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A Comprehensive Review of Complication Rates After Surgery for Adult Deformity: A Reference for Informed Consent

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Abstract

Objective: An up-to-date review of recent literatures and a comprehensive reference for informed consent specific to ASD complications is lacking. The goal of the present study was to determine current complication rates after ASD surgery, in order to provide a reference for informed consent as well as to determine differences between three-column and non-three-column osteotomy procedures to aid in shared decision making.

Methods: A review of the literature was conducted using the PubMed database. Randomized controlled trials, nonrandomized trials, cohort studies, case–control studies, and case series providing postoperative complications published in 2000 or later were included. Complication rates were recorded and calculated for perioperative (both major and minor) and long-term complication rates. Postoperative outcomes were all stratified by surgical procedure (ie, three-column osteotomy and non-three-column osteotomy).

Results: Ninety-three articles were ultimately eligible for analysis. The data of 11,692 patients were extracted; there were 3,646 complications, mean age at surgery was 53.3 years (range: 25–77 years), mean follow-up was 3.49 years (range: 6 weeks–9.7 years), estimated blood loss was 2,161 mL (range: 717–7,034 mL), and the overall mean complication rate was 55%. Specifically, major perioperative complications occurred at a mean rate of 18.5%, minor perioperative complications occurred at a mean rate of 15.7%, and long-term complications occurred at a mean rate of 20.5%. Furthermore, three-column osteotomy resulted in a higher overall complication rate and estimated blood loss than non-three-column osteotomy.

Conclusions: A review of recent literatures providing complication rates for ASD surgery was performed, providing the most up-to-date incidence of early and late complications. Providers may use such data in helping to counsel patients of the literature-supported complication rates of such procedures despite the planned benefits, thus obtaining a more thorough informed consent.

Keywords: Adult spinal deformity; Complications; Three-column osteotomy; PSO; Scoliosis

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Introduction

Patients with adult spinal deformity (ASD) may be significantly disabled compared with age-matched controls. Many present with pain, progression of curve, imbalance with respect to the sagittal and/or coronal plane, radiculopathy, and spinal stenosis [1,2]. When conservative treatments, such as nonsteroidal anti-inflammatory drugs, exercise, and physical therapy, do not effectively address the aforementioned symptoms, surgery is recommended [1,3,4]. Multiple studies have shown that reconstructive surgery for ASD patients can result in significant and durable improvements in health-related quality of life measures, decreased use of opioid medications, and decreased disability [5−8].

Over the past three decades, the population of ASD surgical candidates has drastically increased likely as a result of a combination of the growing aging population, technological advances in spinal instrumentation, and a broadened array of surgical techniques. For example, the introduction of third-generation pedicle screw instrumentation has facilitated improved deformity correction and stabilization. Moreover, three-column osteotomies (3CO) employing a powerful posterior-only correction strategy, including pedicle subtraction osteotomy (PSO) and vertebral column resection (VCR), have increased in frequency, especially in older patients [9−11]. As a result, many patients, who in the past may have been deemed high-risk and inoperable are now considered for major realignments and reconstructions [5,12].

When obtaining consent from patients for such complex operations, it is imperative to discuss the morbidity and mortality associated with the operation or the untreated condition, both of which increase with age [1,5,13]. Previous reviews of postoperative ASD complication rates have been conducted, but they include adolescent populations or are limited to a specific deformity etiology [14,15]. Moreover, these studies typically do not provide individual complication rates and do not stratify data based on the invasiveness of the osteotomy employed. Overall, the statistics provided by such studies may be outdated and unsuitable for wide applicability in adult deformity surgical candidates.

This paper is a comprehensive review of complication rates exclusive to ASD, with the ultimate goal of providing patients and surgeons with a guiding tool in the surgical decision-making process. The objectives of this review are to answer the following clinical questions:

What are the specific, peer-reviewed literature−supported perioperative (⩽3 months) major and minor complication rates for patients with ASD?
What are the long-term (>3 months) complication rates for this patient population?
Are there substantial differences in complication for non-3CO versus 3CO, both with respect to complication rate and complication type?

Methods

Search strategy

A query of the PubMed database was performed, as well as a review of the bibliographies of eligible articles. The broad search was designed to include the postoperative outcomes for ASD. The following search strings were used: ‘‘adult scoliosis surgery outcome,’’ ‘‘adult scoliosis complications,’’ ‘‘adult ‘spinal deformity’ surgery,’’ ‘‘three column osteotomy,’’ ‘‘pedicle subtraction osteotomy,’’ ‘‘vertebral column resection deformity,’’ and ‘‘sagittal imbalance adult surgery.’’ A filter for studies published in 2000 or later was employed so that studies would largely consist of third-generation instrumentation and the most modern surgical techniques.

Eligibility criteria

Criteria for possible inclusion were the following:

Articles published in 2000 or later
Articles written in English or with a complete English translation
Articles providing quantitative results with respect to perioperative (⩽3 months) and long-term (>3 months) complications and/or estimated blood loss (EBL) specific to ASD
Fully published, peer-reviewed, retrospective or prospective studies including randomized controlled trials, nonrandomized trials, cohort studies, case−control studies, and case series
Articles reporting the results of open or ‘‘hybrid’’ (a combination of open and minimally invasive techniques) approach surgeries
ASD involving the following etiologies: degenerative, idiopathic, neuromuscular, congenital, traumatic, infection-related (eg, tuberculosis), ankylosing spondylitis, osteoporotic, and iatrogenic.

Criteria for exclusion were the following:

Articles that did not provide clear, quantitative complication data specific to ASD surgery
Nonadult patients (patient age <18 years)
Articles that did not have more than 95% of patients undergoing instrumented surgeries
Retrospective studies with less than a 24-month mean clinical and radiographic follow-up (FU) period, unless the patient population exceeded 300 or reported neurological complications only
Prospective studies with less than an 18-month mean clinical and radiographic FU period (because of the paucity of studies)
Studies including tumor-related deformity, unless it constituted less than 1.5% of the study population

Studies with fewer than 5 patients for 3CO, and studies with fewer than 10 patients for non-3CO or mixed (lumped 3CO and non-3CO results) surgeries

Data collection and statistical methods

The following data were extracted: number of patients, type of surgery used (ie, non-3CO or 3CO), etiology of deformity, deformity planes corrected, mean age of patients, length of FU period, EBL, number and types of complications, and overall complication rate. Retrospective studies with a mean follow-up of less than 24 months and prospective studies with a mean follow-up of less than 18 months were excluded from our analysis to maintain uniformity and to attempt to prevent an underestimation of longer-term complicating incidents (eg, hardware failure, nonunion, etc) given these studies have unknown long-term complication rates.

Data for perioperative ($\leqslant$3 months) complications and long-term ($>$3 months) complications were collected. Further, perioperative complications were stratified into ''major'' and ''minor'' complications; the difference in complication severity was generally determined using the system described by Glassman et al. [16]. Complications not mentioned by Glassman's system were categorized based on whether the study in which they were listed described them as major or minor. Additionally, instrument failure, fractures, and pseudarthroses were assumed to have occurred beyond the 3-month perioperative window if unspecified. Moreover, if a study grouped two individual complications (eg, ''instrument failure or pseudarthrosis''), the total number of occurrences was split in half and distributed evenly between the two complications.

Individual complications were tabulated, and rates were calculated by dividing the total number of occurrences by the number of patients affected. The ''number of patients affected'' was calculated by summing the patient populations of the studies reporting a specific complication. This denominator accounted for studies that exclusively reported a specific complication (eg, pseudarthrosis or neurological complications only) or complications within a specific postoperative time frame (eg, perioperative period or long-term complications only); in other words, each denominator was uniquely adjusted for a given complication. The overall mean complication rate was obtained by summing the overall major perioperative complication rate, overall minor perioperative complication rate, and the overall long-term complication rate. General surgical outcomes were presented in a table format similar to that of the systematic review by Yadla et al. [15].

Complications were also distinguished by the surgical procedure used (ie, non-3CO vs. 3CO). SPO, anterior fusion, anteroposterior fusion, and/or posterior fusion without the mention of a more invasive osteotomy (ie, 3CO) were classified as non-3CO. ''Opening-wedge osteotomy'' was categorized as a SPO. PSO and VCR were considered 3CO procedures. The following descriptions were categorized as a PSO: closing wedge osteotomy, transpedicular wedge resection, closing–opening wedge osteotomy, anterior opening–posterior closing, apical lordosating osteotomy, and egg-shell osteotomy. Additionally, anterior opening-posterior closing was categorized as a PSO despite it being an intermediate between PSO and VCR with respect to invasiveness [17]. Aside from ''non-3CO'' and ''3CO,'' a ''mixed'' label was assigned to studies that combined the surgical results of both 3CO and non-3CO patients as well as studies that mentioned the use of osteotomy without further description.

Level of evidence

The level of evidence of a given study was assigned based on the 2005 scoring system adopted by the North American Spine Society [18]. Level I studies include high-quality, randomized trials with a statistically significant difference, or trials with no statistically significant difference but narrow confidence intervals, and systematic reviews of Class I randomized, controlled trials providing consistent results. Level II therapeutic studies include lesser quality randomized, controlled trials, prospective comparative studies, and systematic reviews of Level I or II studies with inconsistent results. Level III therapeutic studies include case–control studies, retrospective comparative studies, and systematic reviews of Level III studies. The lowest relevant level of evidence, Level IV, consists of case series. The studies were reviewed by two people, and any ambiguities regarding the level of evidence were resolved through discussion and a third reviewer's opinion if needed.

Statistical analysis

The number of complications from each study was tabulated. Complication rates were calculated by dividing the number of complications by the available patients and were reported as percentages. Rates were determined for each individual study and for combined studies for the following groups: overall, major, minor, and long-term complications as well as for prospective studies, retrospective studies, patients that underwent a VCR only, and with or without 3CO. The average $\pm$ 1 standard deviation of the complication rates for each group was also calculated.

