity.

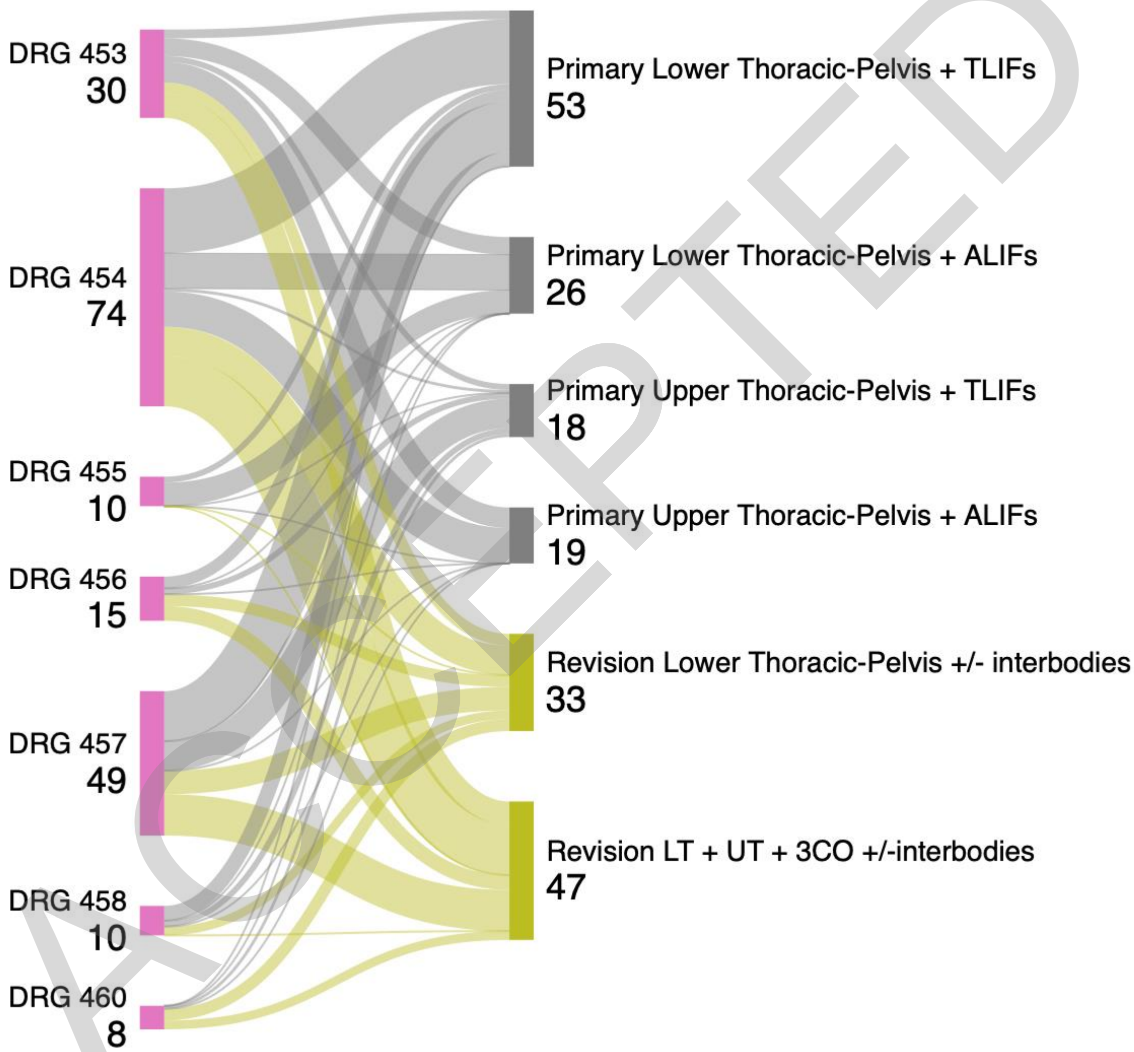

Figure 2. Graphical representation of significant variation in spinal deformity-specific DRGs *within* 6 commonly performed surgical strategies to address adult spinal deformity.

