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REVIEW ARTICLE

Adjacent segment degeneration after lumbar spinal fusion compared with motion-preservation procedures: a meta-analysis

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Abstract
Purpose This meta-analysis aimed to evaluate the efficacy of motion-preservation procedures to prevent the adjacent segment degeneration (ASDeg) or adjacent segment disease (ASDis) compared with fusion in lumbar spine.
Methods PubMed, Embase and the Cochrane Library were comprehensively searched and a meta-analysis was performed of all randomized controlled trials and well designed prospective or retrospective comparative cohort studies assessing the lumbar fusion and motion-preservation procedures. We compared the ASDeg and ASDis rate, reoperation rate, operation time, blood loss, length of hospital stay, visual analogue scale (VAS) and oswestry disability index (ODI) improvement of the two procedures.
Results A total of 15 studies consisting of 1474 patients were included in this study. The meta-analysis indicated that the prevalence of ASDeg, ASDis and reoperation rate on the adjacent level were lower in motion-preservation procedures group than in the fusion group ($P = 0.001$; $P = 0.0004$; $P < 0.0001$). Moreover, shorter length of hospital stay was found in motion-preservation procedures group ($P < 0.0001$). No difference was found in terms of operation time ($P = 0.57$), blood loss ($P = 0.27$), VAS ($P = 0.76$) and ODI improvement ($P = 0.71$) between the two groups.
Conclusions The present evidences indicated that the motion-preservation procedures had an advantage on reducing the prevalence of ASDeg, ASDis and the reoperation rate due to the adjacent segment degeneration compared with the lumbar fusion. And the clinical outcomes of the two procedures are similar.

Keywords Adjacent segment degeneration · Adjacent segment disease · Lumbar spinal fusion · Motion-preservation procedures · Meta-analysis

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Introduction

Lumbar fusion is a traditional intervention applied to the treatment of lumbar degenerative disease [1]. Although favorable clinical outcomes can be achieved, complications of lumbar fusion with rigid fixation gained increasing attention, such as the degeneration on the adjacent level. Omair et al. [2] deemed that fusion was one of the risk factors for adjacent segment disc degeneration as well as age and genetic factors in patients treated for chronic low back pain. Similarly, fusion was associated with adjacent segment disease in a review study by Radcliff et al. [3]. To reduce the undesirable complications of rigid fixation, motion-preservation devices have been developed in diversity. However, evidence to support the use of motion-preservation procedures for fusion in the lumbar spine is limited.

Adjacent segment degeneration (ASDeg) or adjacent segment disease (ASDis) is a long-term complication after lumbar fusion. It has been reported that the motion-preservation devices could protect the spine from mechanical overload imposed by the rigid fixation of the spine while retaining spine movement and preventing adjacent segment degeneration in many articles [4–7].

Chunpeng Ren et al. published a meta-analysis, in 2013, about the adjacent segment degeneration and disease after lumbar fusion and concluded that the lumbar fusion may result in a higher prevalence of adjacent segment degeneration or disease than motion-preservation procedures. However, more well-designed retrospective studies about the ASDeg or ASDis after lumbar fusion compared with motion-preservation procedures were published in recent years [8, 9]. It is necessary to conduct an updated systematic review and meta-analysis to evaluate the efficacy of motion-preservation procedures to prevent the ASDeg or ASDis compared with lumbar fusion.

Methods

Literature search strategy

Electronic databases, including MEDLINE, Embase, Cochrane Library, were searched for relevant reports published up to June 30, 2015 using the following keywords: "lumbar spinal fusion", "total disc arthroplasty", "total disc replacement", "interspinous implants", "interspinous spacers", "dynamic stabilization", "dynesys", "X-STOP", "Coflex", "Wallis", "DIAM", "Topping-off", "adjacent segment degeneration", "adjacent segment deterioration", and "adjacent segment disease".

Literature screening

Randomized controlled trials (RCTs) and retrospective or prospective studies were selected. To be specific, studies were included when they met with the following criteria: (1) patients who had degenerative disc disease, discherniation, radiculopathy, and spondylolisthesis and underwent lumbar fusion or motion-preservation device surgery; (2) studies reported on the prevalence of ASDeg or ASDis, or reoperation rate for adjacent segment after lumbar fusion or motion-preservation device surgery; (3) a follow-up time of no less than 12 months. The following articles were excluded: (1) case reports, review articles, comments, letters, biomechanical studies and animal experiments; (2) duplicate publications; (3) studies that did not meet the inclusion criteria.

Data extraction

The primary outcome of interest include: the prevalence of ASDeg and ASDis and reoperation rate. The secondary outcome of interest include: operation time, blood loss, length of hospital stay, VAS and ODI improvement. Continuous variable were recorded only when the mean and standard deviations (SD) were reported. When exact mean and SD were not reported, these values were estimated from available graphs using the software Getdata. Two authors (Aixing Pan and Xiaolong Chen) independently extracted the data from the articles included. Discrepancies between the reviewers were resolved by discussion and consensus.

Studies quality assessment

Methodological quality of these studies was independently graded by two investigators (Aixing Pan and Hui Guo). The Newcastle–Ottawa Scale (NOS) [1, 4–10] was used to assess the quality for cohort studies. High quality study was defined as the NOS score $\geq$7. The RCTs were evaluated according to Jadad scale [11]. High-quality study was defined as the Jadad score $\geq$4.

Statistical analysis

Statistical analyses were performed by RevMan5.3 software (available from the Cochrane Collaboration at http://www.cochrane.org). Standardized mean difference (SMD) and 95 % confidence interval (CI) were calculated for continuous data. Odds ratio (OR) and 95 % CI were used for dichotomous data. Heterogeneity was explored using I^2 statistic and the result of the Chi-squared test. Significant heterogeneity was assumed when the I^2 value was greater than 50 %. Fixed-effects model was applied when $I^2 < 50$ % and random-effects model was applied when $I^2 > 50$ %. A sensitivity analysis was conducted by including only prospective studies. Subgroup analysis was performed by comparing fusion with single dynamic procedures (such as Dynesys, x-stop and total disc replacement) and Topping-off procedure (interspinous process device, such as Dynesys, Coflex or DIAM, was implanted proximal to the fusion). However, if the heterogeneity could not be eliminated, random-effects model was used for the combined analysis of the studies. Publication bias was assessed using the funnel plot method.