Results

Search results

The queries ''adult scoliosis surgery outcome,'' ''adult scoliosis complications,'' ''three column osteotomy,''

"pedicle subtraction osteotomy," "vertebral column resection deformity," and "sagittal imbalance surgery adult" yielded 995, 1,324, 52, 159, 418, and 170 results, respectively. Ultimately, 93 studies (Tables 1 and 2) were deemed suitable for analysis; 12 studies (12.9%) were prospective, 5 (~5.4%) were Level II studies, 19 (~20.4%) were Level III studies, and 69 (~74.2%) were Level IV studies (Fig.). Moreover, 80 of the 93 studies (86%) provided complications data with respect to perioperative and long-term outcomes, whereas 13 (14%) provided data with respect to a specific complication only and/or complications within a specific postoperative time frame (Table 1).

Overall outcomes

There was a total of 11,692 patients with reported postoperative outcomes (Table 1), though only 11,318 patients provided complication data. Overall, the mean age was 53.3 years (range: 25–77 years), mean follow-up was 3.49 years (range: 6 weeks–9.7 years), and estimated blood loss was 2,161 mL (range: 717–7,034 mL). There was a total of 3,615 complications, and an overall complication rate of 55%. Overall, complication rates ranged from 0 complications per patient to 1.7 complications per patient (Table 2). Specifically, major perioperative complications occurred at a mean rate of 18.5%, minor perioperative complications occurred at a mean rate of 15.7%, and long-term complications occurred at a mean rate of 20.5% (Tables 3–5).

Major perioperative complications

The top five leading *individual* major perioperative complications were neurological deficit (322 instances; 3.1%), unspecified complication requiring surgery (148 instances; 3.0%), severe/deep wound infection (232 instances; 2.4%), instrumentation/graft failure (62 instances; 1.3%), and excessive bleeding (122 instances; 1.2%). However, in aggregating wound infection, pneumonia, sepsis, line-related infection, and pancreatitis rates, overall infection was the leading major complication (286 instances; 3.2%). Additionally, in aggregating unspecified pulmonary, respiratory distress syndrome/respiratory failure, pleural effusion/pneumothorax requiring intervention, and reintubation, the overall respiratory complication rate was the fifth most frequent major complication (101 instances; 2.1%) behind overall infection, neurological deficit, unspecified complication requiring surgery, and severe/deep wound infection (Table 3).

Minor perioperative complications

The top five leading *individual* minor perioperative complications were "unspecified or other" (302 instances; 3.1%), dural tear (292 instances; 3.0%), ileus/gastrointestinal complication (101 instances; 2.1%), transient neurological deficit (148 instances; 1.5%), and superficial or nonoperative wound infection (99 instances; 1.0%). Disregarding the ambiguous "unspecified or other" complication, deep vein thrombosis was the fifth most common individual minor complication (66 instances; 0.7%). However, in aggregating pleural effusion, pneumothorax, pulmonary congestion, hemothorax, and unspecified pulmonary complication rates, overall respiratory complication superseded deep vein thrombosis as the fifth most common minor complication (46 instances; 1.0%) (Table 4).

Long-term complications

The top five leading *individual* long-term complications were pseudarthrosis (337 instances; 7.6%), instrumentation/graft failure (295 instances; 3.3%), proximal junctional kyphosis (PJK, 119 instances; 2.9%), adjacent segment degeneration (105 instances; 2.7%), and symptomatic instrumentation possibly requiring removal (80 instances; 2.0%). In aggregating pseudarthrosis, instrumentation/graft failure, PJK, adjacent segment degeneration, symptomatic instrumentation possibly requiring removal, and unspecified revision, overall instrument-related failure was the leading long-term complication (939 instances; 20.5%) (Table 5).

Retrospective versus prospective data

There was a notable disparity in the amount of retrospective data versus prospective data available; whereas 81 studies, 10,671 patients, and 3,077 complications were retrospectively reported, 12 studies, 1,021 patients, and 538 complications were prospectively reported. Mean patient age was similar: 53.4 years (range: 26.8–77) for retrospective data and 52.5 years (range: 25–72) for prospective data. Mean FU was 3.80 years (range: 0.11–9.7) for retrospective data but 2.10 years (range: 0.11–4.64) for prospective data. Mean EBL was 2,221 mL (range: 717–7,034 mL) for retrospective data and 1,909 mL (range: 985–3,520 mL) for prospective data. Finally, the overall mean retrospective complication rate was 53% (range: 0%–169%), but the overall mean prospective complication rate was 74% (range: 9%–109%) (Table 2).

Non-3CO versus 3CO versus VCR

Non-3CO

There were 32 non-3CO studies reporting data on 1,600 patients (28 studies and 1,432 patients of which were retrospectively reported); mean age was 52.4 years (range: 26.8–74), mean FU was 3.98 years (range: 2–9.7 years), and EBL was 1,718 mL (range: 950–2,850 mL). Non-3CO patients experienced 584 total complications at an overall complication rate of 45% (Table 2). The overall *major* perioperative complication rate was 8.9%. The top five leading *major* perioperative complications (including aggregated complications) were overall infection (3.1%);

Table 1
Studies reporting complications following surgery for adult spinal deformity.

Authors and year	Level of evidence	Study design	Patients	Surgery	Etiology	Deformity plane	Mean age (at surgery)	Mean or median FU (years)	EBL (mL)	No. of complications	Complication rate
Acosta et al., 2011 [19]	IV	Retrospective	21	Mixed (10 PSO)	Sc, AS, U	S, C	77	3.43	—	35	1.67
Ahn et al., 2002 [20]	IV	Prospective	83	Mixed (38 PSO)	PS, Deg, AS, Sc, Cong, U	S, C	49.8	4.64	3,520	79	0.95
Ali et al., 2003 [1]	IV	Retrospective	28	Non-3CO	Sc	S, C	48.5	2	1,600	5	0.18
Arun et al., 2011 [21]	III	Retrospective, cohort	31	Mixed (12 PSO)	AS	S	54.7	5	—	16	0.52
Berven et al., 2001 [22]	IV	Retrospective	13	3CO (PSO)	PS, AS, Sc, In	S	45.1	4.75	—	10	0.77
Berven et al., 2007 [23]	IV	Retrospective	38	Non-3CO	Sc	S, C	64	2.33	—	24	0.63
Bess et al., 2007 [24]	III	Retrospective, cohort	56	Mixed	Sc, Cong, PS, PT	S, C	49	3.6	—	23	0.41
Bess et al., 2013 [25]	II	Prospective, cohort	279	Mixed	Sc	S, C	57	2.4	1,914	304	1.09
Bezer et al., 2007 [26]	IV	Retrospective	16	3CO (PSO)	In	S	51	8.95	2,780	2	0.13
Bhagat et al., 2013 [27]	IV	Retrospective	48	Mixed (8 PSO, 2 VCR)	Sc	S, C	64	3	—	27	0.56
Boachie-Adjei et al., 2006 [28]	IV	Retrospective	24	3CO (PSO)	PS, PT, AS, Deg, Cong		48	4	2,700	17	0.71
Boachie-Adjei et al., 2007 [29]	IV	Retrospective	10	Non-3CO	Sc	S, C	60.6	5.2	—	3	0.3
Bridwell et al., 2003 [30]	IV	Prospective	33	3CO (PSO)	Sc, Deg, PT, AS	S	53.4	2	2,386	32	0.97
Bridwell et al., 2003 [31]	IV	Retrospective	27	3CO (PSO)	Sc, Deg, PT, AS	S	52.4	2	2,396	24	0.89
Bridwell et al., 2009 [7]	II	Prospective, matched cohort	85	Mixed	Sc	C	60	2	—	31 (15 major; 16 minor)	—
Brodano et al., 2013 [32]	IV	Retrospective	20	Non-3CO	Sc	C	55.3	2.5	—	15	0.75
Buchowski et al., 2007 [33]	IV	Retrospective	108	3CO (PSO)	Sc, Deg, PT, PS, AS, Cong	S	54.8	—		12	0.11
Chang et al., 2005 [34]	IV	Retrospective	26	3CO (ALO)	Ost		71.6	3.2	717	2	0.08
Chang et al., 2005 [12]	III	Retrospective, cohort	66	Non-3CO	AS	S	33.5	3.6	1,101	27	0.41
			51	3CO (PSO)			36.3	3.5	1,915	17	0.33
Chang et al., 2008 [35]	IV	Retrospective	83	3CO (COWO)	PS, PT, AS, Deg	S	66.1	2	3,340	45	0.54
Charosky et al., 2012 [36]	IV	Retrospective	306	Mixed (27 PSO)	Sc	S, C	63	4.5	—	175	0.57
Chen et al., 2001 [37]	IV	Retrospective	78	3CO (PSO)	AS	S	37	3.83	1,150	11	0.14
Chen et al., 2011 [38]	III	Retrospective, cohort	71	Non-3CO	Sc	S, C	42.9	2	1,678	20	0.28
Cho et al., 2005 [39]	III	Retrospective, cohort	30	Non-3CO	Sc, Deg, PT, AS, PS	S	40.1	2	1,392	14	0.47
			41	3CO (PSO)			40.1	2	2,617	24	0.59
Cho et al., 2007 [40]	IV	Retrospective	47	Non-3CO	Sc	S, C	66.6	3.8	2,106	33	0.7
Cho et al., 2008 [41]	IV	Retrospective	50	Non-3CO	Sc	S, C	65.5	4.3	2,176	33	0.66
Cho et al., 2012 [42]	III	Retrospective, cohort	166	Mixed (42 PSO, 2 VCR)	Sc, Deg, PT, PS, Cong, AS, U	S, C	53.7	3.5	1,403	124	0.75
Cho et al., 2012 [43]	III	Retrospective, cohort	250	Mixed (39 PSO, 6 VCR)	Sc	S, C	51.4	3.6	1,236	128	0.51

(*Continued on next page*)

Table 1 (*Continued*)

