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SYSTEMATIC REVIEW

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Efficacy and safety of long fusion versus short fusion in degenerative scoliosis: a systematic review and meta-analysis

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Abstract

Background This study aimed to evaluate the efficacy and safety of long fusion versus short fusion in patients with degenerative scoliosis.

Methods Databases were systematically searched up to June 2024. The authors applied Review Manager 5.4 to manage the data and perform the analysis.

Results After the selection of 611 studies from electronic databases, 13 studies were eligible for inclusion. These 13 studies included 1261 patients: 534 patients underwent long fusion, and 727 underwent short fusion. At baseline, the Cobb angle, coronal imbalance, and sagittal imbalance were greater in the long fusion group. There was no difference in the VAS back, Cobb angle, ODI, hospital stay, revision surgery, adjacent segment degeneration, sacral slope, pelvic tilt, Cobb angle, lumbar lordosis, coronal balance, or sagittal balance at the final follow-up. The surgery time, complication rates, and amount of blood loss were greater in the long fusion group.

Conclusions Long fusion leads to superior radiographic improvement, particularly in reducing the Cobb angle and reconstructing coronal and sagittal balance. The long fusion group was inferior in terms of increased surgical time, more blood loss, and higher postoperative complication rates. At the final follow-up, there was no difference in the clinical or radiographic outcomes between the long and short groups. For patients with a large coronal Cobb angle and significant coronal or sagittal imbalance, long fusion surgery should be performed. On the other hand, for patients whose milder deformities and clinical symptoms are the main concern, short fusion surgery is recommended.

Keywords Long fusion, Short fusion, Degenerative scoliosis

Introduction

Degenerative scoliosis is defined as a Cobb angle greater than 10 degrees in the coronal plane, with or without sagittal imbalance or abnormal pelvic orientation in skeletally mature patients [1]. Unlike adolescent idiopathic scoliosis and neuromuscular scoliosis, degenerative scoliosis is often accompanied by progressive structural changes in the spine, such as spondylolysis and spinal canal stenosis [2]. Clinical symptoms include low back pain and intermittent claudication.

The widely acknowledged pathological basis for degenerative scoliosis is primarily disc degeneration, which leads to an imbalance of forces in the spine segments, accelerating the degeneration of intervertebral discs and facet joints. Through multiple cycles of this

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process, degenerative changes occur in the spine and, in severe cases, lead to coronal or sagittal plane imbalance [3, 4].

The primary goals of surgery are decompression, fusion, and, to some extent, correction of the deformity to improve the patient's clinical symptoms and prevent further progression of the scoliotic deformity. Since patients with degenerative scoliosis are often elderly and generally in poor condition, with a greater risk of postoperative complications, the range of fusion and fixation needs to be carefully selected. Currently, there is no uniform definition of long- and short-segment fusion. Based on previous studies, long-segment fusion is defined as the fusion of an average of ≥ 3 segments (some studies suggest ≥ 5 segments) or fusion extending to or beyond the upper and lower vertebrae of the scoliosis curve. Short-segment fusion is defined as the fusion of an average of < 3 segments (some studies suggest < 5 segments) or fusion shorter than the upper and lower vertebrae of the scoliosis curve.

Although previous meta-analyses have been conducted, the studies included were all published before 2017 [5, 6]. In the past 7 years, several studies have been published. This study incorporates the latest publications on long and short fusion in degenerative scoliosis, providing a more comprehensive meta-analysis of various indicators. The aim of this study was to evaluate the efficacy and safety of long fusion versus short fusion in patients with degenerative scoliosis.

Methods

Search strategy

The authors conducted a systematic search of databases, including PubMed, the Cochrane Library, Embase, and Web of Science, up to June 2024. The authors employed the terms "long" AND "short" AND "degenerative scoliosis". Additionally, they screened the reference lists of the included articles to ensure the inclusion of all relevant studies.

Inclusion criteria

The inclusion criteria were as follows.

P (patients): Patients diagnosed with degenerative scoliosis.
I (intervention): Patients who underwent short fusion.
C (comparison): Patients who underwent long fusion.
O (outcomes): Outcomes include clinical outcomes and radiographic outcomes.
S (study design): All comparative studies: case–control studies, cohort studies, randomized clinical trials. Only studies published in peer-reviewed journals were considered for inclusion. Only studies published in English were eligible for inclusion.

Exclusion criteria

I. Patients diagnosed with tuberculosis, infection, fractures, tumors, or rheumatoid diseases.
II Review, case reports; technical notes.

Study selection and data extraction

Two authors independently conducted screening, data extraction, and quality assessment of the retrieved literature. Initially, they performed preliminary screening by reading titles and abstracts. The remaining literature was then assessed by reading the full text to select literature that met the conditions and simultaneously conducting quality evaluations. Zhe Qiang, the corresponding author, supervises the entire process and resolves any discrepancies. Data extraction involved information on the first author, publication year, study type, baseline details, clinical outcomes, and radiographic outcomes.

Evaluation of risk of bias

Observational studies were assessed for bias using the Newcastle–Ottawa Scale [7].

Data analysis

Review Manager 5.4 was utilized for data analysis. Mean differences (MDs) with 95% confidence intervals (CIs) are calculated for continuous variables, and odds ratios (ORs) with 95% CIs are used for dichotomous outcomes. Higgins' I-squared statistic was used to determine heterogeneity, with a random-effects model applied for $I^2 > 50\%$ and a fixed-effects model for lower heterogeneity. Funnel plots were generated to assess publication bias, and the corresponding author oversaw the entire analysis process. In statistical terms, $P < 0.05$ indicates a significant difference.