Results

Searching results

A total of 686 literatures were retrieved according to the search strategy. After application of the inclusion and exclusion criteria, 15 studies including 1474 patients were finally included in the meta-analysis (Fig. 1).

Baseline characteristics

As shown in Table 1, the study ID, country, study design, study quality, follow-up period, intervention, sample size and age of the patients were listed. Primary data about ASDeg, ASDis and reoperation were list on Table 2. The

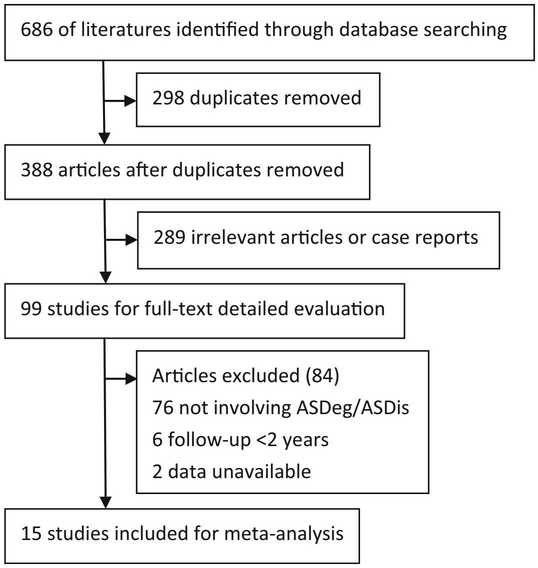

Fig. 1 The flow chart of literature selection

study included retrospective and prospective cohort studies (9) as well as RCTs (6). The follow-up period ranged from 2 to 6.4 years. Of the 1474 patients, 687 underwent fusion and 787 underwent motion-preservation procedures. The fusion surgery procedures included posterior lumbar interbody fusion (PLIF), posterolateral lumbar fusion (PLF), transforaminal lumbar interbody fusion (TLIF), single-level fusion (SLF) and anterior lumbar interbody fusion (ALIF). Motion-preservation procedures included Dynesys, x-stop, TDR (total disc replacement), Graf (Gralf ligamentoplasty), Wallis, IPDS (isobar posterior dynamic stabilization, Scient'x, France) and Topping-off construct.

ASDeg

Nine studies [1, 4–18] consisting of 554 patients reported the incidence of ASDeg after lumbar fusion or motion preserving device surgery. The prevalence of ASDeg after long-term follow up in lumbar fusion group was significant higher than the nonfusion group [37.5 vs. 18.6 %; OR = 3.03; 95 % CI (1.56, 5.89); $P = 0.001 < 0.05$] (Fig. 2). Significant heterogeneity was detected for ASDeg ($I^2 = 49$ %) and the random-effects model was applied. Subgroup analysis according to the type of motion-preservation procedure (single level dynamic fixation or Topping-off procedure) came to the same result that the dynamic procedures had an advantage on reducing the incidence of ASDeg.

ASDis

Seven studies [8, 9, 14, 19–23] consisting of 712 patients compared the prevalence of ASDis between lumbar fusion and nonfusion procedures. The fixed-effects model was applied to compare the ASDis incidence between the two groups ($I^2 = 0$ %). The pooled estimate revealed that the prevalence of ASDis in fusion group was higher than motion preserving group without heterogeneity and the difference was significant [14.4 vs.. 5.1 %; OR = 2.81; 95 % CI (1.59, 4.96); $P = 0.0004 < 0.05$] (Fig. 3).

Subgroup analysis was performed according to the type of motion-preservation procedure (single level dynamic fixation or Topping-off procedure). The analysis of single level dynamic fixation studies showed the same result. However, the analysis of Topping-off studies indicated that the prevalence of ASDis in Topping-off group had no significant difference compared with fusion [18.4 . 6.5 %; OR = 2.78; 95 % CI (0.99, 7.78); $P = 0.05$] (Fig. 4).

Reoperation

The relevant data regarding the reoperation due to the adjacent segment disease were documented in 12 articles [1, 4–12, 14, 16–24] including 1249 patients. No heterogeneity was detected for reoperation rate ($I^2 = 0$ %) and the fixed-effects model was applied. The pooled estimate revealed that the reoperation rate in fusion group was higher than motion preserving group and the difference was significant [7.7 vs. 1.1 %; OR = 4.82; 95 % CI (2.39, 9.71); $P < 0.0001$] (Fig. 5).

Operation time

Data regarding operation time were available in five studies [9, 16, 17, 19, 20] consisting of 472 patients. The random-effects model was applied to compare the operation time between the two groups with a high heterogeneity ($I^2 = 100$ %). The cause of heterogeneity was investigated by subgroup analysis according to the different type of motion-preservation devices. The result of subgroup analysis showed that there was no significant difference of operation time in TDR and fusion group [SMD = −36.80; 95 % CI (−135.11, 61.51); $P = 0.46 > 0.05$]. Meanwhile, the operation time of Dynesys was shorter than fusion [SMD = 36.47; 95 % CI (2.06, 70.88); $P = 004 < 0.05$]. However, it spent more time in IPDS procedure than fusion [SMD = −86.42; 95 % CI (−94.60, −78.24); $P < 0.0001$] (Fig. 6).