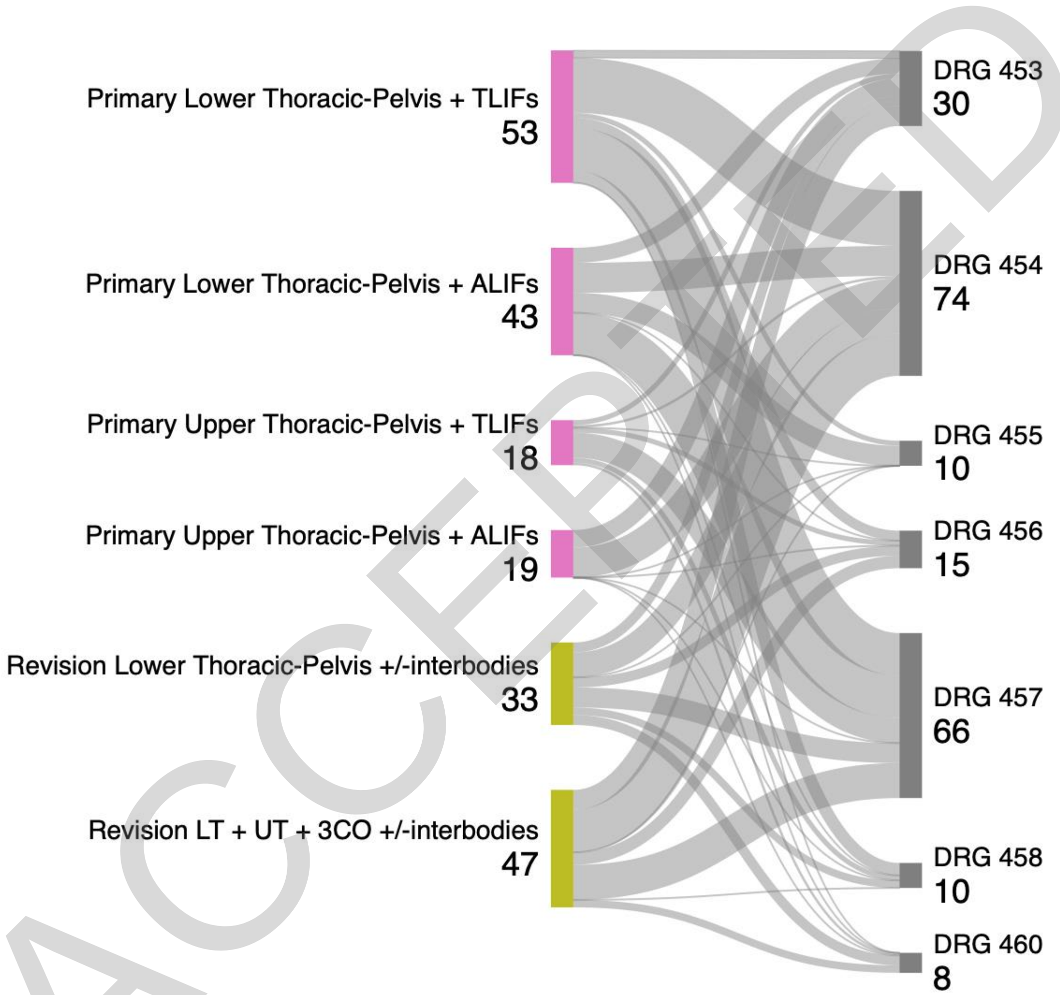

Table 1. Heterogeneity of reimbursement, demographics, and operations for adult spinal deformity patients, stratified by Medicare Diagnosis-Related Groups (DRG)