Results

The initial search included 322 studies. Excluding duplicates, 191 articles were screened by title and abstract. All 146 relevant articles were assessed through content: 13 studies met the inclusion criteria for data analysis. The characteristics of the included studies are shown in Table 1. The study selection flow chart is shown in Fig. 1. The 13 eligible articles included 15 comparison groups, with 534 patients who underwent long fusion and 727 who underwent short fusion. All the studies were

Table 1 Characteristic of included studies

Study	Country	Sample size		Age		Baseline Cobb		Baseline LL	
		Short	Long	Short	Long	Short	Long	Short	Long
Cho 2008	South Korea	28	22	64.4 ± 8.1	66.9 ± 6.4	16.3 ± 4.7	21.7 ± 6.0	32.7 ± 10.9	25.7 ± 14.7
Liu 2009	China	34	63	54.7	54.7	17.6 ± 2.8	24.3 ± 4.5	30.6 ± 8.1	21.7 ± 7.5
Transfeldt 2010	USA	43	20	70 (50–93	63 (51–80)	–	–	–	–
Faldini 2015	Italy	57	24	–	–	24	45	45	24
Jiang 2016 (I)	China	59	21	62.9 ± 9.99	58.2 ± 6.32	13.59 ± 4.87	13.44 ± 3.81	–	–
Jiang 2016 (II)	China	28	34	67.3 ± 8.54	64.0 ± 3.29	28.50 ± 17.60	26.50 ± 4.68	–	–
Wang 2016 (I)	China	35	39	58.1 ± 7.3	63.7 ± 8.8	21.8 ± 5.8	41.4 ± 6.3	17.3 ± 13.2	5.1 ± 28.1
Wang 2016 (II)	China	34	39	61.9 ± 8.4	63.7 ± 8.8	29.0 ± 9.6	41.4 ± 6.3	3.5 ± 23.3	5.1 ± 28.1
FS 2016	Switzerland	53	39	66.3 ± 11.6	66.4 ± 10.5	19.1 ± 6.9	21.5 ± 8.4	–	–
Chai 2018	China	48	35	71.1 ± 6.1	68.6 ± 6.7	23.5 ± 9.0	22.7 ± 6.5	–	–
Zhang 2019	China	16	12	64.6 ± 4.7	64.3 ± 4.1	18.9 ± 4.1	21.8 ± 5.6	30.5 ± 3.7	28.1 ± 5.6
Bai 2020	China	20	33	64.6 ± 8.7	62.0 ± 8.6	17.8 ± 7.6	19.8 ± 8.4	40.0 ± 16.1	31.2 ± 16.3
Luo 2020	China	108	42	62.50 ± 7.78	62.50 ± 7.78	22.86 ± 10.40	45.84 ± 34.27	44.92 ± 3.13	25.39 ± 4.05
Song 2022	China	42	36	60.8 ± 8.4	57.1 ± 7.9	30.5 ± 7.9	36.6 ± 9.4	11.9 ± 16.1	6.5 ± 10.5
Ledesma 2023	USA	122	75	64.5 ± 8.18	63.3 ± 9.19	18.6 ± 6.86	31.1 ± 14.4	–	–

case–control studies. The risk of bias data are shown in Table 2.

Clinical outcomes

Vas

Pooled analysis of 4 studies [8–11] reported similar VAS back scores between short and long fusion [MD: 0.15, 95% CI: (−0.17, 0.47), P = 0.36; heterogeneity Chi2 = 1.27, df = 3, P = 0.74, I2 = 0%], as shown in Fig. 2. VAS leg pain was less common in the long fusion group according to the pooled analysis [MD: 0.79, 95% CI: (0.56, 1.02), P < 0.00001; heterogeneity Chi2 = 3.77, df = 3, P = 0.29, I2 = 21%], as shown in Fig. 3.

ODI

Chai 2018, Jiang 2016(II) and Liu 2016 reported higher ODIs with long fusion [12–14]. At the same time, Liu 2016(II), Luo 2020, Wang 2016(I), and Wang 2016(II) reported higher ODIs in short fusion [10, 14, 15]. Pooled analysis including 10 studies with 12 groups revealed similar ODIs [MD: -2.16, 95% CI: (-8.16, 3.84), P = 0.48; heterogeneity Chi2 = 384.07, df = 11, P < 0.00001, I2 = 97%] between short- and long-term fusion [8–10, 12–18], as shown in Fig. 4.

Hospital stay

Pooled analysis including 7 studies with 8 groups revealed no difference [MD: − 1.55, 95% CI: (− 3.38, 0.28), P = 0.1; heterogeneity Chi2 = 77.14, df = 6, P < 0.00001, I2 = 92%] in hospital stay [8, 10, 12, 13, 16–18], as shown in Fig. 5.

Blood loss

All the studies reported less blood loss in the short fusion group. In addition, the pooled analysis revealed average blood loss of less than 748.08 ml in the short fusion group [8, 10, 12–16, 18] [MD: − 748.08, 95% CI: (− 909.84, − 586.32), P < 0.00001; heterogeneity Chi2 = 211.58, df = 9, P < 0.00001, I2 = 96%], as shown in Fig. 6.

Revision surgery

Seven studies reported revision surgery [9, 11, 12, 14, 16, 17, 19]. Chai 2018 [12] reported greater revision in short fusion groups, and Transfeldt [17] 2010 reported the opposite. Five studies reported no difference between groups. Pooled analysis revealed no difference [OR: 0.61, 95% CI: (0.25, 1.52), P = 0.29; heterogeneity Chi2 = 18.55, df = 6, P = 0.005, I2 = 68%] between groups, as shown in Fig. 7.

Complications

Luo 2020 [10] reported fewer complication events in short fusion groups, and other studies reported no difference. Pooled analysis revealed that complications were lower in the low-density group [OR: 0.49, 95% CI: (0.35, 0,68), P < 0.0001; heterogeneity Chi2 = 13.47, df = 10, P = 0.20, I2 = 26%] between the two groups [8–12, 15–19], as shown in Fig. 8.