Blood loss

Data regarding blood loss were available in five studies [9, 16, 17, 19, 20] consisting of 472 patients. The random-effects model was applied to compare the operation time between the two groups with a high heterogeneity ($I^2 = 99$ %). The cause of heterogeneity was investigated by subgroup analysis. Subgroup analysis was performed

Table 1 Basic character of the included studies

Study	Country	Design	Quality	Follow up (years)	Intervention		Sample size		Age (years)	
					F	NF	F	NF	F	NF
Yang et al. [9]	China	Retro	7[a]	4	PLIF	IPDS	51	62	46.6 (12.1)	44.3 (13.0)
Lu et al. [8]	China (Taiwan)	Retro	7[a]	3.4	PLIF	Topping-off (DIAM)	42	49	59.0 (8.6)	64.5 (7.2)
Lee et al. [18]	Korea	Retro	8[a]	2	PLIF	Topping-off (DIAM)	50	25	65.9 (8.5)	65.4 (8.7)
Yu et al. [16]	China (Taiwan)	Retro	7[a]	3	PLIF	Dynesys	25	35	63.1 (4.4)	60.8 (4.8)
Yu et al. [17]	China (Taiwan)	RCT	4[b]	3	PLIF	Dynesys	26	27	55.5 (7.0)	52.2 (8.3)
Azzazi and Elhawary [15]	Egypt	RCT	1[b]	2	PLF/TLIF	X-stop	30	30	–	–
Putzier et al. [23]	Germany	RCT	4[b]	6.4	SLF	Topping-off (Dynesys and Allospine)	25	22	44.6	44.9
Kaner et al. [22]	Turkey	Pro	8[a]	3.4	PLF	Topping-off	20	26	58.1 (8.5)	63.7 (11.3)
Berg et al. [19]	Sweden	RCT	6[b]	5	PLF/PLIF	TDR	72	80	38.5 (7.8)	40.2 (8.1)
Guyer et al. [20]	USA	RCT	2[b]	5	ALIF	TDR	43	90	40.0 (8.6)	38.8 (8.7)
Kanayama et al. [21]	Japan	Retro	7[a]	3.4	PLF/PLIF	Graf	153	65	62	63
Korovessis et al. [34]	Greece	Pro	7[a]	4.5	PLF	Wallis	21	24	64 (11)	65 (13)
Kumar et al. [13]	UK	Pro	8[a]	2	PLF/PLIF	Dynesys	12	20	50	50
McAfee et al. [24]	USA	RCT	3[b]	2	ALIF	TDR	99	205	18–55	
Kanayama et al. [12]	Japan	Retro	8[a]	5	PF	Graf	18	27	58 (11)	55 (15)

Retro retrospective cohort study, *Pro* prospective cohort study, *RCT* randomized controlled trial

[a] Newcastle-Ottawa Scale (NOS) score

[b] Jadad scale score

Table 2 Data regarding ASDeg, ASDis and reoperation rate

Study	F		NF		N		NF		N		NF	
	ASDeg	Total	ASDeg	Total	ASDis	Total	ASDis	Total	Re-op	Total	Re-op	Total
Yang et al. [9]	23	51	26	62	–[a]	–	–	–	–	–	–	–
Lu et al. [8]	20	42	3	29	9	42	3	29	3	42	1	29
Lee et al. [18]	24	50	6	25	–	–	–	–	7	50	2	25
Yu et al. [16]	5	25	6	35	–	–	–	–	2	25	0	35
Yu et al. [17]	6	26	1	27	–	–	–	–	3	26	0	27
Azzazi and Elhawary [15]	7	30	2	30	–	–	–	–	–	–	–	–
Putzier et al. [23]	–	–	–	–	6	25	2	22	1	25	0	22
Kaner et al. [22]	–	–	–	–	1	20	0	26	1	20	0	26
Berg et al. [19]	–	–	–	–	6	72	1	80	6	72	1	80
Guyer et al. [20]	–	–	–	–	8	43	5	90	2	43	1	90
Kanayama et al. [21]	–	–	–	–	21	153	6	65	11	153	1	65
Korovessis et al. [34]	6	21	1	24	3	21	0	24	3	21	0	24
Kumar et al. [13]	2	12	4	20	–	–	–	–	–	–	–	–
McAfee et al. [24]	–	–	–	–	–	–	–	–	2	99	0	205
Kanayama et al. [12]	10	18	3	27	–	–	–	–	5	18	1	27