DRG	453	454	455	456	457	458	460	p
N = 314	40 (12.7%)	153 (48.7%)	16 (5.1%)	18 (5.7%)	63 (20.1%)	10 (3.2%)	15 (4.8%)	
Reimbursements ($)	81,029 ± 17,838 (65,283 - 137,325)	37,485 ± 12,254 (35,095 - 121,089)	37,936 ± 10,406 (28,043-54,227)	76,331 ± 9,308 (66,486 - 96,287)	58,802 ± 11,615 (44,539 - 103,161)	45,936 ± 6,926 (33,323 - 55,086)	34,660 ± 12,784 (11,401 - 60,402)	<0.01
Demographics								
Age (avg +/- SD; range)	67.2 ± 7.1 (47.0-79.6)	63.7 ± 10.8 (27.1-83.1)	65.3 ± 7.4 (50.0-75.1)	65.2 ± 13.2 (32.0-79.3)	66.1 ± 9.5 (37.0-82.3)	68.1 ± 7.0 (52.5-78.1)	66.0 ± 9.0 (46.8-78.4)	0.38
BMI (avg +/- SD; range)	29.0 ± 5.9 (18.6-41.6)	27.6 ± 5.7 (15.4-42.8)	30.1 ± 5.7 (20.7-40.0)	31.2 ± 3.1 (24.1-34.3)	28.1 ± 4.8 (18.6-42.5)	25.3 ± 5.9 (18.2-39.6)	27.9 ± 3.4 (21.9-35.0)	0.04
Sex Male Female	 17 (42.5%) 23 (57.5%)	 59 (38.6%) 89 (58.2%)	 7 (43.8%) 9 (56.3%)	 9 (50%) 9 (50%)	 24 (38.1%) 39 (61.9%)	 4 (40.0%) 6 (60.0%)	 9 (60.0%) 6 (40.0%)	 0.79
ASA (avg +/- SD; range)	2.7 ± 0.6 (1-4)	2.5 ± 0.6 (1-4)	2.1 ± 0.6 (1-3)	2.7 ± 0.6 (2-4)	2.6 ± 0.5 (2-4)	2.3 ± 0.5 (2-3)	2.6 ± 0.5 (2-3)	<0.01
CCI (avg +/- SD; range)	1.8 ± 2.2 (0-9)	1.0 ± 1.6 (0-11)	0.8 ± 0.9 (0-3)	1.7 ± 1.6 (0-6)	1.0 ± 1.5 (0-7)	0.6 ± 0.8 (0-2)	1.1 ± 1.7 (0-6)	0.06
Frailty score (avg +/- SD; range)	4.7 ± 2.7 (0-11)	3.1 ± 2.3 (0-11)	2.4 ± 1.7 (0-6)	4.6 ± 2.6 (0-9)	3.7 ± 2.6 (0-12)	2.5 ± 1.6 (0-5)	3.6 ± 2.0 (0-7)	<0.01
Operative Details								
Revision Primary	19 (47.5%) 21	49 (32.0%) 104	1 (6.3%) 15	7g (38.9%)	27 (42.9%) 36	3 (30.0%)	10 (66.7%)	<0.01

	(52.5%)	(68.0%)	(93.8%)	11 (61.1%)	(57.1%)	7 (70.0%)	5 (33.3%)	
UIV Upper thoracic (T1-T6) UIV Lower thoracic (T7-T12)	20 (50%) 20 (50%)	77 (50%) 76 (50%)	4 (25%) 12 (75%)	11 (61.1%) 7 (38.9%)	23 (36.5%) 40 (63.5%)	3 (30%) 7 (70%)	7 (46.7%) 8 (53.3%)	0.16
Anterior + Posterior Posterior only	21 (52.5%) 19 (47.5%)	45 (29.4%) 108 (70.6%)	8 (50.0%) 8 (50.0%)	0 (0%) 18 (100%)	0 (0%) 63 (100%)	0 (0%) 10 (100%)	0 (0%) 15 (100%)	<0.01
Interbody (yes) Interbody (no)	35 (87.5%) 5 (12.5%)	123 (80.4%) 30 (19.6%)	13 (81.3%) 3 (18.8%)	2 (11.1%) 16 (88.9%)	7 (11.1%) 56 (88.9%)	3 (30%) 7 (70%)	2 (26.7%) 13 (86.7%)	0.10
Avg # level of interbody ALIF TLIF	1.2 ± 1.7 (0-6) 0.8 ± 1.1 (0-3)	0.7 ± 1.2 (0-6) 1.2 ± 1.3 (0-5)	0.8 ± 0.8 (0-2) 1.1 ± 1.3 (0-3)	0 0.3 ± 0.8 (0-3)	0 0.3 ± 0.8 (0-3)	0 0.5 ± 0.9 (0-3)	0 0.4 ± 0.7 (0-2)	<0.01 <0.01
3CO PSO VCR	11 (27.5%) 9 (81.8%) 2 (18.2%)	34 (22.2%) 28 (82.4%) 6 (17.6%)	1 (6.3%) 1 (100.0%) 0 (0%)	6 (33.3%) 5 (83.3%) 1 (16.7%)	18 (28.6%) 17 (94.4%) 1 (5.6%)	0% 0 (0%) 0 (0%)	2 (26.7%) 2 (100%) 0 (0%)	<0.10
Blood transfusions	25 (62.5%)	76 (50%)	2 (12.5%)	11 (61.1%)	29 (46.0%)	2 (20%)	4 (26.7%)	0.01

Table 2. Heterogeneity of post-operative quality metrics associated with episode of care for adult spinal deformity patients, stratified by Medicare Diagnosis-Related Groups (DRG)