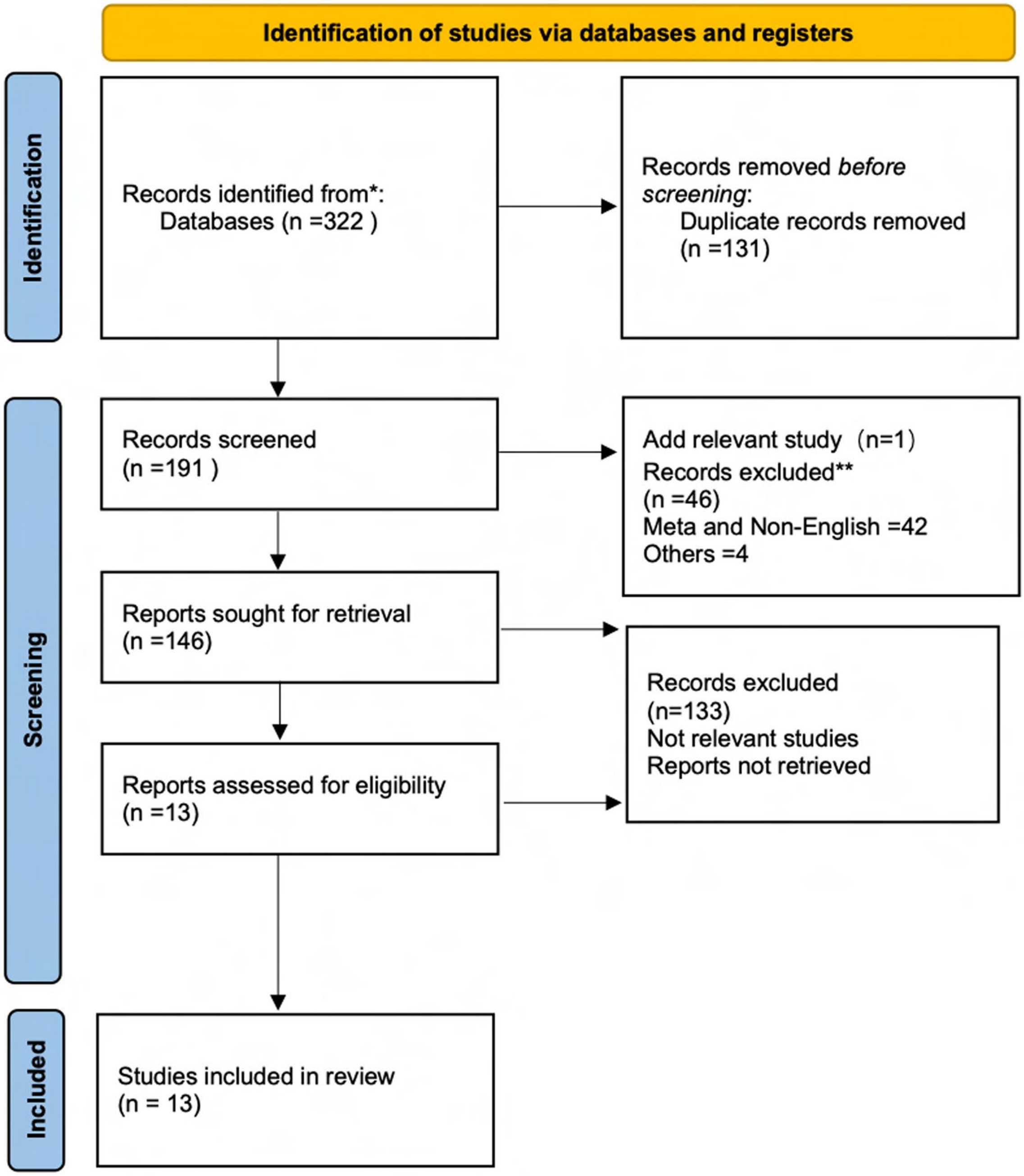

Fig. 1 Flowgram of study selection

Adjacent segment degeneration

FS 2016 [19] reported less adjacent segment degeneration, whereas other studies reported no difference. Pooled analysis revealed no difference [OR: 1.25, 95% CI (0.80, 1.96), $P=0.32$; heterogeneity Chi2 = 11.87, df = 6, $P=0.07$, I2 = 49%] between groups in adjacent segment degeneration [8, 9, 11, 12, 14, 16, 19], as shown in Fig. 9.

Surgical duration

All included studies reported shorter operative times. Pooled analysis revealed that the average surgery time in the short group was 107.81 min shorter than that in the long fusion group [8, 10, 12–16, 18] [MD: −107.81, 95% CI: (−132.51, −83.1), $P<0.00001$; heterogeneity Chi2 = 102.25, df = 9, $P<0.00001$, I2 = 91%], as shown in Fig. 10.

Table 2 Risk of bias assessment using the Newcastle–Ottawa scale for observational studies

Study	Selection				Comparability		Outcome			Total scores
	Exposed Cohort	Non-exposed Cohort	Ascertainment Of exposure	Outcome of interest	The most important factor	Additional factor	Assessment of outcomes	Length of follow up	Adequacy of follow up	
Tao 2010	★	★	★	★	★	★	★	★	★	9
Tsirikos 2012	★	★	★	★	★	★	★	★	★	9
Bharucha 2013	★	★	★	★	★	★	☆	★	★	9
Liu 2015	★	★	★	★	★	★	☆	★	★	9
Morr 2015	★	★	★	★	★	★	★	★	★	9
Wang 2016	★	★	★	★	★	★	★	★	★	9
Kemppainen 2016	★	★	★	★	★	★	★	★	★	9
Ketenci 2016	★	★	★	★	★	★	☆	★	★	9
Shen 2017	★	★	★	★	★	★	★	★	★	9
Luo 2017	★	★	★	★	★	★	★	★	★	9
Sariyilmaz 2018	★	★	★	★	★	★	☆	★	★	8
Yeh 2019	★	★	★	★	★	★	☆	★	★	8
Şenköylü 2020	★	★	★	★	★	★	☆	★	★	8
Ferlic 2021	★	★	★	★	★	★	★	★	★	9
Lertudomphonwanit 2022	★	★	★	★	★	★	★	★	★	9
Chotigavanichaya 2023	★	★	★	★	★	★	★	★	★	9
Chang 2023	★	★	★	★	★	★	★	★	★	9
Baymurat 2023	★	★	★	★	★	★	★	★	★	9

	Experimental			Control				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
Bai 2020	2.1	2	20	1.9	1.8	33	8.8%	0.20 [−0.87, 1.27]
Ledesma 2023	3.43	2.46	122	3.67	2.74	75	17.5%	−0.24 [−1.00, 0.52]
Luo 2020	2.57	1.36	108	2.36	1.15	42	53.9%	0.21 [−0.22, 0.64]
Song 2022	3	2.1	42	2.7	1	36	19.7%	0.30 [−0.41, 1.01]
Total (95% CI)			**292**			**186**	**100.0%**	**0.15 [−0.17, 0.47]**

Heterogeneity: Chi² = 1.27, df = 3 (P = 0.74); I² = 0%
Test for overall effect: Z = 0.91 (P = 0.36)