F fusion, *NF* nonfusion, *Re-op* reoperation

[a] – not available

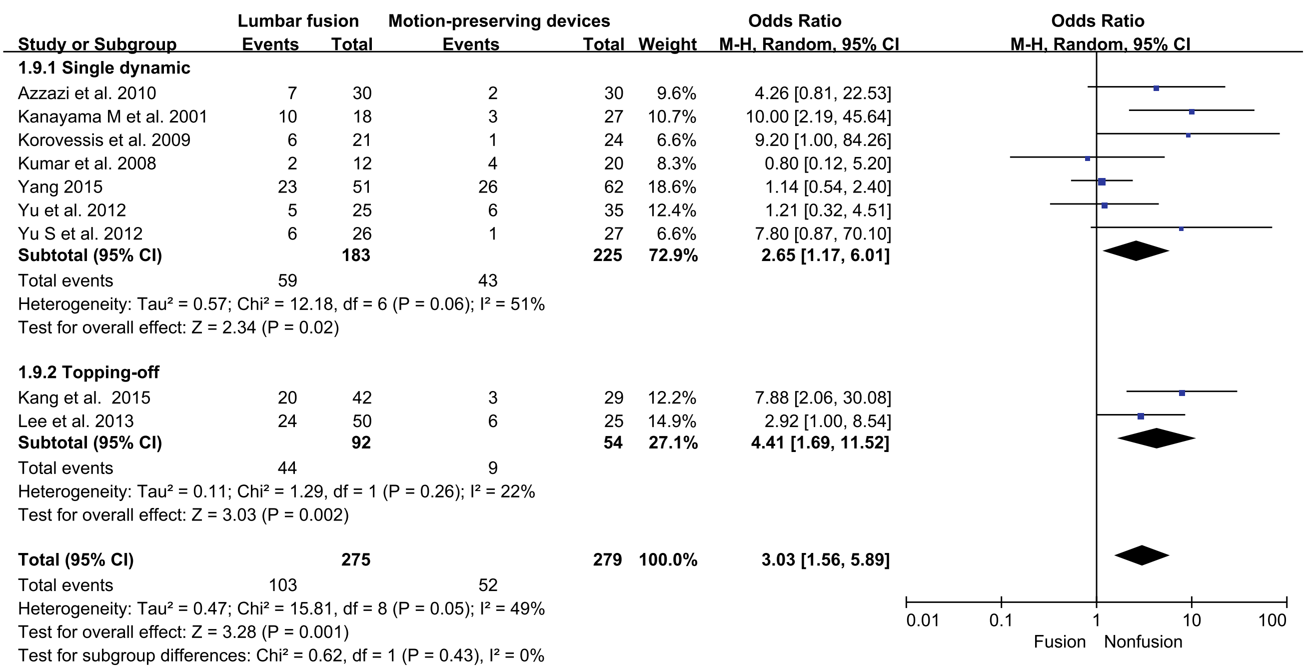

Fig. 2 Forest plot of subgroup analysis comparing ASDeg for lumbar fusion versus nonfusion. *M-H* Mantel–Haenszel, *CI* confidence interval

according to the different type of motion-preservation devices. The result showed that the blood loss of TDR and fusion had no significant difference [SMD $= -59.94$; 95 % CI (-165.91, 46.02); $P = 0.27 > 0.05$]. The blood loss of Dynesys group was less than the fusion group and the difference was significant [SMD $= 133.74$; 95 % CI (27.38, 248.09); $P = 0.01 < 0.05$]. The blood loss of IPDS group was more than the fusion group with a significant difference [SMD $= -197.94$; 95 % CI (-218.90, -176.98); $P < 0.00001$] (Fig. 7).

Study or Subgroup	Lumbar fusion Events	Lumbar fusion Total	Motion-preserving devices Events	Motion-preserving devices Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Berg et al. 2009	6	72	1	80	5.4%	7.18 [0.84, 61.17]
Guyer et al. 2009	8	43	5	90	16.5%	3.89 [1.19, 12.70]
Kanayama et al. 2009	21	153	6	65	45.5%	1.56 [0.60, 4.08]
Kaner et al. 2010	1	20	0	26	2.5%	4.08 [0.16, 105.52]
Kang et al. 2015	9	42	3	29	17.5%	2.36 [0.58, 9.62]
Korovessis et al. 2009	3	21	0	24	2.5%	9.27 [0.45, 190.73]
Putzier et al. 2010	6	25	2	22	10.1%	3.16 [0.57, 17.62]
Total (95% CI)		**376**		**336**	**100.0%**	**2.81 [1.59, 4.96]**
Total events	54		17			

Heterogeneity: Chi² = 3.19, df = 6 (P = 0.79); I² = 0%
Test for overall effect: Z = 3.56 (P = 0.0004)

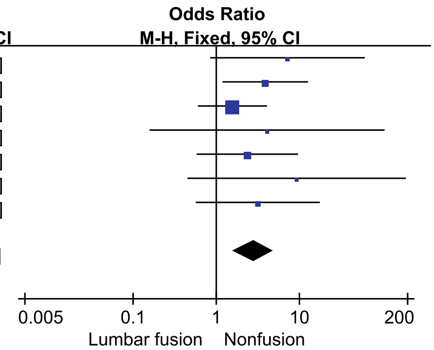

Fig. 3 Forest plot comparing ASDis for lumbar fusion versus motion preservation procedures. *M-H* Mantel–Haenszel, *CI* confidence interval

Study or Subgroup	Lumbar fusion Events	Lumbar fusion Total	Motion-preserving devices Events	Motion-preserving devices Total	Weight	Odds Ratio M-H, Fixed, 95% CI
1.2.1 Single dynamic						
Berg et al. 2009	6	72	1	80	5.4%	7.18 [0.84, 61.17]
Guyer et al. 2009	8	43	5	90	16.5%	3.89 [1.19, 12.70]
Kanayama et al. 2009	21	153	6	65	45.5%	1.56 [0.60, 4.08]
Korovessis et al. 2009	3	21	0	24	2.5%	9.27 [0.45, 190.73]
Subtotal (95% CI)		**289**		**259**	**69.9%**	**2.82 [1.43, 5.58]**
Total events	38		12			
Heterogeneity: Chi² = 3.06, df = 3 (P = 0.38); I² = 2%						
Test for overall effect: Z = 2.98 (P = 0.003)						
1.2.2 Topping-off						
Kaner et al. 2010	1	20	0	26	2.5%	4.08 [0.16, 105.52]
Kang et al. 2015	9	42	3	29	17.5%	2.36 [0.58, 9.62]
Putzier et al. 2010	6	25	2	22	10.1%	3.16 [0.57, 17.62]
Subtotal (95% CI)		**87**		**77**	**30.1%**	**2.78 [0.99, 7.78]**
Total events	16		5			
Heterogeneity: Chi² = 0.13, df = 2 (P = 0.94); I² = 0%						
Test for overall effect: Z = 1.94 (P = 0.05)						
Total (95% CI)		**376**		**336**	**100.0%**	**2.81 [1.59, 4.96]**
Total events	54		17			

Heterogeneity: Chi² = 3.19, df = 6 (P = 0.79); I² = 0%
Test for overall effect: Z = 3.56 (P = 0.0004)
Test for subgroup differences: Chi² = 0.00, df = 1 (P = 0.98), I² = 0%

