North American Spine Society Journal (NASSJ) 12 (2022) 100177

Contents lists available at ScienceDirect

North American Spine Society Journal (NASSJ)

journal homepage: www.elsevier.com/locate/xnsj

Systematic Reviews /Meta-analyses

Comparison of long-term outcomes of spinal fusion surgeries supplemented with "topping-off" implants in lumbar degenerative diseases: A systematic review and network meta-analysis

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ARTICLE INFO

Keywords:
Topping-off, hybrid dynamic fusion
Lumbar fusion
Adjacent segment degeneration
Adjacent segment disease
Network meta-analysis

ABSTRACT

Background Context: Spinal fusion surgery is a common treatment for lumbar degenerative diseases and has been associated with the long-term complication of adjacent segment disease (ASD). In recent years, the "topping-off" technique has emerged as a new surgical method, combining spinal fusion with a hybrid stabilization device (HSD) or interspinous process device (IPD) proximal to the fused vertebrae.

Methods: A literature search using the PubMed, Cochrane Central Register of Controlled Trials, EMBASE, and Web of Science databases identified eligible studies comparing topping-off implant(s) with spinal fusion surgery for lumbar degenerative diseases. Risk of bias was assessed using the Cochrane RoB 2.0 tool for randomized controlled trials and the Newcastle–Ottawa scale for retrospective studies. Each outcome was analyzed using the statistical Confidence in NMA (CINeMA) 1.9.0 software.

Results: 17 RCTs and retrospective studies that included 1255 participants and five interventions were identified. The topping-off implants device for intervertebral assisted motion (DIAM; OR = 0.235, $p < 0.001$), Dynesys (OR = 0.413, $p < 0.001$), and Coflex (OR = 0.417, $p < 0.01$) significantly lowered the incidence of radiographic adjacent segment degeneration (RASDeg) compared with spinal fusion surgery alone. Spinal fusion supplemented with DIAM significantly reduced the incidence of clinical adjacent segment disease (CASD) (OR = 0.358, $p = 0.032$).

Conclusions: Spinal fusion supplemented with DIAM substantially reduced the incidence of radiographic and clinical adjacent segment disease. No significant difference was observed between the treatment comparators for reoperation due to ASD and back pain relief score.

FDA device/drug status: Investigational: DIAM ® Spinal Stabilization System (Medtronic); Wallis (Zimmer Spine). Approved: Coflex (Paradigm Spine); Dynesys (Zimmer Spine., Inc).

Author disclosures: ***KC:*** Nothing to disclose. ***Y-CC:*** Nothing to disclose. ***C-YL***: Nothing to disclose. ***T-JH***: Nothing to disclose. ***Y-CL:*** Nothing to disclose. ***C-JY***: Nothing to disclose. ***JCH:*** Nothing to disclose. ***M-HW:*** Nothing to disclose.

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https://doi.org/10.1016/j.xnsj.2022.100177
Received 14 August 2022; Received in revised form 6 October 2022; Accepted 6 October 2022
Available online 22 October 2022

Introduction

Spinal fusion surgery has been widely used to treat lumbar degenerative diseases such as spinal stenosis, symptomatic spondylolisthesis, and degenerative scoliosis [1,2]. However, adjacent segment disease (ASD) is a potential post-operative complication and adversely affects clinical outcomes [3].

During spinal fusion surgery, two or more vertebrae are permanently connected together, eliminating the dynamic motion in between. Thus, additional stress is placed over the adjacent vertebrae to compensate for the lost motion between the fused segments [4]. The vertebrae that lie above or below the fused segments often degenerate over time due to increased stress and motion, causing adjacent segment disease (ASD) or adjacent segment degeneration (ASDeg) [5].

ASDeg or radiographic adjacent segment degeneration (RASDeg), is defined as radiographic evidence of degenerative changes that occur at a spinal level adjacent to the fused vertebrae, unaccompanied by any clinical symptoms [6]. RASDeg can progress to present with symptomatic pain at the adjacent levels of the fused segments, leading to clinical ASD (CASD) [6]. The incidence of RASDeg in lumbar spinal segments is approximately 40%, whereas that of CASD ranges from 5.2% to 18.2% [7,8].