Authors and year	Level of evidence	Study design	Patients	Surgery	Etiology	Deformity plane	Mean age (at surgery)	Mean or median FU (years)	EBL (mL)	No. of complications	Complication rate
Cho et al., 2013 [44]	IV	Retrospective	34	3CO (PSO)	Deg	S	65.5	3.1	—	16	0.47
Daubs et al., 2007 [45]	IV	Retrospective	46	Mixed (19 PSO)	Sc, AS, Cong, U	S, C	67	4.2	2,056	44	0.96
Deviren et al., 2008 [46]	IV	Retrospective	15	Non-3CO	Sc	S, C	37.5	3.9	—	6	0.4
Dewald et al., 2006 [47]	IV	Retrospective	38	Mixed (10 PSO)	Sc, AS, PS	S	72.4	2.5	—	30	0.79
Eck et al., 2001 [48]	IV	Retrospective	58	Mixed	Sc, PS	S, C	43	5	—	16	0.28
Edwards II et al., 2003 [49]	IV	Retrospective	34	Mixed	PS, Sc, Deg, PT	S, C	45	5.6	—	11	0.32
El-Sharkawi et al., 2011 [50]	II	Prospective, cohort	37	Non-3CO	PT	S	34.8	2.89	1,072	6	0.16
			43	3CO (PSO)			34.8	2.89	1,107	4	0.09
Emami et al., 2002 [51]	III	Retrospective, cohort	54	Mixed	Sc, PS, Deg, U	S, C	54.9	4.75		51	0.94
Finocchiaro et al., 2012 [52]	IV	Retrospective	62	Mixed (16 PSO)	Deg, Sc, PS	S	59	6.37	—	12	0.19
Gavaskar et al., 2011 [53]	IV	Prospective	52	3CO (PSO)	Inf, Cong, PT, U	S	25	2.58	1,100	22	0.42
Glattes et al., 2005 [54]	IV	Retrospective	81	Mixed	Sc, U	S, C	45	5.3	—	21	0.26
Hassanzedah et al., 2013 [10]	IV	Retrospective	51	3CO (15 VCR)	U	S, C	68	2	3,900	29	0.57
Hyun et al., 2010 [55]	IV	Retrospective	13	3CO (PSO)	PS, PT, Deg	S	59	6.08	2,984	22	1.69
Ikenaga et al., 2007 [56]	IV	Retrospective	67	3CO (PSO)	PT, Deg, Cong	S	68.8	3.8	1,988	43	0.64
Jang et al., 2007 [57]	IV	Retrospective	19	Non-3CO	PS	S	62	2.58	—	4	0.21
Jang et al., 2009 [58]	IV	Retrospective	21	Non-3CO	Deg	S	64.5	2.67	1,800	5	0.24
Kasliwal et al., 2012 [59]	III	Retrospective, matched cohort	60	Mixed (6 PSO or VCR)	Sc	S, C	64	2	1,716	38	0.63
Kasten et al., 2010 [60]	IV	Retrospective	78	Mixed (PSO)	Sc, PS, U, PT	S, C	67.6	3.7	—	48	0.62
Kim et al., 2005 [61]	IV	Retrospective	96	Non-3CO	Sc	S, C	42.2	5.9	—	16	0.17
Kim et al., 2006 [62]	IV	Retrospective	232	Mixed	Sc, U, PS	S, C	40.8	5		40	0.17
Kim et al., 2006 [63]	IV	Retrospective	144	Mixed	Sc, PS, PT, U	S, C	52	3.9	—	34	0.24
Kim et al., 2007 [64]	IV	Retrospective	35	3CO (PSO)	PS, Sc, Deg, PT, U	S	53.1	5.8	—	25	0.71
Kim et al., 2007 [65]	IV	Retrospective	12	Mixed (6 PSO)	AS, PS, PT	S	42.8	4.25	—	7	0.58
Kim et al., 2008 [66]	III	Retrospective, cohort	48	Non-3CO	Sc	S, C	49.6	3.7	—	19	0.4
Lapp et al., 2001 [67]	III	Retrospective, cohort	44	Mixed	Sc, PS, Cong, PT	S, C	42.6	3.5	—	27	0.61
Lenke et al., 2010 [68]	IV	Retrospective	16	3CO (VCR)	Sc, U	S, C	43.5	2.2	1,691	7	0.44
Lenke et al., 2013 [69]	IV	Prospective	256	Mixed (202 3CO)	Cong, U, PS	S, C	57.7	0.11	—	44	0.17
Li et al., 2009 [70]	III	Retrospective, cohort	34	Mixed	Sc	S, C	75.1	2.8	—	6	0.18
Norton et al., 2013 [71]	IV	Retrospective	423	3CO (PSO, VCR)	U	S	—	0.11	—	360	0.85
Ohtori et al., 2012 [72]	IV	Retrospective	20	Non-3CO	Sc, Deg, PS	S, C	66	3	—	5	0.25
Okuda et al., 2012 [11]	III	Retrospective, cohort	26	Non-3CO	Ost	S	74	4.17	1,472	17	0.65
			14	3CO (PSO)			73	4.17	1,581	15	1.07
O'Shaughnessy et al., 2009 [73]	IV	Retrospective	15	3CO (14 PSO, 1 VCR)	AS, PS, PT, Sc	S	56	3.5	—	16	1.07
Park et al., 2013 [74]	IV	Retrospective	24	Mixed (23 PSO)	AS	S	38	2.47	—	2	0.08
Patedar et al., 2008 [75]	IV	Retrospective	361	Mixed	Sc, PS, U	S, C	48	7	2,817	20	0.06

Patedar et al., 2008 [76]	IV	Retrospective	—	Mixed	Sc, PS, U	S, C	48	7	2,817	10	—
Peelle et al., 2008 [77]	IV	Retrospective	30	Non-3CO	Sc	S, C	40	3.3	—	4	0.13
Ploumis et al., 2010 [78]	II	Prospective, matched cohort	28	Non-3CO	Sc	C	72	2	—	5	0.18
Qian et al., 2012 [79]	IV	Retrospective	7	3CO (PSO)	AS	S	41.7	3.17	2,670	0	0
Rhee et al., 2003 [80]	IV	Retrospective	42	Mixed (25 PSO)	PS, AS, Sc, U	S	47	2	2,018	25	0.6
Rose et al., 2009 [81]	II	Prospective, matched cohort	68	Non-3CO	Sc	S, C	38.3	3	985	10	0.15
Sansur et al., 2011 [82]	IV	Retrospective	4,980	Mixed	Sc	S, C	54.1	—	—	669	0.13
Scheer et al., 2014 [83]	IV	Retrospective	374	3CO (299 PSO, 75 VCR)	U	S, C	—	—	2,722	—	—
Shapiro et al., 2003 [84]	IV	Retrospective	16	Mixed	Sc	S, C	66.3	3.4	1,833	12	0.75
Smith et al., 2002 [85]	IV	Retrospective	15	Non-3CO	Sc	S, C	37.5	5.1	—	8	0.53
Smith et al., 2011 [86]	IV	Retrospective	578	Mixed (157 PSO, 14 VCR)	PS, Inf, Deg, Cong, U	S	58	—	—	171	0.3
Suk et al., 2002 [87]	IV	Retrospective	70	3CO (VCR)	Sc, Cong, In	S, C	27.4	2.8	2,333	24	0.34
Suk et al., 2005 [88]	IV	Retrospective	16	3CO (VCR)	Sc, Cong	S, C	29	4.7	7,034	4	0.25
Suk et al., 2005 [89]	IV	Retrospective	25	3CO (VCR)	Sc, PT, Inf	S, C	38	4.19	2,810	5	0.2
Takahashi et al., 2002 [90]	III	Retrospective, cohort	58	Non-3CO	Sc	S, C	35.2	3.6	—	17	0.29
Toyone et al., 2012 [91]	IV	Prospective	14	3CO (PSO)	Sc	S, C	67	2.7	1,090	4	0.29
Tsai et al., 2011 [92]	III	Retrospective, cohort	58	Non-3CO	Sc	S, C	68.9	3.2	1,598	59	1.02
Wang et al., 2002 [93]	III	Retrospective, cohort	22	Non-3CO	Sc	C	26.8	4.7	1,170	4	0.18
Wang et al., 2008 [94]	IV	Retrospective	13	3CO (VCR)	Sc	S, C	31	2.54	2,412	4	0.31
Wang et al., 2009 [95]	IV	Retrospective	8	3CO (VCR)	Inf	S	27.5	2.55	2,933	1	0.13
Wang et al., 2010 [96]	IV	Prospective	8	3CO (PSO)	AS	S	34.5	1.56	2,200	2	0.25
Weistroffer et al., 2008 [97]	IV	Retrospective	50	Non-3CO	Sc, AS, Cong	S, C	54	9.7	—	69	1.38
Wu et al., 2008 [98]	IV	Retrospective	26	Non-3CO	Sc	S, C	64.2	3	1,678	4	0.15
Yagi et al., 2013 [99]	IV	Retrospective	57	Non-3CO	Sc	C	53.8	4.8	2,034	11	0.19
Yagi et al., 2014 [100]	III	Retrospective, case-control	66	Non-3CO	Sc	S, C	56.5	5.1	2,850	19	0.29
Yang et al., 2006 [101]	IV	Retrospective	35	3CO (PSO)	Sc, PT, AS, PS	S	57.4	2	5,800	32	0.91
Zeng et al., 2013 [17]	III	Retrospective, cohort	19	3CO (19 PSO)	PT, PS, In, Cong	S	38.5	2.58	1,370	4	0.21
			23	3CO (23 AOPC)			38.5	2.58	2,300	6	0.26
			39	VCR			38.5	2.58	2,710	15	0.38
Zhang et al., 2010 [102]	IV	Retrospective	5	3CO (VCR)	PT	S, C	36	2	1,362	2	0.4
Zhang et al., 2014 [103]	IV	Retrospective	9	3CO (PSO)	AS	S	41.4	3.33	3,311	7	0.78
Zhu et al., 2012 [104]	III	Retrospective, cohort	19	Non-3CO	AS	S	32.6	2.64	950	8	0.42
			31	3CO (PSO)	AS	S	32.6	2.64	1,740	5	0.16
Zimmerman et al., 2010 [105]	IV	Prospective	35	Non-3CO	Sc	S, C	56.3	4.1	2,735	26	0.74

ALO, apical lordosating osteotomy; AOPC, anterior opening-posterior closing; AS, ankylosing spondylitis; C, coronal; Cong, other congenital/inherited conditions (eg, neurofibromatosis); COWO, closing−opening wedge osteotomy; Deg, degenerative; EBL, estimated blood loss; FU, follow-up; In, infectious; Ost, osteoporotic; PS, postsurgical/iatrogenic; PSO, pedicle subtraction osteotomy; PT, post traumatic scoliosis; S, sagittal; Sc, scoliosis (idiopathic, degenerative, cong., neuromuscular); 3CO, three-column osteotomy; U, unspecified or other coronal and/or sagittal imbalance; VCR, vertebral column resection.