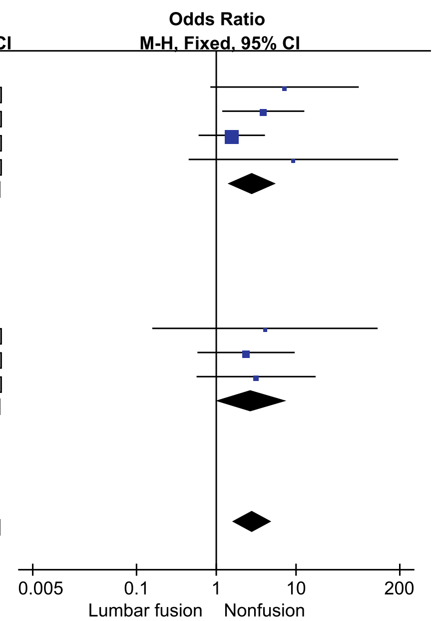

Fig. 4 Forest plot of subgroup analysis comparing ASDis for lumbar fusion versus motion preservation procedures. *M-H* Mantel–Haenszel, *CI* confidence interval

Study or Subgroup	Lumbar fusion Events	Lumbar fusion Total	Motion-preserving devices Events	Motion-preserving devices Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Berg et al. 2009	6	72	1	80	9.5%	7.18 [0.84, 61.17]
Guyer et al. 2009	2	43	1	90	6.7%	4.34 [0.38, 49.25]
Kanayama et al. 2009	11	153	1	65	14.2%	4.96 [0.63, 39.22]
Kanayama M et al. 2001	5	18	1	27	6.3%	10.00 [1.06, 94.68]
Kaner et al. 2010	1	20	0	26	4.4%	4.08 [0.16, 105.52]
Kang et al. 2015	3	42	1	29	12.0%	2.15 [0.21, 21.80]
Korovessis et al. 2009	3	21	0	24	4.3%	9.27 [0.45, 190.73]
Lee et al. 2013	7	50	2	25	25.0%	1.87 [0.36, 9.76]
McAfee et al. 2006	2	99	0	205	3.5%	10.54 [0.50, 221.62]
Putzier et al. 2010	1	25	0	22	5.4%	2.76 [0.11, 71.15]
Yu et al. 2012	2	25	0	35	4.1%	7.55 [0.35, 164.47]
Yu S et al. 2012	3	26	0	27	4.7%	8.19 [0.40, 166.83]
Total (95% CI)		**594**		**655**	**100.0%**	**4.82 [2.39, 9.71]**
Total events	46		7			

Heterogeneity: Chi² = 3.03, df = 11 (P = 0.99); I² = 0%
Test for overall effect: Z = 4.39 (P < 0.0001)

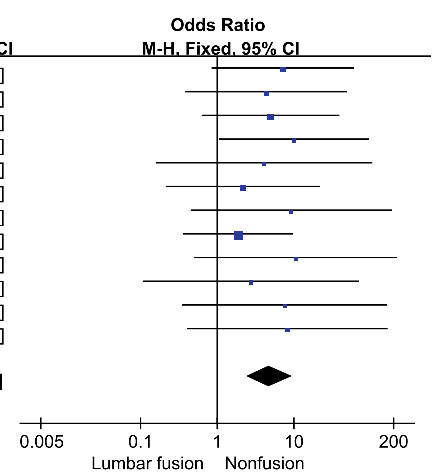

Fig. 5 Forest plot comparing reoperation rate for lumbar fusion versus motion-preservation procedures. *M-H* Mantel–Haenszel, *CI* confidence interval

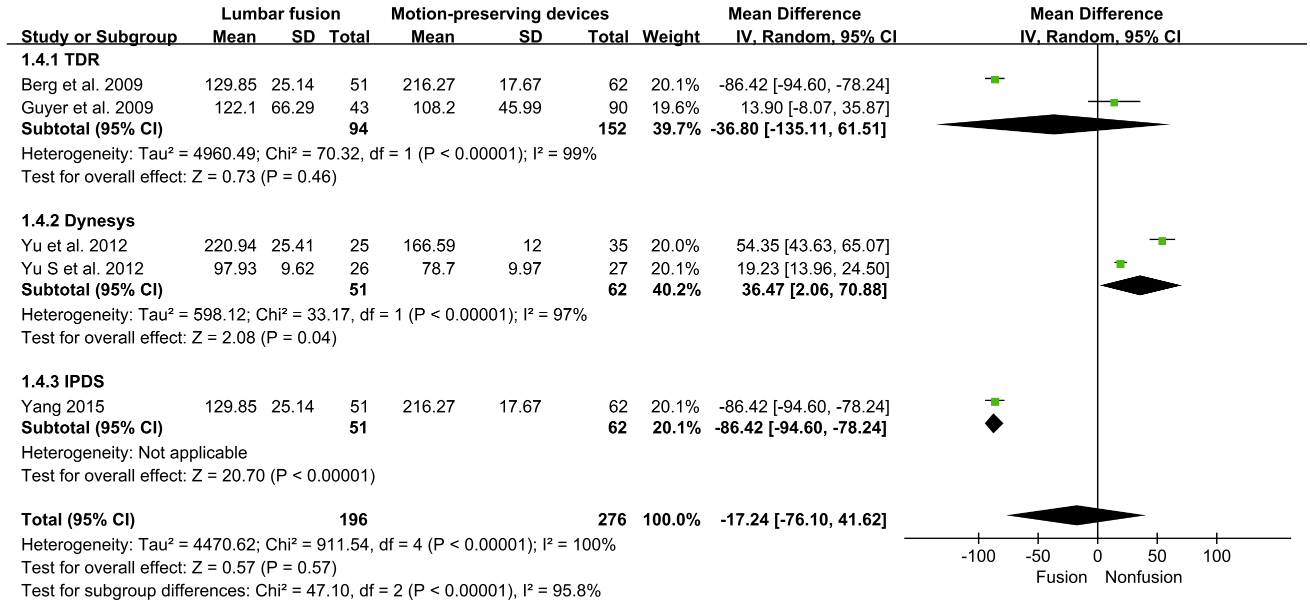

Fig. 6 Forest plot comparing operation time for lumbar fusion versus motion-preservation procedures. *SD* standard deviation, *IV* inverse variance, *CI* confidence interval