ASDeg has been reported to be associated with risk factors such as fusion length, age, surgical method, and sagittal alignment [1,9,10]. Upper adjacent segments are more prone to degenerate than lower segments due to compensatory increase in loading transfer and range of motion at the disc and facet joints [11]. Many patients often have to undergo a second or third reoperation for symptomatic treatment. The incidence of revisional lumbar surgery in the presence of ASD has been reported to be approximately 2–15% [12].

In recent years, the "topping-off" technique has emerged as a new surgical method combining conventional spinal fusion with a dynamic hybrid stabilization device (HSD) or interspinous process device (IPD) at proximal adjacent segments to the spinal fusion construct [13]. Khoueir et al. classified posterior dynamic stabilization devices into three categories: (1) HSDs with pedicle screw/rod instruments such as DTO and Dynesys; (2) IPDs such as Wallis, X-STOP, DIAM (device for intervertebral assisted motion), and Coflex; and (3) total facet replacement systems [14]. The implantation of these devices provides a transitional zone between the caudal fused construct and the cephalad mobile segments, decreasing stress placed on the adjacent segments [13,15].

Numerous clinical trials and pairwise meta-analyses comparing various topping-off devices with spinal fusion surgery alone have been performed [13,16-23]. However, because each study only includes one or two devices, integrating information on the relative efficacy of commonly used topping-off implants is difficult. Currently, NMAs comparing the radiographic or clinical efficacy and safety of various topping-off implants are lacking [24]. Therefore, we conducted a comprehensive NMA and evaluated the long-term effectiveness of topping-off and fusion-only constructs in preventing ASDeg and ASD.

Methods

Protocol and registration

This study was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA)-P guidelines [25]. The study protocol was registered at the PROSPERO registrar of systematic reviews under the ID: CRD42022290513.

Literature search

A systematic search was conducted on the PubMed, Cochrane Central Register of Controlled Trials (CENTRAL), EMBASE, and Web of Science databases to identify potential eligible studies published between January 1, 1980, and June 5, 2021. We performed a search in the advanced fields by using a combination of medical subject headings (MeSH) terms and keywords: "lumbar," "lumbar degenerative disease," "lumbar spinal stenosis," "lumbar disc herniation," "spinal diseases," "spinal disorders," "hybrid stabilization," "dynamic fusion," "dynamic stabilization," "dynamic hybrid," "topping off," "interspinous process" "Wallis," "DIAM," "Coflex," "Dynesys," "spinal fusion," "adjacent segment degeneration," "adjacent segment disease," and "adjacent segment pathology." We also checked reference lists to find additional qualifying studies.

Two reviewers (KC & YC) independently completed the title and abstract screening to select potential articles. The full-text versions of the articles were downloaded and reviewed based on the inclusion and exclusion criteria. A third reviewer (MW) approved the study selection process and settled any disagreements regarding any uncertainties of the included studies.

Study selection

The inclusion criteria for the studies of the NMA were as follows: (1) The study design had at least a 1-year follow-up period and total sample size >20 patients. Two-arm or three-arm studies were considered. (2) The participants were older than 18 years old and were diagnosed as having lumbar degenerative disc diseases, including but not limited to spondylolisthesis, lumbar spinal stenosis, and disc herniation, and were unresponsive to conservative treatment. Randomized, nonrandomized controlled trials and retrospective cohort studies were included. All surgical approaches for spinal fusion were considered.

(3) For interventions in the experimental group, studies that directly involved spinal fusion with the addition of topping-off implant(s) involving a supplemental flexible pedicle screw system or interspinous process device at the supra-adjacent or infra-adjacent index level were considered. (4) Interventions in the control group included instrumented spinal fusion surgery alone using methods such as posterior lumbar interbody fusion, posterolateral fusion, circumferential fusion, and transforaminal lumbar interbody fusion. (5) Studies reported at least one of the following outcomes: incidence of RASDeg, incidence of CASD, reoperation rate due to ASD, or visual analog scale (VAS) back pain score.