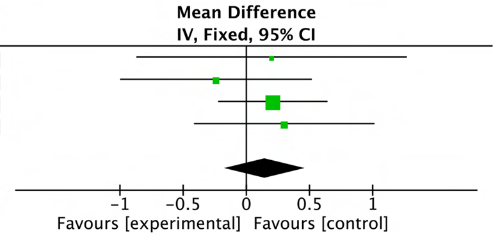

Fig. 2 Comparision between long fusion versus short fusion in VAS back scores

	Experimental			Control				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
Bai 2020	2.1	2	20	1.5	1.7	33	4.8%	0.60 [−0.45, 1.65]
Ledesma 2023	2.96	2.78	122	2.59	2.44	75	9.7%	0.37 [−0.37, 1.11]
Luo 2020	2.41	0.9	108	1.48	0.69	42	73.1%	0.93 [0.66, 1.20]
Song 2022	2.2	1.8	42	1.8	1.1	36	12.4%	0.40 [−0.25, 1.05]
Total (95% CI)			**292**			**186**	**100.0%**	**0.79 [0.56, 1.02]**

Heterogeneity: Chi² = 3.77, df = 3 (P = 0.29); I² = 21%
Test for overall effect: Z = 6.77 (P < 0.00001)

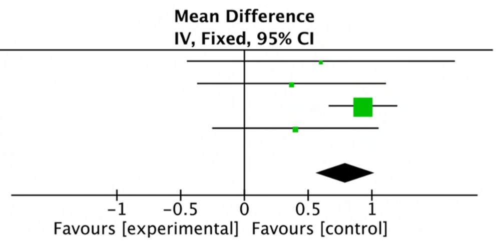

Fig. 3 Comparision between long fusion versus short fusion in VAS leg scores

	Experimental			Control				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bai 2020	32.4	8.9	20	33.1	8.9	33	8.5%	−0.70 [−5.64, 4.24]
Chai 2018	23.6	4.7	48	18.5	3.5	35	9.0%	5.10 [3.34, 6.86]
Cho 2008	48.6	27.6	28	47.8	17.1	22	6.5%	0.80 [−11.67, 13.27]
Jiang 2016 (I)	24.68	14.8	59	55.55	16.66	21	7.8%	−30.87 [−38.93, −22.81]
Jiang 2016 (II)	55.54	5.77	28	23.38	12.1	34	8.6%	32.16 [27.57, 36.75]
Ledesma 2023	24	18.6	122	29.5	16.9	75	8.5%	−5.50 [−10.55, −0.45]
Liu 2009	25.1	5.2	34	21.6	5.7	63	8.9%	3.50 [1.26, 5.74]
Luo 2020	12.59	3.82	108	19.53	7.76	42	8.9%	−6.94 [−9.39, −4.49]
Transfeldt 2010	33.9	19.5	43	39.5	18.7	20	7.2%	−5.60 [−15.66, 4.46]
Wang 2016 (I)	21.8	2.5	35	30.4	8.9	39	8.8%	−8.60 [−11.51, −5.69]
Wang 2016 (II)	22.4	4.2	34	30.4	8.9	39	8.8%	−8.00 [−11.13, −4.87]
Zhang 2019	15.9	5.8	16	19.8	5.9	12	8.6%	−3.90 [−8.28, 0.48]
Total (95% CI)			**575**			**435**	**100.0%**	**−2.16 [−8.16, 3.84]**

Heterogeneity: Tau² = 103.85; Chi² = 384.07, df = 11 (P < 0.00001); I² = 97%
Test for overall effect: Z = 0.71 (P = 0.48)

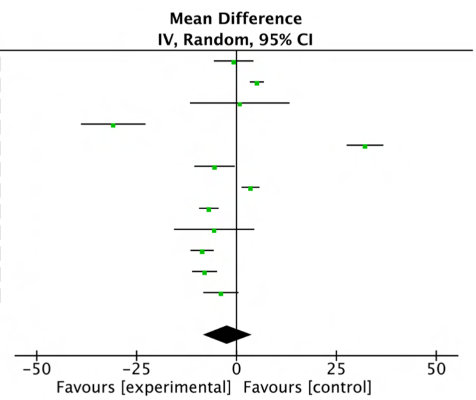

Fig. 4 Comparision between long fusion versus short fusion in ODI

	Experimental			Control				Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bai 2020	13.2	4.4	20	16.7	6	33	12.4%	−3.50 [−6.31, −0.69]
Chai 2018	10.4	1.8	48	10.8	2.6	35	16.6%	−0.40 [−1.40, 0.60]
Cho 2008	18.4	8.3	28	23.3	11.2	22	6.6%	−4.90 [−10.50, 0.70]
Jiang 2016 (I)	16.45	2.14	59	15.35	2.65	21	16.1%	1.10 [−0.16, 2.36]
Jiang 2016 (II)	18.65	1.56	28	17.25	1.54	34	16.9%	1.40 [0.62, 2.18]
Luo 2020	6.31	1.8	108	9.17	2.97	42	16.6%	−2.86 [−3.82, −1.90]
Transfeldt 2010	4.6	0	43	8.2	0	20		Not estimable
Zhang 2019	10.8	2.3	16	15.3	2.6	12	14.8%	−4.50 [−6.35, −2.65]
Total (95% CI)			**350**			**219**	**100.0%**	**−1.55 [−3.38, 0.28]**

Heterogeneity: Tau² = 5.01; Chi² = 77.14, df = 6 (P < 0.00001); I² = 92%
Test for overall effect: Z = 1.66 (P = 0.10)

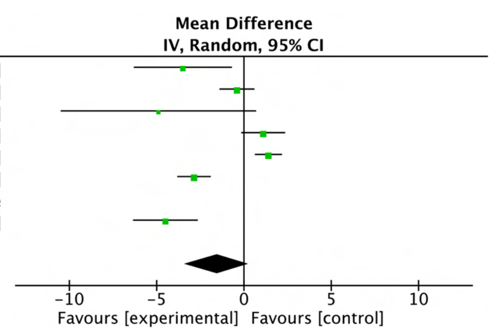

Fig. 5 Comparision between long fusion versus short fusion in hospital stay

Radiographic outcomes

Cobb angle

Among the included studies, 5 comparison groups were comparable in terms of the Cobb angle before surgery, and the other 6 groups indicated that the Cobb angle was greater for long fusion. The overall baseline Cobb