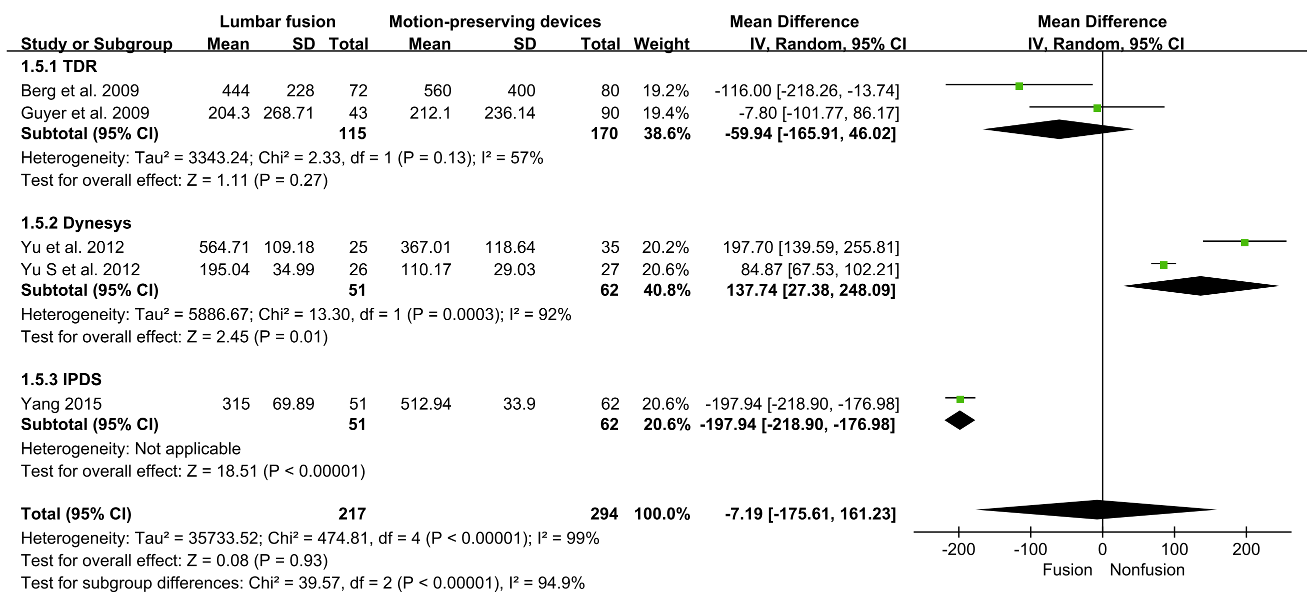

Fig. 7 Forest plot comparing blood loss for lumbar fusion versus motion-preservation procedures. *SD* standard deviation, *IV* inverse variance, *CI* confidence interval

Length of hospital stay

Data regarding length of hospital stay were available in five studies [16, 17, 19, 20] consisting of 398 patients. The random-effects model was applied to compare the length of hospital stay between the two groups with a high heterogeneity ($I^2 = 74$ %). The cause of heterogeneity was investigated by subgroup analysis and sensitivity analysis but could not be ascertained. The pooled estimate revealed that the length of hospital stay in nonfusion group was shorter than the fusion group and the difference was significant [SMD = 1.18; 95 % CI (0.65, 1.72); $P < 0.0001$] (Fig. 8).

VAS improvement

Eight studies [8, 9, 14, 16, 19, 20, 22, 23] consisting of 680 patients reported the preoperative and postoperative VAS

Study or Subgroup	Lumbar fusion Mean	SD	Total	Motion-preserving devices Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.6.1 TDR								
Berg et al. 2009	5.9	1.2	72	4.4	1.6	80	27.6%	1.50 [1.05, 1.95]
Guyer et al. 2009	4.3	1.78	43	3.7	0.9	90	24.8%	0.60 [0.04, 1.16]
Subtotal (95% CI)			**115**			**170**	**52.4%**	**1.07 [0.19, 1.95]**
Heterogeneity: Tau² = 0.34; Chi² = 6.01, df = 1 (P = 0.01); I² = 83%								
Test for overall effect: Z = 2.37 (P = 0.02)								
1.6.2 Dynesys								
Yu et al. 2012	7.91	1.66	25	7.14	0.96	35	21.0%	0.77 [0.05, 1.49]
Yu S et al. 2012	7.23	0.89	26	5.5	0.92	27	26.6%	1.73 [1.24, 2.22]
Subtotal (95% CI)			**51**			**62**	**47.6%**	**1.29 [0.35, 2.23]**
Heterogeneity: Tau² = 0.36; Chi² = 4.65, df = 1 (P = 0.03); I² = 78%								
Test for overall effect: Z = 2.69 (P = 0.007)								
Total (95% CI)			**166**			**232**	**100.0%**	**1.18 [0.65, 1.72]**
Heterogeneity: Tau² = 0.22; Chi² = 11.70, df = 3 (P = 0.008); I² = 74%								
Test for overall effect: Z = 4.33 (P < 0.0001)								
Test for subgroup differences: Chi² = 0.11, df = 1 (P = 0.74), I² = 0%								

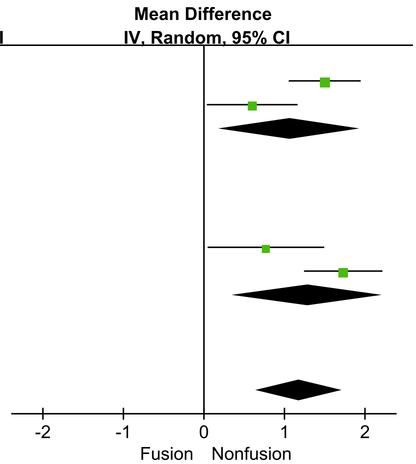

Fig. 8 Forest plot comparing length of hospital stay for lumbar fusion versus motion-preservation procedures. *SD* standard deviation, *IV* inverse variance, *CI* confidence interval