The following studies provided complication data limited to the following: [15], overall major and minor rates; [17], neurological only; [106], instrument-related only; [83], instrument-related only; [24], proximal junctional kyphosis only; [32], pseudarthrosis only; [33,34], pseudarthrosis only; [40], short-term neurological only; [42,55], short-term only; [48], death only; [49].

Table 2
Overview of studies reporting complications and/or EBL following surgery for adult spinal deformity.

	Studies	Patients	Total no. of complications	Mean age (at surgery)	Mean FU (years)	EBL (mL)	Overall complication rate
All Studies	93	11,692*	3,615	53.3 (25–77)	3.49 (0.11–9.7)	2,161 (717–7,034)	0.6 (0–1.7)
All non-3CO	32	1,600	584	52.4 (26.8–74)	3.98 (2–9.7)	1,718 (950–2,850)	0.5 (0.1–1.4)
All 3CO	38	2,142*	969	49.8 (25–73)	2.32 (0.11–8.95)	2,492 (717–7,034)	0.7 (0–1.7)
All VCR	9	206	72	34.7 (27.4–58)	3.00 (2–4.7)	2,815 (1,362–7,034)	0.4 (0.1–0.7)
Retrospective (All)	81	10,671*	3,077	53.4 (26.8–77)	3.80 (0.11–9.7)	2,221 (717–7,034)	0.5 (0–1.7)
Retrospective (non-3CO only)	28	1,432	537	53.0 (26.8–74)	4.14 (2–9.7)	1,783 (950–2,850)	0.5 (0.1–1.4)
Retrospective (3CO only)	33	1,992*	905	51.2 (27.4–73)	2.31 (0.11–8.95)	2,625 (717–7,034)	0.7 (0–1.7)
Retrospective (VCR only)	9	206	72	34.7 (27.4–58)	3.00 (2–4.7)	2,815 (1,362–7,034)	0.4 (0.1–0.7)
Prospective (All)	12	1,021	538	52.5 (25–72)	2.10 (0.11–4.64)	1,909 (985–3,520)	0.7 (0.1–1.1)
Prospective (non-3CO only)	4	168	47	46.9 (34.8–72)	3.04 (2–4.1)	1,445 (985–2,735)	0.3 (0.2–0.7)
Prospective (3CO only)	5	150	64	38.5 (25–67)	2.50 (1.56–2.89)	1,443 (1,090–2,386)	0.4 (0.1–1.0)
Prospective (VCR only)	0	0	—	—	—	—	—

EBL, estimated blood loss; FU, follow-up; 3CO, three-column osteotomy; VCR, vertebral column resection.

Not all studies provided complications or EBL; "mixed" (lumped non-3CO and 3CO data) studies are not explicitly shown; Bridwell et al. 2009 population was excluded from calculations (only used as comparative reference).

* Scheer et al. 2014 population (374 patients) was included for EBL data.

severe/deep wound infection (2.8%); neurological deficit (1.4%); overall hematoma, the aggregate of epidural hematoma, wound hematoma or seroma, and retroperitoneal hematoma (0.9%); and instrumentation/graft failure (0.6%) (Table 6). The overall *minor* perioperative complication rate was 15.4%. The top five leading *minor* perioperative complications (including aggregated complications) were ileus/gastrointestinal complications (3.4%), dural tear (3.0%), urinary tract infection (1.7%), unspecified or other (1.5%), and transient neurological deficit (1.3%) (Table 7).

Finally, the overall *long-term* complication rate was 21.2%. The top five long-term complications (including aggregated complications) were overall instrument-related failure (20.2%), pseudarthrosis (6.4%), instrument/graft failure (5.2%), adjacent segment degeneration (4.7%), and PJK (2.0%) (Table 8).

3CO

There were 38 3CO studies reporting data on 2,142 patients (33 studies and 1,992 patients of which were

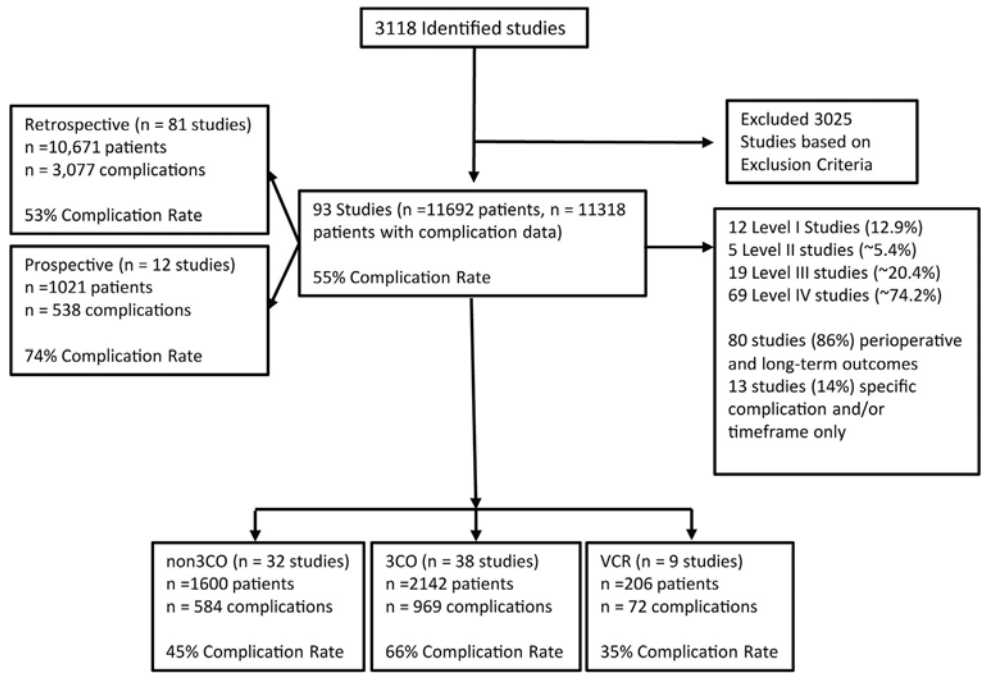

Fig. Flow diagram of identified studies, number of patients, and complication rates by level of evidence, type of study and type of osteotomy performed.

Table 3
All studies: individual major complication rates.

Major complications	All		Retrospective		Prospective	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Neurological deficit (not transient, not full recovery, resolved with reoperation, or classified as "major")	322 (3.1)	3.1% ± 4.3% (0%−17.2%)	240 (2.6)	3% ± 4% (0%−16.3%)	82 (8.8)	3.9% ± 6.2% (0%−17.2%)
Unspecified requiring surgery	148 (3.0)	0.5% ± 3.2% (0%−24.4%)	80 (1.9)	0.2% ± 2.1% (0%−18.9%)	68 (10)	2.2% ± 7.3% (0%−24.4%)
Wound infection requiring debridement and/or reoperation (especially deep)	232 (2.4)	2.6% ± 3.7% (0%−20%)	213 (2.3)	2.6% ± 3.7% (0%−20%)	19 (2.8)	1.8% ± 3.5% (0%−11.4%)
Instrumentation/graft failure (breakage, dislodgement, or resulting in inadequate correction) requiring revision	62 (1.3)	1.1% ± 3% (0%−15.2%)	43 (1.0)	1% ± 2.7% (0%−13.3%)	19 (2.8)	2% ± 4.6% (0%−15.2%)
Excessive bleeding	122 (1.2)	0.6% ± 3.1% (0%−24.1%)	122 (1.3)	0.7% ± 3.3% (0%−24.1%)	0 (0)	0% ± 0% (0%−0%)
Unspecified pulmonary	43 (0.9)	0.1% ± 0.4% (0%−3.2%)	43 (1.0)	0.1% ± 0.4% (0%−3.2%)	0 (0)	0% ± 0% (0%−0%)
Pulmonary embolism or thrombosis of major vessel	71 (0.7)	0.8% ± 1.9% (0%−9.5%)	66 (0.7)	0.9% ± 2% (0%−9.5%)	5 (0.7)	0.4% ± 0.9% (0%−2.9%)
Respiratory distress syndrome/respiratory failure	28 (0.6)	0.3% ± 1% (0%−4.9%)	28 (0.7)	0.3% ± 1% (0%−4.9%)	0 (0)	0% ± 0% (0%−0%)
Pneumonia/lung infection	27 (0.6)	0.6% ± 2% (0%−14.3%)	20 (0.5)	0.6% ± 2.1% (0%−14.3%)	7 (1.0)	0.5% ± 1.1% (0%−3.6%)
Vascular injury (intraoperative)	22 (0.5)	0.4% ± 1.5% (0%−10.9%)	17 (0.4)	0.3% ± 1.4% (0%−10.9%)	5 (0.7)	0.7% ± 1.6% (0%−4.8%)
Death	44 (0.4)	0.3% ± 0.9% (0%−5.3%)	41 (0.4)	0.3% ± 0.9% (0%−5.3%)	3 (0.4)	0.1% ± 0.3% (0%−1.1%)
Epidural hematoma	39 (0.4)	0.6% ± 1.9% (0%−10.5%)	39 (0.4)	0.7% ± 2% (0%−10.5%)	0 (0)	0% ± 0% (0%−0%)
Wound hematoma or seroma	38 (0.4)	0.2% ± 1% (0%−6.3%)	36 (0.4)	0.3% ± 1% (0%−6.3%)	2 (0.3)	0.1% ± 0.2% (0%−0.7%)
Pleural effusion or pneumothorax (requiring intervention)	15 (0.3)	0.5% ± 2.5% (0%−20%)	9 (0.2)	0.4% ± 2.4% (0%−20%)	6 (0.9)	1.1% ± 2.7% (0%−8.6%)
Reintubation	15 (0.3)	0.3% ± 1.2% (0%−7.4%)	13 (0.3)	0.2% ± 1.1% (0%−7.4%)	2 (0.3)	0.6% ± 1.8% (0%−6.1%)
Stroke	15 (0.3)	0.2% ± 0.9% (0%−6.7%)	13 (0.3)	0.2% ± 1% (0%−6.7%)	2 (0.3)	0.1% ± 0.2% (0%−0.7%)
Vertebral compression fracture	12 (0.2)	0.6% ± 2.6% (0%−15.8%)	11 (0.3)	0.5% ± 2.4% (0%−15.8%)	1 (0.2)	1.1% ± 3.8% (0%−12.5%)
Sepsis	23 (0.2)	0.1% ± 0.5% (0%−2.9%)	20 (0.2)	0.1% ± 0.5% (0%−2.9%)	3 (0.4)	0.1% ± 0.3% (0%−1.1%)
Myocardial infarction/cardiac arrest	22 (0.2)	0.3% ± 1.2% (0%−9.5%)	20 (0.2)	0.3% ± 1.2% (0%−9.5%)	2 (0.3)	0.3% ± 0.9% (0%−3)
Misplaced screw possibly causing nerve-related pain (requiring reoperation)	10 (0.2)	0.4% ± 1.5% (0%−8.3%)	10 (0.2)	0.5% ± 1.6% (0%−8.3%)	0 (0)	0% ± 0% (0%−0%)
Congestive heart failure or unspecified cardiac	9 (0.2)	0.1% ± 0.3% (0%−2.4%)	5 (0.1)	0% ± 0.3% (0%−2.4%)	4 (0.6)	0.1% ± 0.4% (0%−1.4%)
Compartment syndrome with or without shock (abdominal or extremity)	7 (0.1)	0.2% ± 1% (0%−7.4%)	6 (0.1)	0.2% ± 1.1% (0%−7.4%)	1 (0.2)	0.3% ± 0.9% (0%−3%)
Cardiorespiratory (non−pleural effusion)/systemic	6 (0.1)	0.1% ± 1.1% (0%−10%)	6 (0.1)	0.1% ± 1.1% (0%−10%)	0 (0)	0% ± 0% (0%−0%)
Visual acuity change	12 (0.1)	0.2% ± 0.7% (0%−3.7%)	10 (0.1)	0.2% ± 0.6% (0%−3.7%)	2 (0.3)	0.3% ± 0.9% (0%−3%)
Pedicle or laminar fracture (intraoperative)	4 (0.1)	0.1% ± 0.5% (0%−4.8%)	0 (0)	0% ± 0% (0%−0%)	4 (0.6)	0.4% ± 1.5% (0%−4.8%)
Wound dehiscence requiring surgery	4 (0.1)	0% ± 0.3% (0%−3.2%)	2 (0.1)	0% ± 0.4% (0%−3.2%)	2 (0.3)	0.1% ± 0.2% (0%−0.7%)
Fistula	3 (0.1)	0.1% ± 1.1% (0%−10%)	3 (0.1)	0.2% ± 1.2% (0%−10%)	0 (0)	0% ± 0% (0%−0%)
Gastrointestinal complication (bleeding, ischemia, or other)	3 (0.1)	0.1% ± 0.9% (0%−6.7%)	3 (0.1)	0.1% ± 0.9% (0%−6.7%)	0 (0)	0% ± 0% (0%−0%)
Line-related infection	3 (0.1)	0.1% ± 0.6% (0%−4.8%)	3 (0.1)	0.1% ± 0.6% (0%−4.8%)	0 (0)	0% ± 0% (0%−0%)
Post-thoracotomy syndrome or other pain-related issues	3 (0.1)	0.1% ± 0.4% (0%−2.4%)	1 (0.0)	0% ± 0.3% (0%−2.4%)	2 (0.3)	0.2% ± 0.7% (0%−2.4%)