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Bai 2020	455	289.2	20	1,715.2	1,084.5	33	7.0%	−1260.20 [−1651.32, −869.08]
Chai 2018	230	62	48	720	280	35	11.3%	−490.00 [−584.41, −395.59]
Cho 2008	1,671	604	28	2,819	1,097	22	5.4%	−1148.00 [−1658.08, −637.92]
Jiang 2016 (I)	448	121	59	1,118	300	21	10.9%	−670.00 [−801.97, −538.03]
Jiang 2016 (II)	612	85	28	1,250	258	34	11.4%	−638.00 [−730.26, −545.74]
Liu 2009	809	95	34	1,627	63	63	11.7%	−818.00 [−853.52, −782.48]
Luo 2020	439.7	212.29	108	762.32	186.24	42	11.5%	−322.62 [−391.72, −253.52]
Wang 2016 (I)	448	213.4	35	1,574.5	606.2	39	10.0%	−1126.50 [−1329.46, −923.54]
Wang 2016 (II)	685.2	349.2	34	1,574.5	606.2	39	9.6%	−889.30 [−1112.85, −665.75]
Zhang 2019	571.9	202.5	16	1,162.5	117.3	12	11.1%	−590.60 [−709.97, −471.23]
Total (95% CI)			**410**			**340**	**100.0%**	**−748.08 [−909.84, −586.32]**

Heterogeneity: $Tau^2 = 57734.23$; $Chi^2 = 211.58$, df = 9 (P < 0.00001); $I^2 = 96\%$
Test for overall effect: Z = 9.06 (P < 0.00001)

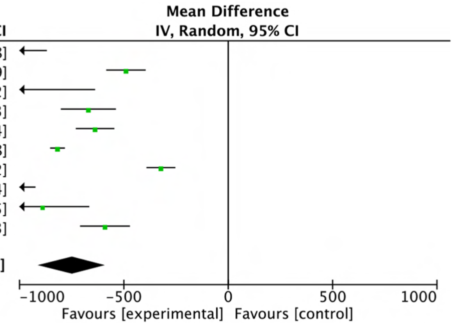

Fig. 6 Comparision between long fusion versus short fusion in blood loss

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Random, 95% CI
Chai 2018	16	48	1	35	10.4%	17.00 [2.13, 135.69]
Cho 2008	4	28	3	22	13.2%	1.06 [0.21, 5.30]
FS 2016	8	53	11	39	17.6%	0.45 [0.16, 1.26]
Ledesma 2023	11	122	19	75	19.2%	0.29 [0.13, 0.66]
Liu 2009	1	34	5	63	9.8%	0.35 [0.04, 3.14]
Song 2022	4	42	4	36	14.3%	0.84 [0.19, 3.64]
Transfeldt 2010	5	43	9	20	15.6%	0.16 [0.04, 0.58]
Total (95% CI)		**370**		**290**	**100.0%**	**0.61 [0.25, 1.52]**
Total events	49		52			

Heterogeneity: $Tau^2 = 0.95$; $Chi^2 = 18.55$, df = 6 (P = 0.005); $I^2 = 68\%$
Test for overall effect: Z = 1.05 (P = 0.29)

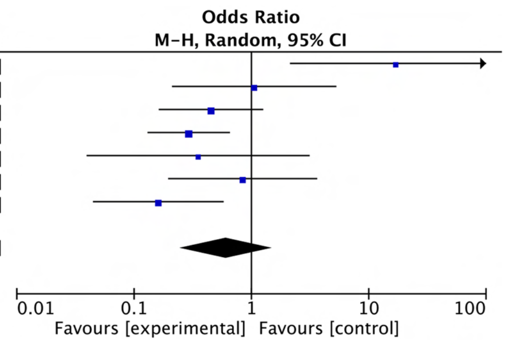

Fig. 7 Comparision between long fusion versus short fusion in revision surgery

Study or Subgroup	Experimental Events	Experimental Total	Control Events	Control Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Bai 2020	5	20	11	33	6.8%	0.67 [0.19, 2.31]
Chai 2018	6	48	5	35	5.6%	0.86 [0.24, 3.07]
Cho 2008	18	28	15	22	6.6%	0.84 [0.26, 2.75]
FS 2016	14	53	11	39	10.2%	0.91 [0.36, 2.31]
Ledesma 2023	2	122	4	75	5.3%	0.30 [0.05, 1.66]
Luo 2020	10	108	16	42	22.9%	0.17 [0.07, 0.41]
Song 2022	17	42	14	36	9.8%	1.07 [0.43, 2.66]
Transfeldt 2010	17	43	11	20	10.0%	0.53 [0.18, 1.56]
Wang 2016 (I)	5	35	11	39	9.8%	0.42 [0.13, 1.38]
Wang 2016 (II)	4	34	11	39	9.9%	0.34 [0.10, 1.19]
Zhang 2019	0	16	2	12	3.0%	0.13 [0.01, 2.92]
Total (95% CI)		**549**		**392**	**100.0%**	**0.53 [0.38, 0.75]**
Total events	98		111			

Heterogeneity: $Chi^2 = 13.11$, df = 10 (P = 0.22); $I^2 = 24\%$
Test for overall effect: Z = 3.62 (P = 0.0003)

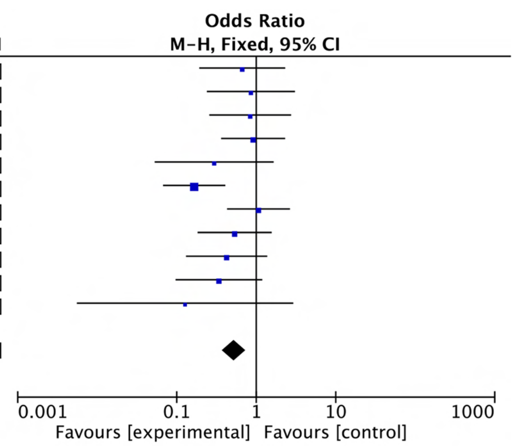

Fig. 8 Comparision between long fusion versus short fusion in complications

angle was smaller (7.13) in the short fusion group [8–11, 13–16, 18] [MD: −7.13, 95% CI: (−11.29, −2.97), P = 0.0008; heterogeneity Chi2 = 182.13, df = 10, $P < 0.00001$, I2 = 95%], as shown in Fig. 11. Surgeons prefer long fusion in patients with larger Cobb angles. Jiang 2016(II) and Song 2022 reported a greater Cobb angle in the short fusion group at the final visit. However, Ledesma 2023, Wang 2016(I), and Wang 2016(II) reported greater Cobb angles in long fusion groups at the final visit. The final meta-analysis revealed no difference [MD: 1.08, 95% CI: (−1.63, 3.79), $P = 0.43$; heterogeneity Chi2 = 94.68, df = 10, $P < 0.00001$, I2 = 89%]