Study or Subgroup	Lumbar fusion Mean	SD	Total	Motion-preserving devices Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Berg et al. 2009	2.93	3.16	72	3.69	3.1	80	7.7%	-0.76 [-1.76, 0.24]
Guyer et al. 2009	4.03	2.42	43	3.85	2.45	90	9.9%	0.18 [-0.70, 1.06]
Kaner et al. 2010	6.85	1.08	20	6.58	0.99	26	20.9%	0.27 [-0.34, 0.88]
Kang et al. 2015	5.5	1.8	42	5.6	2.1	49	12.0%	-0.10 [-0.90, 0.70]
Korovessis et al. 2009	3.8	3	21	4.2	2.1	24	3.3%	-0.40 [-1.93, 1.13]
Putzier et al. 2010	4.27	1.21	25	3.71	1.38	22	13.8%	0.56 [-0.19, 1.31]
Yang 2015	7.48	1.64	51	7.54	1.05	62	28.4%	-0.06 [-0.58, 0.46]
Yu S et al. 2012	4.15	2.77	26	4.33	2.37	27	4.0%	-0.18 [-1.57, 1.21]
Total (95% CI)			**300**			**380**	**100.0%**	**0.04 [-0.23, 0.32]**
Heterogeneity: Chi² = 5.65, df = 7 (P = 0.58); I² = 0%								
Test for overall effect: Z = 0.31 (P = 0.76)								

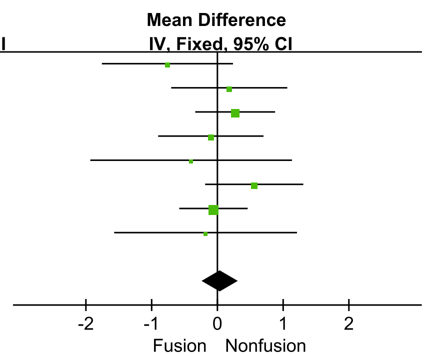

Fig. 9 Forest plot comparing VAS improvement for lumbar fusion versus motion-preservation procedures. *SD* standard deviation, *IV* inverse variance, *CI* confidence interval

scores or the VAS improvement. No heterogeneity was detected for the VAS improvement ($I^2 = 0$ %). The fixed-effects model was applied to compare the VAS improvement between fusion and nonfusion group. The pooled data indicated that there was no significant difference in VAS improvement between fusion and nonfusion group [SMD = 0.04, 95 % CI (−0.23, 0.32); $P = 0.76 > 0.05$] (Fig. 9).

ODI improvement

Eight studies [8, 9, 14, 16, 19, 20, 22, 23] consisting of 680 patients reported the preoperative and postoperative ODI scores or the VAS improvement. The random-effects model was applied to compare the operation time between the two groups with a high heterogeneity ($I^2 = 72$ %). The cause of heterogeneity was investigated by subgroup analysis according to the single dynamic procedure and topping-off surgery but could not be ascertained. The pooled estimate revealed that there was no significant difference found in the two groups [SMD = −1.18; 95 % CI (−4.08, 1.73); $P = 0.71 > 0.05$] (Fig. 10).

Publication bias

Funnel plots for reoperation of adjacent segment is displayed in Fig. 11. As shown, the included studies were all within the confidential intervals. The shape of the funnel plots revealed symmetric distribution, which suggested that there was no significant publication bias.

Discussion

Adjacent segment degeneration is a broad term encompassing many complications adjacent to the fusion segment, including disc herniation, stenosis, spondylolisthesis, instability, hypertrophic facet arthritis. Whether lumbar fusion can accelerate ASDeg and ASDis is controversial. The reported incidence of radiographically ASDeg varies

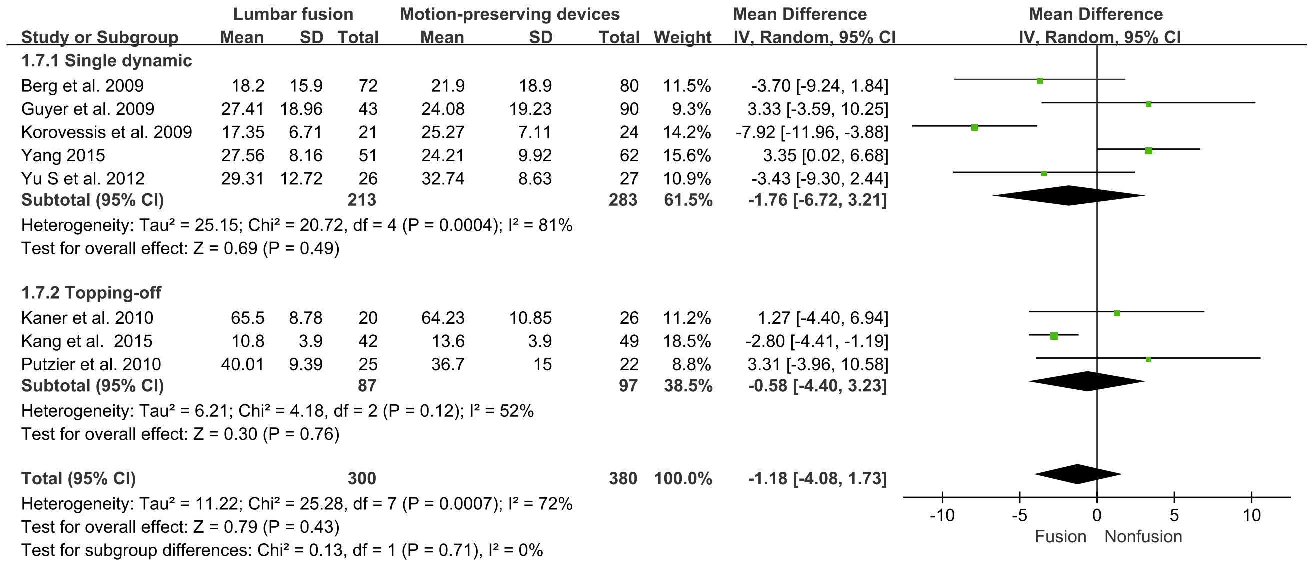

Fig. 10 Forest plot comparing ODI improvement for lumbar fusion versus motion-preservation procedures. *SD* standard deviation, *IV* inverse variance, *CI* confidence interval