(*Continued on next page*)

Table 3 (*Continued*)

Major complications	All		Retrospective		Prospective	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Breakdown of L5–S1 disc (perioperative not long-term)	2 (0.0)	0% ± 0.3% (0%–2.1%)	2 (0.1)	0.1% ± 0.3% (0%–2.1%)	0 (0)	0% ± 0% (0%–0%)
Cerebral edema	2 (0.0)	0% ± 0.1% (0%–0.6%)	2 (0.1)	0% ± 0.1% (0%–0.6%)	0 (0)	0% ± 0% (0%–0%)
Incision abdominal hernia (reoperation)	2 (0.0)	0.1% ± 0.6% (0%–4.8%)	1 (0.0)	0.1% ± 0.5% (0%–4.8%)	1 (0.2)	0.2% ± 0.8% (0%–2.7%)
Painful rib remnant requiring excision	2 (0.0)	0.1% ± 1% (0%–6.7%)	2 (0.1)	0.2% ± 1.1% (0%–6.7%)	0 (0)	0% ± 0% (0%–0%)
Renal failure	2 (0.0)	0% ± 0.2% (0%–2%)	2 (0.1)	0% ± 0.2% (0%–2%)	0 (0)	0% ± 0% (0%–0%)
Ischemia in extremities	1 (0.0)	0.1% ± 0.5% (0%–4.8%)	1 (0.0)	0.1% ± 0.5% (0%–4.8%)	0 (0)	0% ± 0% (0%–0%)
Massive fluid overload	1 (0.0)	0% ± 0.3% (0%–3%)	0 (0)	0% ± 0% (0%–0%)	1 (0.2)	0.3% ± 0.9% (0%–3%)
Multiple-organ failure	1 (0.0)	0% ± 0% (0%–0.2%)	1 (0.0)	0% ± 0% (0%–0.2%)	0 (0)	0% ± 0% (0%–0%)
Pancreatitis	1 (0.0)	0.1% ± 0.7% (0%–6.3%)	1 (0.0)	0.1% ± 0.7% (0%–6.3%)	0 (0)	0% ± 0% (0%–0%)
Retroperitoneal hematoma	1 (0.0)	0% ± 0.3% (0%–2.9%)	0 (0)	0% ± 0% (0%–0%)	1 (0.2)	0.3% ± 0.9% (0%–2.9%)
Total major	1,379 (18.5)	13.6% ± 14.5% (0%–79.4%)	1,135 (16.5)	13.5% ± 13.9% (0%–79.4%)	244 (32.6)	14.9% ± 18.5% (0%–52%)

n (%) indicates the total number of complications for all studies and the corresponding percentage. The mean, standard deviation (SD), and range were calculated from the individual complication rates for each study.

retrospectively reported); mean age was 49.8 years (range: 25–73 years), mean FU was 2.32 years (range: 0.11–8.95 years), and EBL was 2,492 mL (range: 717–7,034 mL). 3CO patients experienced 969 total complications at an overall complication rate of 66% (Table 2). The overall *major* perioperative complication rate was 31.8%.The top five leading *major* perioperative complications (including aggregated complications) were excessive bleeding (6.8%), neurological deficit (6.7%), unspecified requiring surgery (4.9%), overall infection (4.1%), and severe/deep wound infection (3.2%) (Table 6). The overall *minor* perioperative complication rate was 15.0%. The top five leading *minor* perioperative complications (including aggregated complications) were dural tear (3.8%), transient neurological deficit (2.7%), deep vein thrombosis (1.7%), ileus/gastrointestinal complications (1.4%), and unspecified or other (1.2%) (Table 7). Finally, the overall *long-term* complication rate was 18.7%. The top five long-term complications (including aggregated complications) were overall instrument-related failure (16.7%), pseudarthrosis (6.4%), instrument/graft failure (5.8%), PJK (3.2%), and vertebral compression fracture (1.5%) (Table 8).

Of note, there was a significant difference in the complication rates between non-3CO patients and 3CO patients when compared within the retrospective studies ($p < .0001$) or the prospective studies ($p = .0068$) individually.

VCR

There were 9 VCR studies reporting data on 206 patients (entirely retrospective); mean age was 34.7 years (range: 27.4–58 years), mean FU was 3.00 years (range: 2–4.7 years), and EBL was 2,815 mL (range: 1,362–7,034 mL). There were 72 complications at an overall complication rate of 35% (Table 2). The overall *major* perioperative complication rate was 13.1%. The top six leading *major* perioperative complications (including aggregated complications) were neurological deficit (4.4%), overall hematoma (3.9%), epidural hematoma (3.4%), as well as severe/deep wound infection, instrument/graft failure, and overall infection (all three tied at 1.9%). The overall *minor* perioperative complication rate was 18.5%. The top eight leading *minor* perioperative complications (including aggregated complications) were transient neurological deficit (5.3%), overall respiratory (4.4%), hemothorax (2.9%), dural tear (2.4%), as well as instrument failure, pleural effusion, unspecified or other, and hypotension (all four tied at 1.5%). Finally, the overall *long-term* complication rate was 3.7%. The top five long-term complications (including aggregated complications) were overall instrument-related failure (3.1%), instrument/graft failure (1.6%), vertebral compression fracture (1.0%), as well as pseudarthrosis and PJK (both tied at 0.5%).

Table 4
All studies: minor complication rates.