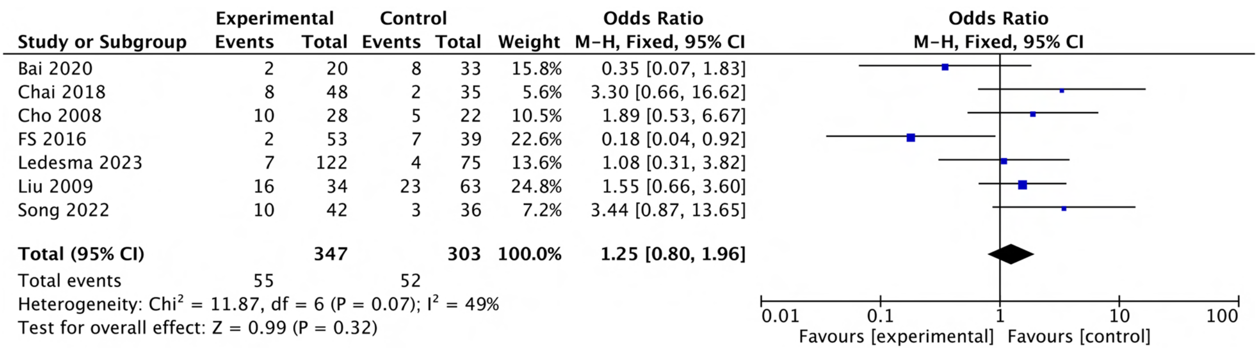

Fig. 9 Comparision between long fusion versus short fusion in adjacent segment degeneration

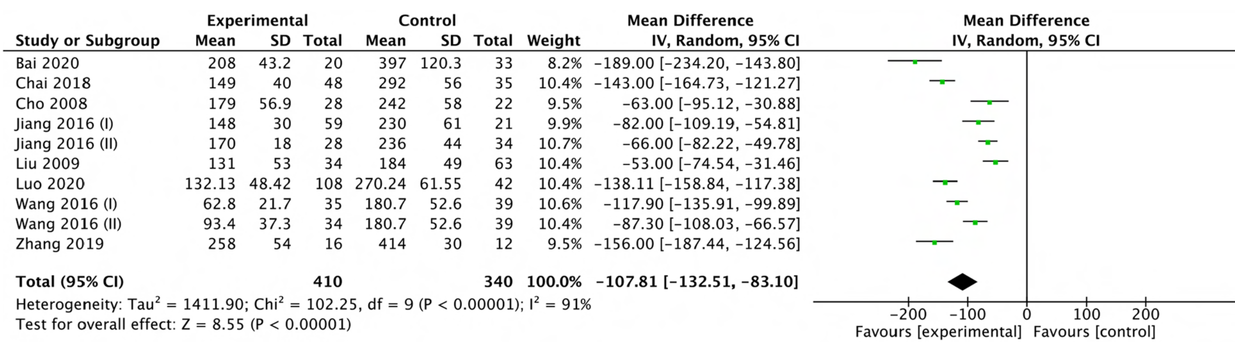

Fig. 10 Comparision between long fusion versus short fusion in surgical duration

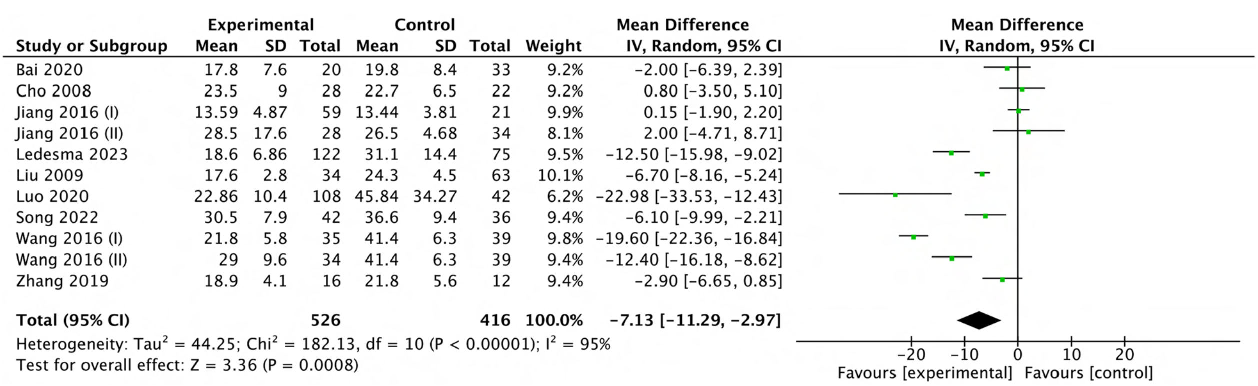

Fig. 11 Comparision between long fusion versus short fusion in Cobb angle baseline

in the final follow-up Cobb angle between the short and long groups [8–11, 13–16, 18], as shown in Fig. 12.

Sacral slope (SS), lumbar lordosis (LL), and pelvic tilt (PT)

There were no differences between the short- and long-fusion groups in the SS, LL, or PT at either the baseline ($P>0.05$) or the final follow-up ($P>0.05$) [8, 10, 11, 14–16, 18], as shown in 13–18.