Studies that did not conduct comparisons between spinal fusion and adjacent topping-off implant surgery or specify the topping-off device used were excluded. Abstracts, observational studies, case reports, case series, systemic reviews, meta-analyses, non-English language studies, and studies with incomplete data or low-quality data were also excluded.

Data extraction

We first created a custom-made Excel worksheet to organize and extract relevant study characteristics and outcomes from the studies. Two reviewers (KC & YC) independently extracted data from the studies, and any disagreements were settled by a third reviewer (MW). The search results from online databases were imported to Endnote X20 (Clarivate, Philadelphia, PA, USA) in which duplicates were removed.

In the included studies, the following items were extracted: leading author, publication year, type of study design, country of study, treatment and comparator, sample size, demographic characteristics, mean follow-up period, number of fused segments, level of the implant device. Outcomes extracted for the NMA included incidence of RASDeg or CASD, reoperation rate due to ASD, and preoperative and postoperative VAS back pain score. Data were extracted for the first and final time points in the follow-up period as listed in Table 1.

Risk of bias assessment within individual studies

Two reviewers (KC & YC) independently evaluated the internal validity of the trials by using the Cochrane risk of bias (RoB) 2.0 tool and Newcastle–Ottawa scale (NOS) criteria [26,27]. Any disagreements were resolved by a third reviewer (JH). The RoB 2.0 tool was used to

Table 1
Basic demographic data and summary of study characteristics included in the review.

Study	Country	Topping off implant	Spinal fusion method	# of patients, (Male/Female)		Mean age, years (SD or range)		Mean follow-up (months)		Levels for dynamic device	Mean # of levels fused
				Topping off	Spinal Fusion	Topping off	Spinal Fusion	Topping off	Spinal Fusion		
Zhu 2015	Taiwan	Wallis	PLIF	22 (14/8)	23 (11/12)	44.5	40	24.8	23.7	L4-L5	1
Korovessis 2009*	Greece	Wallis	PLIF	24	21	65 ± 13	64 ± 11	54 ± 6		L3-L4	2-3
Korovessis 2018	Greece	Wallis DIAM	PLIF	17 18	20	64 ± 17 59 ± 13	61 (12)	56 ±		L4-L5	1
Lee 2013	Korea	DIAM	PLIF	25 (10/15)	50 (20/30)	65.4 ± 8.7	65.9 ± 8.5	46.8 ± 22.8		L2-L5	1
Lu 2015	Taiwan	DIAM	PLIF	49 (16/33)	42 (14/28)	64.5 ± 7.2	59.1 ± 8.6	41.2 ± 7.2	41.5 ± 8.6	—	2-4
Kwang 2020	Korea	DIAM	PLIF	14 (4/10)	37 (17/20)	59.1 ± 6.4	58.8 ± 8.4	58.5 ± 30.6	75.9 ± 36.1	L3-L4	1
Li 2019	China	Coflex	PLIF	45 (21/24)	54 (25/29)	53.5 (46-59)	65.7 (60-75)	47.2		L3–L4	2
Liu 2012	China	Coflex	PLIF	31 (20/11)	43 (28/15)	44.6	60.51	24.8		L4-L5	1-2
Chen 2016	China	Coflex	PLIF	76 (48/28)	88 (54/34)	57.3 ± 5.1	58.3 ± 4.6	47.0 ± 4.8	47.45 ± 5.1	—	1
Yuan 2017	China	Coflex	PLIF	42 (18/24)	45 (22/23)	58.5 ± 8.6	57.6 ± 6.8	65.6 ± 4.7	64.9 ± 2.6	—	—
Bredin 2017*	France	Dynesys	PLIF	33	25	60.3	61.3	93.6 ± 16.5	91.7 ± 13.5	L2-L5	1-2
Zhang 2016	China	Dynesys	PLIF	46 (31/15)	50 (37/13)	48.1 ± 12.3	52.3 ± 12.9	53.6 ± 5.3	55.2 ± 6.8	L3-S1	1-3
Zhang 2017	China	Dynesys	PLIF	45 (18/27)	45 (17/29)	48.3 ± 2.4	50.1 ± 1.8	28.8 ± 0.6	29.9 ± 0.8	L4-S1	2
Putzier 2010*	Germany	Dynesys	PLIF	30 (17/13)	30 (14/16)	44.9 (27-62)	44.6 (27-63)	76.4		L3-L5	1
Kuo 2018	Taiwan	Dynesys	TLIF	56 (21/35)	23 (8/15)	60.1 ± 10.8	58.0 ± 11.7	34.7	36.3	L4-5	1
Wu 2017	China	Dynesys	PLIF	26 (14/12)	31 (18/13)	49.6 ± 8.3	52.5 ± 6.9	50.3	52.8	L3-S1	2-4
Herren 2018*	Germany	Dynesys	PLIF	15 (6/9)	14 (8/6)	60.9 (47-80)	61.8 (34-76)	37.68		L2-S1	2