Minor complications	All		Retrospective		Prospective	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Unspecified or other	302 (3.1)	1.8% ± 7.1% (0%−47.6%)	204 (2.3)	1.5% ± 6.4% (0%−47.6%)	98 (14.4)	3.2% ± 10.6% (0%−35.1%)
Dural tear	292 (3.0)	4.2% ± 6.1% (0%−25%)	269 (3.0)	4.2% ± 6% (0%−25%)	23 (3.4)	3.6% ± 6.3% (0%−20.5%)
Ileus/gastrointestinal complication	101 (2.1)	2.2% ± 6.7% (0%−44.4%)	84 (2.0)	2.3% ± 7.1% (0%−44.4%)	17 (2.5)	0.7% ± 1.7% (0%−5.4%)
Transient neurological deficit (foot drop, brachial plexopathy, peroneal nerve palsy, radiculopathy, cauda equina, partial spinal cord injury, etc), on transient intraoperation	148 (1.5)	2.6% ± 4.9% (0%−30.8%)	103 (1.1)	2.4% ± 5% (0%−30.8%)	45 (4.8)	4% ± 4.2% (0%−11.5%)
Wound infection (medical/interventional treatment) or superficial	99 (1.0)	1.2% ± 2.1% (0%−10%)	91 (1)	1.2% ± 2.2% (0%−10%)	8 (1.2)	0.8% ± 1.5% (0%−3.8%)
Deep vein thrombosis	66 (0.7)	1% ± 2.4% (0%−14.3%)	58 (0.6)	1% ± 2.3% (0%−14.3%)	8 (1.2)	1.3% ± 2.8% (0%−9.1%)
Urinary tract infection	32 (0.7)	0.8% ± 2.8% (0%−18%)	23 (0.6)	0.7% ± 2.5% (0%−18%)	9 (1.3)	1.4% ± 4.3% (0%−14.3%)
Delirium	28 (0.6)	0.4% ± 1.3% (0%−7.8%)	28 (0.7)	0.5% ± 1.4% (0%−7.8%)	0 (0)	0% ± 0% (0%−0%)
Cerebrospinal fluid leak	20 (0.4)	0.2% ± 1% (0%−7.7%)	17 (0.4)	0.2% ± 1.1% (0%−7.7%)	3 (0.4)	0.3% ± 0.7% (0%−2.4%)
Arrhythmia or tachycardia	15 (0.3)	0.3% ± 1.4% (0%−11.8%)	14 (0.3)	0.2% ± 1.4% (0%−11.8%)	1 (0.2)	0.3% ± 0.9% (0%−2.9%)
Unspecified or miscellaneous infection (eg, yeast)	15 (0.3)	0.2% ± 0.8% (0%−5.3%)	14 (0.3)	0.1% ± 0.7% (0%−5.3%)	1 (0.2)	0.3% ± 0.9% (0%−2.9%)
Pleural effusion	12 (0.3)	0.3% ± 2.1% (0%−18.8%)	12 (0.3)	0.4% ± 2.2% (0%−18.8%)	0 (0)	0% ± 0% (0%−0%)
Pneumothorax	11 (0.2)	0.3% ± 1.3% (0%−6.7%)	10 (0.2)	0.3% ± 1.3% (0%−6.7%)	1 (0.2)	0.3% ± 0.9% (0%−2.9%)
Pulmonary congestion	10 (0.2)	0.2% ± 1.8% (0%−17.2%)	10 (0.2)	0.2% ± 2% (0%−17.2%)	0 (0)	0% ± 0% (0%−0%)
Hemothorax	7 (0.2)	0.2% ± 1% (0%−7.1%)	7 (0.2)	0.2% ± 1.1% (0%−7.1%)	0 (0)	0% ± 0% (0%−0%)
Hypotension	7 (0.2)	0.3% ± 1.3% (0%−7.7%)	7 (0.2)	0.3% ± 1.4% (0%−7.7%)	0 (0)	0% ± 0% (0%−0%)
Other intraoperation	7 (0.2)	0% ± 0.3% (0%−1.8%)	7 (0.2)	0% ± 0.3% (0%−1.8%)	0 (0)	0% ± 0% (0%−0%)
Instrumentation failure (managed conservatively)	6 (0.1)	0.1% ± 0.6% (0%−4.3%)	6 (0.2)	0.1% ± 0.7% (0%−4.3%)	0 (0)	0% ± 0% (0%−0%)
Unspecified pulmonary (resolved via simple measures)	6 (0.1)	0% ± 0.2% (0%−2%)	6 (0.2)	0% ± 0.2% (0%−2%)	0 (0)	0% ± 0% (0%−0%)
Wound healing complications (nonsurgical)	6 (0.1)	0.1% ± 0.7% (0%−6.3%)	3 (0.1)	0.1% ± 0.7% (0%−6.3%)	3 (0.4)	0.1% ± 0.3% (0%−1.1%)
Other iatrogenic damage	4 (0.1)	0.2% ± 1.7% (0%−15.4%)	2 (0.1)	0.2% ± 1.7% (0%−15.4%)	2 (0.3)	0.4% ± 0.9% (0%−2.9%)
Pedicle infraction (intra)	4 (0.1)	0% ± 0.2% (0%−1.2%)	4 (0.1)	0% ± 0.2% (0%−1.2%)	0 (0)	0% ± 0% (0%−0%)
Subluxation or translation at surgical site (intraoperative)	3 (0.1)	0.3% ± 1.9% (0%−12.5%)	2 (0.1)	0.2% ± 1.5% (0%−11.1%)	1 (0.2)	1.1% ± 3.8% (0%−12.5%)
Fever of unknown origin	2 (0.0)	0% ± 0.1% (0%−0.6%)	2 (0.1)	0% ± 0.1% (0%−0.6%)	0 (0)	0% ± 0% (0%−0%)
Hematoma, seroma, or bursa (no surgery)	2 (0.0)	0% ± 0.4% (0%−3.3%)	1 (0.0)	0% ± 0.4% (0%−3.3%)	1 (0)	0% ± 0.1% (0%−0.4%)
Miscellaneous cutaneous complications	2 (0.0)	0% ± 0.4% (0%−3.3%)	2 (0.1)	0% ± 0.4% (0%−3.3%)	0 (0)	0% ± 0% (0%−0%)
Retained drain	2 (0.0)	0% ± 0.1% (0%−0.6%)	2 (0.1)	0% ± 0.1% (0%−0.6%)	0 (0)	0% ± 0% (0%−0%)
Reversible coagulopathy	2 (0.0)	0% ± 0.2% (0%−2%)	2 (0.1)	0% ± 0.2% (0%−2%)	0 (0)	0% ± 0% (0%−0%)
Exacerbation of carpal tunnel requiring release	1 (0.0)	0% ± 0.2% (0%−1.7%)	1 (0.0)	0% ± 0.2% (0%−1.7%)	0 (0)	0% ± 0% (0%−0%)
Revision (intraoperative)	1 (0.0)	0% ± 0% (0%−0.4%)	1 (0.0)	0% ± 0% (0%−0.4%)	0 (0)	0% ± 0% (0%−0%)
Symptomatic gallstones	1 (0.0)	0% ± 0.3% (0%−2.4%)	1 (0.0)	0% ± 0.3% (0%−2.4%)	0 (0)	0% ± 0% (0%−0%)
Thrombophlebitis	1 (0.0)	0% ± 0.2% (0%−1.7%)	1 (0.0)	0% ± 0.2% (0%−1.7%)	0 (0)	0% ± 0% (0%−0%)
Total minor	1,215 (15.7)	15.1% ± 15.8% (0%−77.8%)	994 (14.5)	15% ± 15.6% (0%−77.8%)	221 (30.5)	18% ± 17.4% (0%−57%)

n (%) indicates total number of complications for all studies and the corresponding percentage. The mean, standard deviation (SD), and range were calculated from the individual complication rates for each study.

Table 5
All studies: long-term complications.

Long-term complications	All		Retrospective		Prospective	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Pseudarthrosis	337 (7.6)	6.5% ± 8.3% (0%–38.5%)	311 (8.3)	6.4% ± 8.4% (0%–38.5%)	26 (3.8)	5.2% ± 7.3% (0%–24.2%)
Instrumentation/graft failure (breakage, dislodgement, screw loosening, or resulting in sagittal/coronal decompensation)	295 (3.3)	5.4% ± 8.9% (0%–46.2%)	271 (3.2)	5.4% ± 9.1% (0%–46.2%)	24 (3.5)	5% ± 8.5% (0%–21.4%)
Proximal junctional kyphosis, especially requiring extension	119 (2.9)	3.1% ± 6.4% (0%–30.8%)	119 (3.4)	3.5% ± 6.7% (0%–30.8%)	0 (0)	0% ± 0% (0%–0%)
Adjacent segment degeneration	105 (2.7)	2.1% ± 5.7% (0%–31.9%)	103 (3.2)	2.3% ± 6% (0%–31.9%)	2 (0.3)	0.6% ± 1.8% (0%–6.1%)
Symptomatic screws/skin impingement/ prominent hardware/painful graft possibly requiring removal	80 (2.0)	1.6% ± 3.8% (0%–22%)	69 (2.0)	1.6% ± 3.8% (0%–22%)	11 (1.6)	1.9% ± 3.4% (0%–8.1%)
Vertebral compression fracture	33 (0.8)	1.7% ± 9.5% (0%–85.7%)	28 (0.8)	1.8% ± 10% (0%–85.7%)	5 (0.7)	0.5% ± 1.8% (0%–6%)
Late deep infection	18 (0.5)	0.4% ± 1.7% (0%–10%)	18 (0.6)	0.5% ± 1.8% (0%–10%)	0 (0)	0% ± 0% (0%–0%)
Neurological deficit	8 (0.2)	0.1% ± 0.6% (0%–4.2%)	8 (0.3)	0.2% ± 0.7% (0%–4.2%)	0 (0)	0% ± 0% (0%–0%)
Superficial wound infection or other wounds	7 (0.2)	0.1% ± 0.5% (0%–4.2%)	7 (0.2)	0.1% ± 0.5% (0%–4.2%)	0 (0)	0% ± 0% (0%–0%)
Other fracture (eg, sacral, pelvic)	5 (0.1)	0.1% ± 0.6% (0%–5.7%)	2 (0.1)	0% ± 0.1% (0%–0.8%)	3 (0.4)	0.6% ± 1.7% (0%–5.7%)
Iliac stress fracture or sacroiliac joint degeneration	3 (0.1)	0.1% ± 0.3% (0%–2.4%)	1 (0.0)	0% ± 0.2% (0%–2.1%)	2 (0.3)	0.2% ± 0.7% (0%–2.4%)
Unspecified revision	3 (0.1)	0.1% ± 0.4% (0%–2.9%)	3 (0.1)	0.1% ± 0.4% (0%–2.9%)	0 (0)	0% ± 0% (0%–0%)
Disc herniation	3 (0.1)	0.1% ± 0.4% (0%–2.6%)	3 (0.1)	0.1% ± 0.4% (0%–2.6%)	0 (0)	0% ± 0% (0%–0%)
Deep vein thrombosis	2 (0.1)	0% ± 0.1% (0%–0.8%)	2 (0.1)	0% ± 0.1% (0%–0.8%)	0 (0)	0% ± 0% (0%–0%)
Death	1 (0.0)	0% ± 0.2% (0%–2.3%)	1 (0.0)	0% ± 0.3% (0%–2.3%)	0 (0)	0% ± 0% (0%–0%)
Hearing loss	1 (0.0)	0% ± 0% (0%–0.4%)	1 (0.0)	0% ± 0% (0%–0.4%)	0 (0)	0% ± 0% (0%–0%)
Pneumonia	1 (0.0)	0% ± 0% (0%–0.4%)	1 (0.0)	0% ± 0% (0%–0.4%)	0 (0)	0% ± 0% (0%–0%)
Total long-term	1,021 (20.5)	15.1% ± 15.8% (0%–77.8%)	948 (22.4)	15% ± 15.6% (0%–77.8%)	73 (10.7)	12% ± 12.7% (0%–36.4%)

n (%) indicates total number of complications for all studies and the corresponding percentage. The mean, standard deviation (SD), and range were calculated from the individual complication rates for each study.