Coronal balance and sagittal balance

The degree of coronal imbalance [MD: -4.77, 95% CI: $(-7.49, -2.05)$, $P=0.00086$; heterogeneity Chi2 $=25.63$, df $=3$, $P<0.00001$, I2 $=88\%$] and sagittal imbalance [MD: -6.18, 95% CI: $(-9.45, -2.91)$, P $=0.0002$; heterogeneity Chi2 $=28.20$, df $=4$, $P<0.00001$, I2 $=86\%$] in the long-segment group were greater than those in the short-segment group, and the difference between the two groups was statistically significant [11, 15, 16, 18]. There

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Bai 2020	13.6	9.2	20	8.5	6.2	33	8.6%	5.10 [0.55, 9.65]
Cho 2008	10.1	5.4	28	6.1	5.5	22	9.9%	4.00 [0.95, 7.05]
Jiang 2016 (I)	5.87	4.98	59	4.22	5.51	21	10.2%	1.65 [−1.03, 4.33]
Jiang 2016 (II)	24	14.91	28	8.66	4.5	34	7.5%	15.34 [9.61, 21.07]
Ledesma 2023	11.6	6.64	122	17.6	11.2	75	10.1%	−6.00 [−8.80, −3.20]
Liu 2009	15.5	3.7	34	14.6	5.1	63	10.8%	0.90 [−0.87, 2.67]
Luo 2020	16.82	19.26	108	12.85	20.42	42	6.3%	3.97 [−3.19, 11.13]
Song 2022	16.4	5.7	42	11.1	5.4	36	10.3%	5.30 [2.83, 7.77]
Wang 2016 (I)	17.2	4.7	35	25.6	15.5	39	8.1%	−8.40 [−13.51, −3.29]
Wang 2016 (II)	15.4	10.1	34	25.6	15.5	39	7.3%	−10.20 [−16.13, −4.27]
Zhang 2019	3.4	2	16	2.8	1.4	12	11.0%	0.60 [−0.66, 1.86]
Total (95% CI)			**526**			**416**	**100.0%**	**1.08 [−1.63, 3.79]**

Heterogeneity: $Tau^2 = 16.91$; $Chi^2 = 94.68$, df = 10 ($P < 0.00001$); $I^2 = 89\%$
Test for overall effect: Z = 0.78 (P = 0.43)

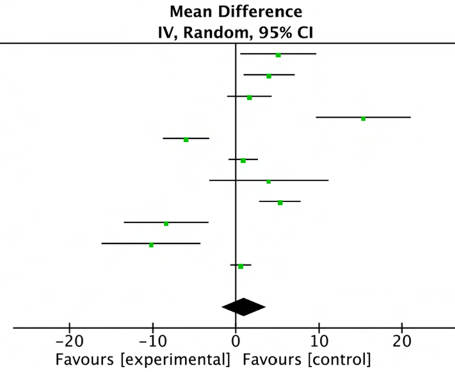

Fig. 12 Comparision between long fusion versus short fusion in Cobb angle final follow-up

were no differences in coronal balance or sagittal balance between the short and long groups at the final follow-up [11, 15, 16, 18], as shown in 22.

Discussion

With increasing age, the incidence of degenerative scoliosis gradually increases. Patients present mainly with low back pain, symptoms of nerve root compression, and intermittent claudication. In severe cases, there may be coronal or sagittal plane imbalance [14].The principles of surgical treatment for degenerative scoliosis encompass comprehensive decompression of the spinal nerves to alleviate patient symptoms, with the goal of achieving balanced reconstruction in both the coronal and sagittal planes. Pure decompression may lead to instability and adjacent degeneration. To prevent iatrogenic instability, the combination of decompression and internal fusion is considered the optimal approach [20, 21]. The debate focuses on whether to opt for long or short fusion to achieve the best outcomes. Degenerative scoliosis patients are often elderly, and the surgery duration is long, with a relatively high risk of complications. Carefully selecting the segments for fusion helps ensure comparable surgical efficacy while maximizing safety, reducing complications, and minimizing iatrogenic injury [21, 22].

A meta-analysis by Lee showed that short-segment fusion had advantages in less blood loss and shorter surgery time, while long-segment fusion achieved better Cobb angle correction, with no significant differences in postoperative VAS or ODI scores [5]. Phan's study found similar overall complication rates but noted fewer pulmonary complications in the short-segment group and better implant stability in the long-segment group [6]. Both studies predate 2017, with a new meta-analysis protocol reported in 2020.6 [23]. This meta-analysis compares short and long fusion for degenerative scoliosis up to February 2024, incorporating post-2017 studies to expand the sample size and enhance result validity while aligning with previous findings.

In terms of clinical indicators, the two groups showed no significant differences in the VAS score or ODI, indicating that the postoperative efficacy of both long-segment and short-segment fusion was relatively satisfactory. Compared with that at baseline, the VAS leg improved in both groups at the final follow-up and was less than 3 points, which represents satisfactory effects at the final follow-up. Four studies reported comparable outcomes between the two groups at the final follow-up. However, the meta-analysis reported greater VAS at the final follow-up in the short-segment group. Short fusion may result in a less stable surgical site than long fusion does, and the lack of adequate stability may increase the motion of the intervertebral joints, causing pain and discomfort. More high-quality studies are needed for analysis. Effective relief of symptoms occurs with sufficient decompression of responsible nerve roots and segments. Similarly, the alleviation of pain also explains the absence of differences in functional impairment.

According to the results of the meta-analysis, short fusion reduces average blood loss by 748.08 ml, shortens the average surgery time by 107.81 min, and has a complication OR of 0.49 compared with the long fusion group. These results effectively demonstrate the advantages of short-segment fusion. Most patients with degenerative scoliosis are elderly and have poor overall health and multiple underlying conditions. Reducing surgery time and intraoperative blood loss can effectively reduce postoperative complications and ensure the safety of the procedure in elderly patients.

Surgery not only alleviates symptoms but also corrects coronal and sagittal balance to suppress scoliosis progression and restore physiological balance. The study found that the Cobb angle and imbalance at baseline were higher in the long fusion group compared to the short fusion group, but these differences disappeared at the final follow-up. This suggests that long fusion is more suitable for correcting severe deformities and restoring spinal balance, although there were no significant postoperative differences between the two groups. LL represents the normal physiological lordosis of the lumbar spine in the sagittal plane. In this study, the baseline LL conditions included in the research reported no differences, and there were no differences in the final LL. The ability to restore lumbar lordosis in the sagittal plane was not different between the long-fusion and short-fusion groups. The SS is a position-related parameter influenced by body position. The SS is widely recognized as a crucial determinant of lumbar LL. The PT is also a position-related parameter that indicates the degree of forward or backward tilt of the pelvis. The PT reflects the degree of compensation for the spinal deformity, with patients compensating for the spinal imbalance through pelvic retroversion (increased PT value). There were no differences in sagittal balance at the final follow-up. Sagittal balance is closely related to LL, PT, and SS. Therefore, there were no differences in sagittal balance between the long fusion group and the short fusion group at the final follow-up.