Data are reported as mean ± SD or mean (range). —, data not available; PLIF (posterior lumbar interbody fusion); TLIF (transverse lumbar interbody fusion); SD (standard deviation)
* Randomized controlled trial included in the network meta-analysis

evaluate prospective clinical studies and RCTs, and the NOS was used to evaluate RoB for retrospective cohort studies.

The domains for assessment were based on the following parameters: randomization, deviation from intended interventions, incomplete outcome data, outcome measurement, and reporting bias. For each domain, the studies were graded as low RoB, medium RoB, or high RoB. We considered the overall RoB of the study to be low RoB if all domains were at low RoB, medium RoB if there was at least one domain of medium RoB, and high RoB if there was at least one high RoB domain or ≥2 domains of medium RoB.

The NOS criteria were used to assess the methodological quality of RoB in both retrospective cohort and case–control studies. The total NOS score determined whether the study was at low RoB (score of 8 or 9), medium RoB (score of 6 or 7), or high RoB (score <5). For cohort studies, six studies were evaluated to be at low RoB overall, and six studies were at medium RoB. One case–control study was assessed to be at low RoB overall.

Statistical analysis

The NMA was performed using the statistical R "netmeta" package in the Confidence in Network Meta-Analysis 1.9.0 (CINeMA, Cochrane, Bern, Switzerland) web-based application to estimate the relative effects and heterogeneity [28]. For each outcome, a network plot was created to investigate the geometry of the network and identify possible comparisons between different treatment modalities. Each treatment was considered as an individual node in the network.

Because we anticipated considerable clinical heterogeneity, we used the random-effects model to perform the NMA. For continuous outcomes, VAS pain score data was converted to a 0–10 scale and mean differences (MDs) and standard deviations were calculated. Odds ratios (ORs) with 95% confidence intervals (CI) were used to evaluate comparisons for dichotomous outcomes, and MDs with 95% CIs were used to evaluate comparisons for continuous outcomes.

To reveal the ranking of treatments, we compared the point estimates using ORs for dichotomous outcomes and MDs for continuous outcomes. Assessment of inconsistency between the direct and indirect treatment comparators in the treatment network was calculated with node splitting models of direct, indirect, and mixed NMA OR estimates.

Confidence in evidence

The quality of evidence for each outcome measure was assessed using an adapted version of the grading recommendations assessment, development, and evaluation (GRADE) methodology with CINeMA 1.9.0 [28,29]. The web application considers the following six domains for evaluation of confidence in the findings of the meta-analysis: within-study bias, reporting bias, indirectness, imprecision, heterogeneity, and incoherence.

Heterogeneity assessment

Heterogeneity was assessed using the study variance for the NMAs (I^2). We defined I^2 <30% as indicative of low heterogeneity, I^2 between 30% and 75% as an indication for moderate heterogeneity, and I^2 greater than 75% as indicative of serious heterogeneity, as recommended by the Cochrane Handbook [30].