DRG	**453**	**454**	**455**	**456**	**457**	**458**	**460**	**p**
Postop								
ICU admit	32 (80.0%)	75 (49.0%)	1 (6.3%)	12 (66.7%)	32 (50.8%)	3 (30%)	5 (33.3%)	<0.01
ICU days	2.8 ± 2.1 (1-12)	1.5 ± 0.7 (0-4)	1	3.7 ± 2.1 (2-9)	1.9 ± 1.9 (0-10)	0.7 ± 0.5 (0-1)	1.8 ± 1.0 (1-4)	<0.01
Hospital length of stay (LOS)	8.7 ± 3.2 (3-14)	7.5 ± 6.3 (3-67)	4.4 ± 1.2 (3-7)	15.3 ± 19.3 (5-87)	7.1 ± 3.0 (2-19)	5.2 ± 2.4 (0-9)	7.3 ± 3.7 (2-19)	<0.01
Discharge Dispo Home SNF/rehab	16 (40%) 16 (40%)	78 (51.0%) 39 (49.0%)	14 (87.5%) 0 (0%)	9 (50%) 7 (38.9%)	38 (60.3%) 23 (36.5%)	9 (90%) 1 (10%)	10 (67.3%) 5 (33.3%)	0.05
Days in Rehab	14.0 ± 7.6 (1-31)	10.6 ± 7.3 (1-30)	n/a	22.8 ± 20.2 (12-68)	12.9 ± 6.8 (3-30)	5	18 ± 20.8 (1-59)	<0.01
Postop adverse events								
In-Hospital Any Cardiopulmonary MI VTE/DVT CVA Delirium Any infections C. diff Sepsis UTI Renal failure Dural tear Superficial SSI Deep SSI New Neuro deficit Mortality	18 (45.0%) 12 0 5 0 4 1 0 0 0 0 0 0 0 6 0	48 (31.4%) 11 0 2 1 1 5 1 0 3 0 1 1 3 23 0	1 (6.3%) 1 0 0 0 0 0 0 0 0 0 0 0 0 0	12 (66.7%) 6 1 2 2 2 1 0 0 1 0 0 0 1 3 0	11 (17.5%) 1 0 0 0 3 0 0 0 0 0 0 1 1 4 0	0 (0%) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	4 (26.6%) 2 0 1 0 0 0 0 0 0 0 0 0 0 0 0	<0.01

<30 days Any Cardiopulmonar y MI VTE/DVT CVA Delirium Any infections C. diff Sepsis UTI Renal failure Dural tear Superficial SSI Deep SSI New Neuro deficit Mortality	10 (25%) 0 0 0 0 0 4 0 2 1 0 0 0 2 1 0	28 (18.3%) 6 0 5 0 1 6 0 2 3 1 1 2 5 5 0	3 (18.8%) 1 0 0 0 0 0 0 0 0 0 0 0 1 0 0	1 (5.6%) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	8 (12.7%) 3 0 1 0 0 1 1 0 0 0 0 0 1 3 0	2 (20%) 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0	2 (13.3%) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.58
30-90 days Any Cardiopulmonar y MI VTE/DVT CVA Delirium Any infections C. diff Sepsis UTI Renal failure Dural tear Superficial SSI Deep SSI New Neuro deficit Mortality	4 (10.0%) 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0	15 (9.8%) 4 1 2 1 1 2 0 1 0 0 0 0 1 3 0	0 (0%) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	1 (6.3%) 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0	8 (12.7%) 0 0 0 0 0 0 0 0 0 0 0 1 0 5 0	1 (10.0%) 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0	1 (6.7%) 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.82

Table 3. Comparative DRG, reimbursement, patient demographic, and operative data between subgroups of 6 commonly performed surgical strategies to address adult spinal deformity.