Sagittal decompensation following long fusion surgeries should not be overlooked, as it is often associated with distal segment complications, such as pseudarthrosis and implant failure at the lumbosacral junction [24]. In addition, in previous studies, screw loosening was a common complication in patients with degenerative lumbar scoliosis who underwent long-segment surgery, particularly at the lowest instrumented vertebra or upper instrumented vertebra. Independent risk factors include lateral subluxation ≥ 8 mm, osteopenia, osteoporosis, fusion extending to the sacrum, postoperative thoracolumbar kyphosis TLK greater than 10°, and sagittal imbalance [25].

The risk of adjacent segment degeneration (ASD) should be considered [26]. Robust internal fixation aids early mobility and bone fusion, but increased stiffness in fused segments can lead to compensatory loads on adjacent segments, altering stress distribution and joint contact points. Convincing biomechanical and clinical data indicate that with the increased stiffness of the fused segments, compensatory movement occurs in the adjacent segments. Loads that were originally distributed across many segments are now concentrated on a few segments, leading to changes in stress distribution and joint contact points [27, 28]. Studies show no significant differences in ASD or sagittal and coronal plane parameters between long and short fusion surgeries at the final follow-up. This indicates that the long-term impact on adjacent segments is comparable for both fusion lengths.

The correct selection of fusion segments is vital for surgical success. As the apex vertebra of scoliosis is often between L2 and L4 and the L4/5 disc commonly degenerates, the distal fusion segment usually extends to L4/5. Whether to fuse to S1 is a hot topic [29, 30]. Fusion ending at the L5 level offers several advantages: less surgical trauma, lower cost, preservation of L5/S1 segment function, retention of lumbosacral mobility, reduced risk of pseudoarthrosis, lower surgical risk, and less impact on hip joint function. However, it carries the risk of progressive adjacent segment degeneration over time and may lead to coronal and sagittal imbalance. Fusion extending to S1 helps achieve better sagittal correction, but the degree of surgical trauma is greater, and the incidence of L5/S1 pseudoarthrosis and hardware failure is greater postoperatively. Therefore, when selecting the fusion segment for patients with DS, it is essential to consider both the local and overall deformities, the patient's main clinical symptoms, and the degree of degeneration at L5/S1.Fusion to S1 should be prioritized in cases requiring greater stability, while fusion to L5 may be preferred when preservation of function and mobility is critical [31, 32].

The choice between long fusion and short fusion depends on the severity of the spinal deformity (such as Cobb angle and sagittal imbalance), the patient's overall health, symptoms and the patient's personal goals and lifestyle. Long fusion is suited for patients with severe deformities who require greater stability, while short-segment fusion is more appropriate for those with milder symptoms who need a lower-risk surgery and a more flexible recovery. Besides, incorporating genetic markers into preoperative evaluations could optimize surgical approach selection and provide personalized treatment plans for different patients. Shang demonstrated that specific genetic mutations might lead to more severe degenerative scoliosis, making these patients more suitable for long fusion surgery to achieve better correction and stability [33].

Although this study only discusses posterior approach surgeries, the methods for reducing surgical trauma are not limited to posterior approach surgeries alone. In recent years, researches have reported Oblique Lateral Interbody Fusion (OLIF) combined with posterior fixation techniques is comparable to posterior internal fusion fixation alone in treating degenerative scoliosis in terms of deformity correction and clinical efficacy. The OLIF technique involves the anterior placement of a large interbody fusion cage, which increases intervertebral height, which can increase the intervertebral height, indirectly decompress the spinal canal, and simultaneously improve coronal and sagittal balance. Subsequently, the second stage of posterior internal fixation further shortens the fixed segments and reduces trauma on this basis, thus optimizing the overall treatment effect [34, 35].

This study has certain limitations: (I) The included studies were case–control studies and not high-quality randomized controlled studies. Therefore, the included studies may have differences in demographics, radiographic baselines, and clinical baselines, such as the degree of the Cobb angle. However, good heterogeneity (I^2) was demonstrated in the final results, suggesting that the results of the studies were consistent. (II) The studies included poor allocation concealment, which may have resulted in selection and allocation bias. Future research should involve multicenter, large-sample, long-term, prospective randomized controlled trials to further assess the differences between the two approaches. (III) There are variations in the classification of long/short fusion among the included studies. The criteria for long and short fusion vary among studies. Some studies classify patients with ≥ 3 segments, others classify patients with ≥ 5 segments, and another group of studies classifies patients based on whether the number of segments exceeds the upper and lower end vertebrae of pathological scoliosis. (IV) The included studies focused on the treatment of patients with degenerative scoliosis, but the included studies did not include further exploration based on classification similar to that of Lenke. It is possible that there are many different classes of degenerative scoliosis and that there is no standardized typology, such as the one used by Lenke. A clear typing of degenerative scoliosis to further guide treatment would be more valuable. (V) Only studies in English were included. Studies in Chinese or other languages were not included. This may introduce bias. (VI) Jiang 2016 used long fusion as a control group twice, which may have inflated the weight of this study in the meta-analysis, potentially impacting the overall effect estimate. This may introduce bias.

Conclusions

Long fusion is superior in terms of radiographic improvement, particularly in reducing the Cobb angle and reconstructing coronal and sagittal balance. In terms of the final sagittal and coronal balance, there was no significant difference compared with short fusion. Both groups exhibited comparable clinical outcomes at the final follow-up. Short fusion is superior in terms of surgical time, intraoperative blood loss, and postoperative complication rates. Considering the overall condition of the patient, weighing the benefits and risks of surgery, and taking into account the coronal Cobb angle and coronal/sagittal imbalance are important. For patients with a large coronal Cobb angle and significant coronal or sagittal imbalance, long fusion surgery should be performed. On the other hand, for patients with milder deformities and clinical symptoms are the main concern, short fusion surgery is recommended.

Supplementary Information

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Supplementary file 1.

Supplementary file 2.

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Author contributions
Bin Zheng, Qiang Zhou, Xuanwen Liu, Qiangzhe design study and extract data. Bin Zheng, Qiang Zhou perform data analysis and prepare figure. Qiang Zhe supervised whole process.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
This study is based on publication, and there is no need for ethical approval.

Consent for publication
All authors agree for publication.

Competing interests
The authors declare that they have no competing interests.

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