Table 6
Individual major complications for three-column osteotomy procedures (3CO) and non-three-column osteotomy procedures (non-3CO).

Major complications	3CO		Non-3CO	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Excessive bleeding	111 (6.8)	1.5% ± 4.8% (0%–24.1%)	0 (0)	0% ± 0% (0%–0%)
Neurological deficit (not transient, not full recovery, resolved with reoperation, or classified as "major")	116 (6.7)	3.3% ± 4.5% (0%–16.3%)	2 (0.1)	0.1% ± 0.5% (0%–2.1%)
Unspecified requiring surgery	80 (4.9)	0.5% ± 3.1% (0%–18.9%)	0 (0)	0% ± 0% (0%–0%)
Wound infection requiring debridement and/or reoperation (especially deep)	52 (3.2)	1.6% ± 3.8% (0%–20%)	0 (0)	0% ± 0% (0%–0%)
Instrumentation/graft failure (breakage, dislodgement, or resulting in inadequate correction) requiring revision	23 (1.4)	1.4% ± 3.4% (0%–15.2%)	0 (0)	0% ± 0% (0%–0%)
Respiratory distress syndrome/respiratory failure	23 (1.4)	0.3% ± 1.2% (0%–4.9%)	0 (0)	0% ± 0% (0%–0%)
Pulmonary embolism or thrombosis of major vessel	21 (1.3)	0.8% ± 2.1% (0%–7.7%)	8 (0.5)	0.5% ± 1.9% (0%–10.5%)
Epidural hematoma	16 (1.0)	1% ± 2.3% (0%–8.6%)	9 (0.6)	0.6% ± 2.5% (0%–13.3%)
Pneumonia/lung infection	10 (0.6)	0.6% ± 2.5% (0%–14.3%)	2 (0.1)	0.3% ± 1.8% (0%–10%)
Reintubation	8 (0.5)	0.6% ± 1.8% (0%–7.4%)	0 (0)	0% ± 0% (0%–0%)
Vascular injury (intraoperative)	8 (0.5)	0.1% ± 0.5% (0%–2.9%)	0 (0)	0% ± 0% (0%–0%)
Wound hematoma or seroma	8 (0.5)	0.4% ± 1.4% (0%–6.3%)	0 (0)	0% ± 0% (0%–0%)
Myocardial infarction/cardiac arrest	7 (0.4)	0.3% ± 0.9% (0%–3.7%)	21 (1.4)	1.8% ± 4% (0%–15%)
Compartment syndrome with or without shock (abdominal or extremity)	6 (0.4)	0.5% ± 1.6% (0%–7.4%)	7 (0.5)	0.4% ± 0.9% (0%–3.3%)
Pleural effusion or pneumothorax (requiring intervention)	6 (0.4)	0.7% ± 3.4% (0%–20%)	1 (0.1)	0.1% ± 0.5% (0%–2.6%)
Visual acuity change	6 (0.4)	0.3% ± 1% (0%–3.7%)	3 (0.2)	0.3% ± 1.5% (0%–8.6%)
Unspecified pulmonary	5 (0.3)	0.1% ± 0.5% (0%–3.2%)	4 (0.3)	0.3% ± 1% (0%–5.3%)
Sepsis	4 (0.3)	0.1% ± 0.5% (0%–2.9%)	1 (0.1)	0% ± 0% (0%–0.2%)
Vertebral compression fracture	4 (0.3)	0.9% ± 3.2% (0%–13.3%)	1 (0.1)	0% ± 0% (0%–0.2%)
Death	3 (0.2)	0.1% ± 0.5% (0%–2.9%)	2 (0.1)	0.2% ± 1% (0%–4.8%)
Stroke	3 (0.2)	0.2% ± 1.1% (0%–6.7%)	4 (0.3)	0.8% ± 2% (0%–6.7%)
Congestive heart failure or unspecified cardiac	2 (0.1)	0.1% ± 0.4% (0%–2.4%)	0 (0)	0% ± 0% (0%–0%)
Fistula	1 (0.1)	0.1% ± 0.5% (0%–2.9%)	0 (0)	0% ± 0% (0%–0%)
Gastrointestinal complication (bleeding, ischemia, or other)	1 (0.1)	0.2% ± 1.1% (0%–6.7%)	1 (0.1)	0.1% ± 0.4% (0%–2%)
Massive fluid overload	1 (0.1)	0.1% ± 0.5% (0%–3%)	1 (0.1)	0% ± 0% (0%–0.2%)
Breakdown of L5–S1 disc (perioperative not long-term)	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Cardiorespiratory (non–pleural effusion)/systemic	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Cerebral edema	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Incision abdominal hernia (reoperation)	0 (0)	0% ± 0% (0%–0%)	7 (0.5)	0.1% ± 0.3% (0%–1.7%)
Ischemia in extremities	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Line-related infection	0 (0)	0% ± 0% (0%–0%)	5 (0.3)	0.3% ± 1.1% (0%–4.3%)
Misplaced screw possibly causing nerve-related pain (requiring reoperation)	0 (0)	0% ± 0% (0%–0%)	2 (0.1)	0.4% ± 1.7% (0%–6.7%)

(*Continued on next page*)

Table 6 (*Continued*)

Major complications	3CO		Non-3CO	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Multiple-organ failure	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Painful rib remnant requiring excision	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Pancreatitis	0 (0)	0% ± 0% (0%–0%)	4 (0.3)	0% ± 0.2% (0%–1%)
Pedicle or laminar fracture (intraoperative)	0 (0)	0% ± 0% (0%–0%)	3 (0.2)	0.1% ± 0.6% (0%–3%)
Post-thoracotomy syndrome or other pain-related issues	0 (0)	0% ± 0% (0%–0%)	1 (0.1)	0.1% ± 0.5% (0%–2.9%)
Renal failure	0 (0)	0% ± 0% (0%–0%)	2 (0.1)	0.3% ± 1% (0%–5.3%)
Retroperitoneal hematoma	0 (0)	0% ± 0% (0%–0%)	42 (2.8)	2.8% ± 3.7% (0%–12%)
Wound dehiscence requiring surgery	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Total major	525 (31.8)	15.1% ± 17.1% (0%–79.4%)	133 (8.9)	9.3% ± 8.4% (0%–30%)

n (%) indicates total number of complications for all studies and the corresponding percentage. The mean, standard deviation (SD), and range were calculated from the individual complication rates for each study.

Table 7
Individual minor complications for three-column osteotomy procedures (3CO) and non-three-column osteotomy procedures (non-3CO).

Minor complications	3CO		Non-3CO	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Dural tear	61 (3.8)	4.9% ± 6.6%	42 (3.0)	3.4% ± 4.4% (0%–15.8%)
Transient neurological deficit (foot drop, brachial plexopathy, peroneal nerve palsy, radiculopathy, cauda equina, partial spinal cord injury, etc), on transient intraoperation	47 (2.7)	3.8% ± 6.5%	18 (1.3)	1.4% ± 2.3% (0%–8%)
Deep vein thrombosis	28 (1.7)	1.5% ± 3.2%	7 (0.5)	0.5% ± 1.4% (0%–6.3%)
Ileus/gastrointestinal complication	23 (1.4)	2% ± 7.9%	47 (3.4)	3.2% ± 7.5% (0%–36.2%)
Unspecified or other	19 (1.2)	0.9% ± 3.9%	21 (1.5)	0.3% ± 1.2% (0%–4.9%)
Wound infection (medical/interventional treatment) or superficial	18 (1.1)	1.2% ± 2.3%	14 (1.0)	1.1% ± 2.3% (0%–10%)
Arrhythmia or tachycardia	11 (0.7)	0.3% ± 1.9%	3 (0.2)	0.2% ± 0.9% (0%–4%)
Pneumothorax	7 (0.4)	0.2% ± 1%	3 (0.2)	0.6% ± 1.8% (0%–6.7%)
Hemothorax	6 (0.4)	0.4% ± 1.5%	1 (0.1)	0.1% ± 0.3% (0%–1.7%)
Hypotension	6 (0.4)	0.7% ± 2%	0 (0)	0% ± 0% (0%–0%)
Instrumentation failure (managed conservatively)	5 (0.3)	0.2% ± 0.9%	1 (0.1)	0.1% ± 0.3% (0%–1.5%)
Cerebrospinal fluid leak	4 (0.3)	0.3% ± 1.4%	1 (0.1)	0% ± 0.3% (0%–1.4%)
Delirium	4 (0.3)	0.2% ± 1.3%	9 (0.7)	0.6% ± 1.6% (0%–6.9%)
Pleural effusion	3 (0.2)	0.5% ± 3.1%	2 (0.1)	0.1% ± 0.7% (0%–4%)
Subluxation or translation at surgical site (intraoperative)	3 (0.2)	0.8% ± 2.9%	0 (0)	0% ± 0% (0%–0%)
Other iatrogenic damage	2 (0.1)	0.4% ± 2.5%	1 (0.1)	0.1% ± 0.5% (0%–2.9%)
Exacerbation of carpal tunnel requiring release	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Fever of unknown origin	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Hematoma, seroma, or bursa (no surgery)	0 (0)	0% ± 0%	1 (0.1)	0.1% ± 0.6% (0%–3.3%)
Miscellaneous cutaneous complications	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Other intraoperation	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Pedicle infraction (intraoperative)	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Pulmonary congestion	0 (0)	0% ± 0%	10 (0.7)	0.6% ± 3.2% (0%–17.2%)
Retained drain	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Reversible coagulopathy	0 (0)	0% ± 0%	1 (0.1)	0.1% ± 0.4% (0%–2%)
Revision (intraoperative)	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Symptomatic gallstones	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Thrombophlebitis	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Unspecified or miscellaneous infection (eg, yeast)	0 (0)	0% ± 0%	4 (0.3)	0.3% ± 1.1% (0%–5.3%)
Unspecified pulmonary (resolved via simple measures)	0 (0)	0% ± 0%	0 (0)	0% ± 0% (0%–0%)
Urinary tract infection	0 (0)	0% ± 0%	23 (1.7)	2.1% ± 4.4% (0%–18%)
Wound healing complications (nonsurgical)	0 (0)	0% ± 0%	3 (0.2)	0.2% ± 1.2% (0%–6.3%)
Total minor	247 (15.0)	17.5% ± 16% (0%–77.8%)	212 (15.4)	13.8% ± 15.6% (0%–63.8%)

n (%) indicates total number of complications for all studies and the corresponding percentage. The mean, standard deviation (SD), and range was calculated from the individual complication rates for each study.