	Primary Lower Thoracic-Pelvis (T7-12) + TLIFs (1-3 levels)	**Primary Lower Thoracic-Pelvis (T7-12) + ALIFs (1-3 levels)**	**Primary Upper Thoracic-Pelvis (T1-T6) + TLIFs (1-3 levels)**	**Primary Upper Thoracic-Pelvis (T1-T6) + ALIFs (1-3 levels)**	**Revision Lower Thoracic-Pelvis (T7-12) +/- interbodies**	**Revision LT + UT + 3CO +/- interbodies**	**p**
N	53	26	18	19	33	47	
DRGs							
453	3 (5.7%)	6 (23.1%)	2 (11.1%)	7 (36.8%)	4 (12.1%)	8 (17.0%)	<0.01
454	22 (41.6%)	12 (46.2%)	1 (5.6%)	12 (63.2%)	10 (30.3%)	17 (36.2%)	
455	2 (3.8%)	8 (30.8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	
456	4 (7.5%)	0 (0%)	2 (11.1%)	0 (0%)	4 (12.1%)	5 (10.6%)	
457	17 (32.1%)	0 (0%)	10 (55.6%)	0 (0%)	8 (24.2%)	14 (29.8%)	
458	5 (9.4%)	0 (0%)	2 (11.1%)	0 (0%)	3 (9.1%)	0 (0%)	
460	0 (0%)	0 (0%)	1 (5.6%)	0 (0%)	4 (12.1%)	3 (6.4%)	
Reimbursements ($)	55,234 ± 10,855 (33,323-86,367)	51,182 ± 19,971 (28,043-90,127)	65,582 ± 19,829 (49,139-113,651)	59,850 ± 13,430 (43,320-88,357)	61,458 ± 25,049 (29,790-137,325)	59,793 ± 18,362 (11,401-104,155)	<0.01
Demographics							
Age (avg +/- SD; range)	63.8 ± 10.3 (32.0-79.3)	70.0 ± 5.2 (57.2-79.8)	61.0 ± 9.2 (45.0-77.2)	63.6 ± 7.2 (48.6-73.4)	67.4 ± 8.5 (42.3-82.3)	63.5 ± 10.5 (32-79.3)	<0.01
BMI (avg +/- SD; range)	27.5 ± 5.9 (18.1-39.6)	28.6 ± 5.0 (21.6-37.6)	27.0 ± 5.8 (16.8-37.6)	27.4 ± 5.2 (18.6-37.7)	30.0 ± 5.5 (20.4-45.6)	29.6 ± 6.4 (18.6-42.8)	0.20
Sex							0.48
Male	23	11	5	5	16	22	
Female	30	15	13	14	17	25	
ASA (avg +/- SD; range)	2.6 ± 0.5 (2-3)	2.4 ± 0.6 (1-3)	2.7 ± 0.6 (2-4)	2.4 ± 0.5 (2-3)	2.8 ± 0.5 (2-4)	2.5 ± 0.5 (1-3)	0.02
CCI (avg +/- SD; range)	0.8 ± 1.1 (0-5)	1.1 ± 1.0 (0-3)	1.3 ± 2.1 (0-8)	0.6 ± 0.8 (0-2)	1.5 ± 2.3 (0-11)	0.9 ± 1.3 (0-5)	0.22
Frailty score	3.2 ± 2.0	3.2 ± 2.4	4.2 ± 2.2	2.8 ± 1.5	4.2 ± 2.2	4.6 ± 2.5	<0.0

(avg +/- SD; range)	(0-8)	(0-11)	(1-8)	(0-6)	(0-10)	(0-10)	1
Operative Details							
Revision	0 (0%)	0 (0%)	0 (0%)	0 (0%)	33	47	n/a
UIV Upper thoracic (T1-T6) UIV Lower thoracic (T7-T12)	0 (0%) 53 (100%)	0 (0%) 26 (100%)	18 (100%) 0 (0%)	19 (100%) 0 (0%)	0 (0%) 33 (100%)	7 (14.9%) 22 (46.9%)	n/a
Interbody (yes)	33 (62.3%)	19 (73.1%)	4 (22.2%)	19 (100%)	15 (45.5%)	19 (40.4%)	<0.01
Avg # level interbody ALIF TLIF	0 1.4±1.2 (0-3)	2.2±0.9 (1-4) 0	0 0.8±1.2 (0-4)	3.0±1.8 (0-6) 0	0.6±1.0 (0-3) 0.4±1.1 (0-5)	0.2±0.5 (0-2) 0.3±0.5 (0-2)	<0.01 <0.01
3CO PSO VCR	 0 (0%) 0 (0%)	 0 (0%) 0 (0%)	 0 (0%) 0 (0%)	 0 (0%) 0 (0%)	 0 (0%) 0 (0%)	47 (100%) 43 (91.4%) 4 (8.5%)	n/a

Table 4. Comparative post-operative quality metrics between subgroups of 6 commonly performed surgical strategies to address adult spinal deformity.