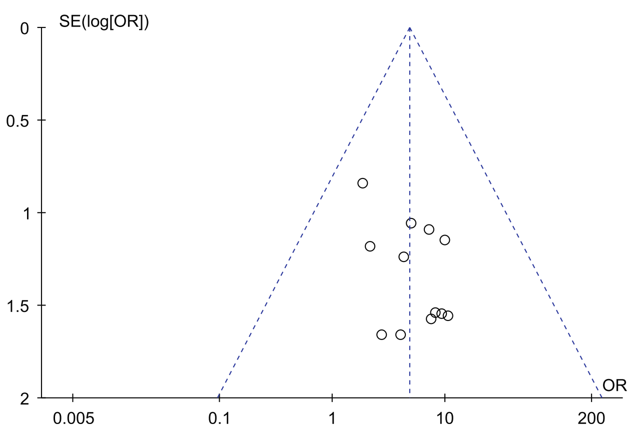

Fig. 11 Funnel plot for reoperation of adjacent segment showed no evidence of publication bias

from 5.6 to 100 % [25–31]. But the incidence of symptomatic ASDeg also known as ASDis is lower, ranging from 2.7 to 21.4 % [8, 14, 19–23, 30, 32]. The reoperation rate on the adjacent segment ranging from 4.0 to 27.8 % [16, 17, 19–21, 23, 30, 32]. The rate of ASDeg is hard to define because of the variable patients and follow-up times in the relevant studies. The result of our meta-analysis showed that the prevalence of ASDeg, ASDis and reoperation rate after lumbar fusion were 37.5, 14.4 and 7.7 % respectively.

The reason of high incidence of ASDeg and ASDis could be explained by mechanical overload imposed by the rigid fixation of the lumbar spine. To prevent ASDeg and ASDis, dynamic or motion-preservation devices, including TDR, Dynesys, DIAM, X-stop, Wallis, Coflex, Graf et al. have been developed to reduce the ASDeg and ASDis [5, 8, 14, 19, 33–35]. Rainey et al. [36] reported a reoperation rate for adjacent segment disease of 2.0 % which is significantly lower than the rates after lumbar fusion. This meta-analysis indicated that the prevalence of ASDeg, ASDis and reoperation rate of the motion-preservation procedures were 18.6, 5.1 and 1.1 % respectively, which was significantly lower than the fusion.

In multilevel lumbar degenerative cases, interspinous process devices, such as Coflex or DIAM, were implanted proximal to the fusion creating a dynamic transition zone, known as Topping-off technique, to reduce the occurrence of ASDeg and ASDis [8, 23, 37]. Lu et al. [8] reported a radiographic ASD rate of 6 % in Topping-off group and a higher rate of 48 % in fusion group. Putzier et al. [23] reported an ASDis incidence of 24 and 9 % in fusion and Topping-off group separately. Lu et al. [8] reported the same result that the Topping-off technique had a lower ASDis incidence of 10.3 versus 21.4 % in fusion group. In our analysis, the Topping-off procedure had a lower ASDeg incidence. However, no significant difference was found in ASDis rate between fusion and Topping-off.

The operation time and blood loss differed from different kinds of dynamic fixation procedures. In this analysis, operation time and blood loss had no difference between TDR and fusion procedure. The posterior Dynesys procedure could be accomplished in a shorter time with less blood loss compared with fusion. However, it took more time to perform IPDS procedure than fusion with more blood loss.

Many studies proved that the motion-preservation procedure could achieve good clinical improvement even in the long-term follow-up [9, 13, 14, 19–21, 38]. The VAS and ODI were both improved in fusion and motion-preservation procedures and no significant difference was found between them. Nevertheless, care should be taken to determine patient selection criteria for motion-preservation procedures [39, 40].

Lumbar fusion is the most widely accepted treatment for lumbar disc degenerative disease [30, 41]. Even though the existing evidence proved that motion-preservation procedures could reduce the prevalence of ASDeg, ASDis and reoperation on the adjacent segment, more complications, such as internal fixation loosening and spinous process fracture, were observed in motion-preservation procedures [42–45]. In the mean time, the different type of motion-preservation devices in the included studies might affect the outcomes and contributed to clinical heterogeneity. Several non-randomized studies were included in our analysis which might introduce methodology bias, and may be inadequately powered to detect true accurate ASDeg or ASDis morbidity in the two groups. More randomized controlled trial focusing on the ASDeg or ASDis comparing fusion and motion-preservation procedures are needed in the future. Meanwhile, the follow-up period in the included studies were relatively short, ranging from 2 to 6.4 years, thus the degeneration on the adjacent level needs to be further observed.

Conclusion

This meta-analysis compared fusion and motion-preservation procedures about prevalence of ASDeg, ASDis, reoperation on adjacent segment and clinical outcomes. The results suggested that motion-preservation procedures could achieve favorable improvement of symptoms as fusion and reduce the incidence of ASDeg, ASDis and reoperation on adjacent segment. However, the results of this meta-analysis should be accepted with caution because of the limitations of the study. Further evaluation and more RCTs are required to confirm and update the results of this study.

Compliance with ethical standards

Conflict of interest None of the authors has any potential conflict of interest. No funds were received in support of this work. No benefits in any form have been or will be received from any commercial party related directly or indirectly to the subject of this manuscript.

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