Table 8
Individual long-term complications for three-column osteotomy procedures (3CO) and non-three-column osteotomy procedures (non-3CO).

Long-term complications	3CO		Non-3CO	
	n (%)	M ± SD (range)	n (%)	M ± SD (range)
Pseudarthrosis	68 (6.4)	6.3% ± 10.6% (0%–38.5%)	76 (6.4)	5.2% ± 5.8% (0%–24%)
Instrumentation/graft failure (breakage, dislodgement, screw loosening, or resulting in sag/coronal decompensation)	62 (5.8)	6.1% ± 10.9% (0%–46.2%)	57 (5.2)	4.9% ± 8.8% (0%–34.6%)
Proximal junctional kyphosis, especially requiring extension	33 (3.2)	2.8% ± 6.5% (0%–30.8%)	22 (2.0)	2.4% ± 5.4% (0%–20%)
Vertebral compression fracture	15 (1.5)	3% ± 14.7% (0%–85.7%)	4 (0.4)	0.5% ± 2.8% (0%–15.4%)
Symptomatic screws/skin impingement/prominent hardware/painful graft possibly requiring removal	9 (0.9)	0.8% ± 2% (0%–8.3%)	19 (1.7)	1.5% ± 4.3% (0%–22%)
Adjacent segment degeneration	4 (0.4)	0.4% ± 1.6% (0%–7.4%)	52 (4.7)	4.2% ± 8.4% (0%–31.9%)
Late deep infection	3 (0.3)	0.3% ± 1.2% (0%–6.7%)	3 (0.3)	0.4% ± 1.8% (0%–10%)
Disc herniation	1 (0.1)	0% ± 0.3% (0%–1.5%)	1 (0.1)	0.1% ± 0.3% (0%–1.7%)
Neurological deficit	1 (0.1)	0.1% ± 0.7% (0%–4.2%)	0 (0)	0% ± 0% (0%–0%)
Superficial wound infection or other wounds	1 (0.1)	0.1% ± 0.7% (0%–4.2%)	0 (0)	0% ± 0% (0%–0%)
Death	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Deep vein thrombosis	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Hearing loss	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Iliac stress fracture or sacroiliac joint degeneration	0 (0)	0% ± 0% (0%–0%)	1 (0.1)	0.1% ± 0.4% (0%–2.1%)
Other fracture (eg, sacral, pelvic)	0 (0)	0% ± 0% (0%–0%)	2 (0.2)	0.2% ± 1% (0%–5.7%)
Pneumonia	0 (0)	0% ± 0% (0%–0%)	0 (0)	0% ± 0% (0%–0%)
Unspecified revision	0 (0)	0% ± 0% (0%–0%)	2 (0.2)	0.1% ± 0.4% (0%–1.7%)
Total long-term	197 (18.7)	17.7% ± 27.6% (0%–123.1%)	239 (21.2)	18.5% ± 15.6% (0%–64%)

n (%) indicates total number of complications for all studies and the corresponding percentage. The mean, standard deviation (SD), and range were calculated from the individual complication rates for each study.

Discussion

Adult spinal deformity is a broad term that encompasses a variety of pathologies. Though its prevalence is difficult to determine, previous studies have reported rates of up to 60% in the elderly population [107]. Corrective surgery is appropriate for patients that are unresponsive to conservative therapies, especially for those with intractable pain, progressive decline in neurological function, significant disability, or deformity [108]; numerous studies have documented significant improvements in quality of life and function after surgery [5–8,10,15,109–112]. Given the rapidly expanding elderly population, it is likely that surgical demand for ASD will increase in the near future [113].

Unfortunately, in contrast to younger age groups, adults typically suffer from more postoperative complications because they are generally of poorer health. Adults tend to have poorer bone quality, reducing the probability of successful instrumentation and fusion [2,90,108]. Furthermore, older age allows for a greater number of degenerative changes to manifest; spinal stenosis, facet arthropathy, and disc degeneration often lead to a more rigid spine, making treatment difficult [2,90,108,114]. In addition, patients older than 50 years often have a multitude of systemic diseases, including cardiovascular diseases and diabetes [5]. Therefore, it is critical to the shared decision-making process as well as medicolegal risk mitigation that patients fully understand the potential complication rates of such procedures. It is important that these are not the result of individual surgeon "best estimates," but are supported with recent data from the literature.

Updated reviews such as this one can serve as convenient references for surgeons and patients when discussing the risk-benefit ratio of surgery for complex conditions. In contrast, previous systematic reviews and large-scale series provide generalized complication data but fail to do one or more of the following items: provide individual complication rates, stratify complications by surgical approach, and distinguish complications by retrospective and prospective data. To our knowledge, the largest recent

systematic review for ASD was specific to adult scoliosis [15]. This paper analyzed 41 studies (3,299 patients) involving both non-3CO and 3CO procedures, and reported a mean patient age of 47.7 years, a mean FU of 3.6 years, and an overall mean complication rate of 41.2% (range: 0–53%). Another reviewed 11 adult scoliosis papers and reported an average complication rate of 44% (range: 10–78%), without specifying mean patient age or FU [14]. In contrast, our data yielded a mean patient age of 53.3 years, a mean FU of 3.49 years, and an overall complication rate of 55%, approximately 10% higher than the aforementioned literature reviews. It is likely that a number of factors account for this disparity in complication rate, such as a broader range of deformity etiologies, an older patient population, a different 3CO to non-3CO patient ratio, and a larger overall study population. Given that our study population was substantially larger than any previous ASD complication study, our results are more statistically powerful and therefore are more likely to accurately delineate complication rates.

Uniquely, our study also serves as a guiding reference for discussing 3CO versus non-3CO procedures. This conversation is particularly important in the context of the high-risk adult population, because even though 3CO offers substantial deformity correction and quality of life improvement [6,45,83,106,115,116], it carries significant risks of morbidity resulting from the operative time, intraoperative blood loss, and technically demanding nature of the procedure [83,115–117]. We found that relative to our non-3CO group, the 3CO cohort had greater EBL (2,492 mL vs. 1,718 mL) and a higher overall complication rate (66% vs. 45%) in spite of the fact that both cohorts had a similar mean age (49.8 vs. 52.4 years). In particular, the overall 3CO complication rate differed from the non-3CO rate largely as a result of the difference in major perioperative rates (31.8% for 3CO vs. 8.9% for non-3CO); 3CO was especially associated with excessive bleeding, as well as higher rates of infection and neurological deficit. Also, there was a significant difference in the complication rates between Non-3CO patients and 3CO patients when compared within the retrospective studies ($p < .0001$) or the prospective studies ($p = .0068$) individually. Moreover, VCR resulted in the greatest blood loss (2,815 mL) though the overall complication rate was only 35% (overall major perioperative complication rate: 13.1%). It is not clear why VCR had the lowest overall complication rate (though the VCR major perioperative complication rate was higher than that of non-3CO) but a younger overall cohort (mean age: 34.7 years), a different set of deformity etiologies, and a less statistically powerful population may have been influencing factors [83]. However, overall, our results seem to confirm the notion that more invasive operations are associated with greater blood loss and complication risks, at least with respect to major perioperative complications.

Our 3CO complication results are similar to that of other literature. For example, in a recent retrospective study of 237 consecutive 3CO patients (156 PSO, 84 VCR, minimum FU of 2 years), Auerbach et al. determined the major medical/surgical complication rate to be 35.2% for 3CO: 38% for PSO and 22% for VCR (this difference was not statistically significant) [115]. The most common 3CO major complications were medical complications and neurological deficit [115]. A parallel comparison cannot be made to Auerbach et al.'s 35.2% major complication rate, as the authors did not specify the time point at which they reported their FU major complications. Nonetheless, our major 3CO perioperative rate was 31.8%. Moreover, our top major perioperative complications included medical complications and neurological deficit.

There are limitations in our data that are worth mentioning. First, 81 of the 93 studies (87%) were retrospective, which inherently restricted the quality of data that could be extracted. The reported rates of complications likely underreport the true values, as a result of selection bias and recall bias. Second, the lack of standardized complication reporting resulted in heterogeneous data that was difficult to tabulate. The definitions of "short-term" and "long-term" as well as "major" and "minor" varied across studies. Currently, there exist no standard method in the literature to classify complication types. We attempted to use the criteria used by Glassman[16] as a standard; however, there are inherent limitations with this system. When complications did not meet the Glassman criteria, we based the classification on what the study itself listed. These methods introduce possible confounders; however, a large prospective study detailing a standard classification system for complications is needed. And although the classification of the complications may have limitations, the rates for each of the individual complications are based on the literature for the listed complication. In addition, although most authors looked at both perioperative and long-term complications, some looked at only one of the two. Further, certain studies broadly reported complications under the heading of "unspecified," leaving a sizeable number of complications uncategorized. In addition, some studies grouped two complications together, such as pseudarthroses and instrumentation failure, forcing us to use an arbitrary separation protocol. Lastly, there were a sizeable number of "mixed" studies (14 studies, 7,950 patients) that did not separate complications or other surgical outcomes by surgical procedure, precluding further analysis of valuable data (Table 2).

Although this study reviews the existing literature for complication rates after surgery for adult deformity, it is likely that some if not most complications, and particularly rare complications, are underreported in the literature and thus are equally underreported in our analysis. The complications with lower percentage rates in our analysis should not be used as an estimate of individual complication rates given this likely underreporting. Given the variability in study design and potential biases, further prospective multicenter studies are needed to fully and accurately evaluate complication rates in ASD.

Conclusion

A comprehensive review of recent literature providing complication rates for ASD surgery was performed, providing the most up-to-date estimate of the incidence of early and late complications. Providers may use such data in helping to counsel patients of the literature-supported complication rates of such procedures despite the planned benefits, thus obtaining a more thorough informed consent. In the future, a greater number of high-quality studies and a standardized method for reporting complications may facilitate data aggregation and yield more accurate estimates of complication rates.

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