	Primary Lower Thoracic-Pelvis (T7-12) + TLIFs (1-3 levels)	**Primary Lower Thoracic-Pelvis (T7-12) + ALIFs (1-3 levels)**	**Primary Upper Thoracic-Pelvis (T1-T6) + TLIFs (1-3 levels)**	**Primary Upper Thoracic-Pelvis (T1-T6) + ALIFs (1-3 levels)**	**Revision Lower Thoracic-Pelvis (T7-12) +/- interbodies**	**Revision LT + UT + 3CO +/- interbodies**	**p**
N	53	26	18	19	33	47	
Postop							
ICU admit	28 (52.8%)	11 (42.3%)	11 (61.1%)	13 (68.4%)	14 (42.4%)	31 (65.6%)	0.11
ICU days	1.9 ± 1.9 (0-9)	1.6 ± 0.9 (1-4)	1.9 ± 1.1 (1-4)	2.2 ± 0.8 (1-4)	2.4 ± 2.4 (1-12)	2.3 ± 2.1 (0-7)	0.51
Hospital length of stay (LOS)	6.9 ± 3.7 (0-25)	5.7 ± 2.4 (3-10)	8.8 ± 4.6 (4-20)	7.7 ± 2.6 (5-13)	9.8 ± 12.2 (2-67)	10.3 ± 14.2 (3-87)	0.24
Discharge Dispo Home SNF/rehab	 30 (56.6%) 23 (43.4%)	 15 (65.2%) 8 (34.8%)	 13 (81.3%) 3 (18.8%)	 9 (69.2%) 4 (30.8%)	 12 (44.4%) 15 (55.6%)	 21 (56.8%) 16 (43.2%)	 0.39
Days in Rehab	11.0 ± 7.1 (3-30)	9.6 ± 3.1 (5-14)	9.2 ± 5.0 (4-20)	11.3 ± 3.2 (9-16)	11.6 ± 6.9 (1-31)	17.3 ± 15.8 (5-68)	<0.01
Postop adverse events							
In-Hospital Any Cardiopulmonary MI VTE/DVT CVA Delirium Any infections C. diff Sepsis UTI Renal failure Dural tear Superficial SSI	 13 (24.5%) 6 1 3 1 1 3 0 0 1 0 0 0	 5 (19.2%) 1 0 1 0 1 0 0 0 0 0 0 0	 7 (38.9%) 1 0 0 0 1 0 0 0 0 0 0 0	 3 (15.8%) 3 0 0 0 0 0 0 0 0 0 0 0	 11 (33.3%) 2 1 1 1 2 0 0 0 0 0 0 0	 16 (34.0%) 5 0 2 0 2 1 0 0 0 0 0 0	 0.41

Deep SSI	2	0	0	0	0	3	
New Neuro deficit	3	4	3	0	3	10	
Mortality	0	0	0	0	0	0	
<30 days							
Any	10 (18.9%)	5 (19.2%)	1 (5.6%)	5 (26.3%)	8 (24.2%)	5 (10.6%)	0.36
Cardiopulmonary	4	1	1	1	1	1	
MI	0	0	0	0	0	0	
VTE/DVT	2	0	0	0	1	0	
CVA	1	0	0	0	0	0	
Delirium	0	0	1	0	0	0	
Any infections	4	2	0	1	2	4	
C. diff	2	0	0	0	0	1	
Sepsis	1	0	0	0	0	2	
UTI	1	0	0	0	0	2	
Renal failure	0	0	0	0	0	0	
Dural tear	0	0	0	0	1	0	
Superficial SSI	0	0	0	1	0	0	
Deep SSI	2	2	0	0	1	1	
New Neuro deficit	2	1	3	1	2	1	
Mortality	0	0	0	0	0	0	
30-90 days							
Any	7 (13.2%)	2 (7.7%)	0 (0)	3 (15.8%)	6 (18.2%)	3 (6.4%)	0.30
Cardiopulmonary	1	0	0	1	1	1	
MI	0	0	0	0	1	0	
VTE/DVT	0	0	0	1	0	1	
CVA	0	0	0	0	1	0	
Delirium	0	0	0	0	1	0	
Any infections	0	0	1	0	1	0	
C. diff	0	0	0	0	0	0	
Sepsis	0	0	1	0	1	0	
UTI	0	0	0	0	0	0	
Renal failure	0	0	0	0	0	0	
Dural tear	0	0	0	0	0	0	
Superficial SSI	0	0	0	0	0	0	
Deep SSI	0	0	0	0	0	1	
New Neuro deficit	3	1	0	0	2	2	
Mortality	0	0	0	1	0	0	