Results

Literature search and quality assessment

The literature search yielded 1116 studies, from which 74 duplicates were removed. After screening and a full-text review, 17 studies with a total of 1255 participants were included in the NMA [7,19,20,23,31-43]. The study selection process is illustrated with a PRISMA flow diagram

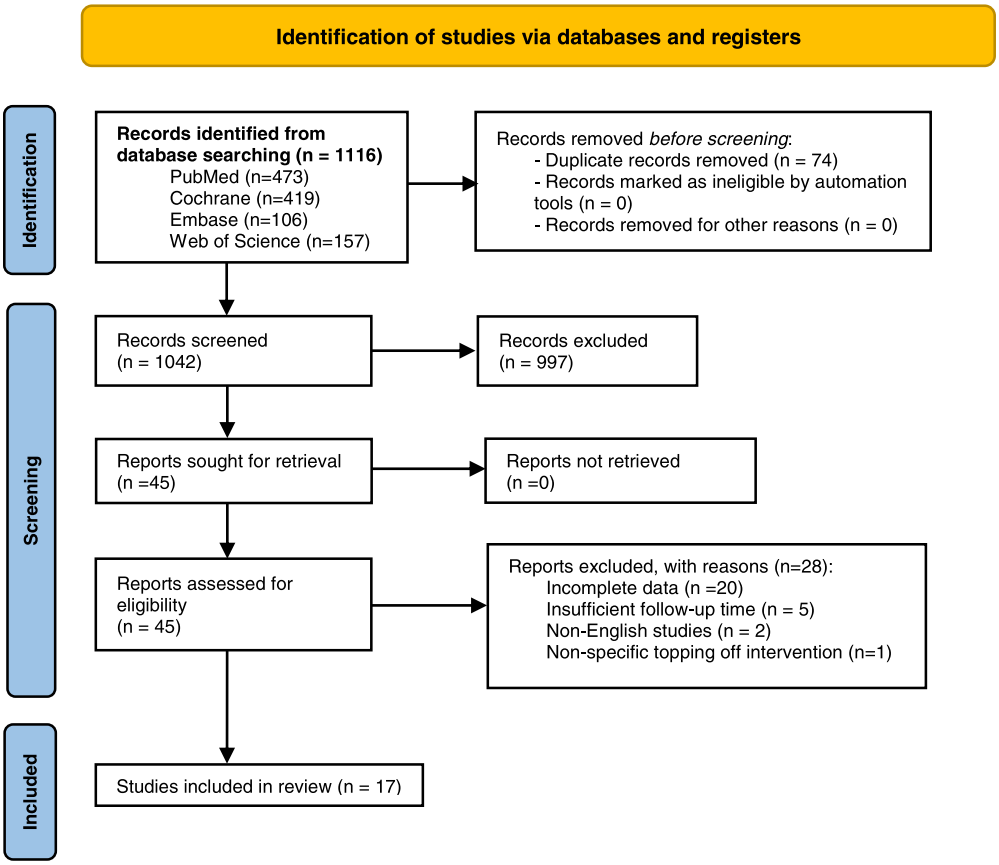


Fig. 1. PRISMA flowchart for searching and selecting eligible studies.

(Fig. 1). A total of 45 studies were retrieved and assessed for eligibility, and 28 studies were excluded due to the following reasons: non-specified topping-off device, presence of incomplete data, insufficient follow-up time (<1-year follow-up), or non-English language text.

Finally, the NMA included a total of 17 studies, with 1 RCT, 2 prospective clinical trials, and 14 retrospective studies. Sixteen trials compared topping-off surgery with fusion-only surgery; one study used a three-arm treatment study design. The baseline characteristics of the included studies are presented in Table 1.

RoB assessment

The results of the quality assessment of the studies are displayed in Fig. 2a, 2b. Of the 17 included studies, 9, 7, and 1 were at low, medium, and high RoB, respectively. The randomized controlled study regarded as having a high RoB was assessed to have a medium RoB in three domains: bias arising from randomization, deviation from the intended intervention, and selection of reported results. All of the retrospective cohort and case-control studies had overall low or medium risk of bias.

NMA results and node splitting

First, the treatment network plots of the primary outcomes from the selected literature were constructed (Fig. 3a-3d). Only DIAM, Wallis, and the spinal fusion surgery alone group had a closed network for all outcomes of interest. The rest of the topping-off appeared as an open network comparison because they could only be directly compared with the spinal fusion surgery alone. Therefore, performing node split analysis was not possible, but they are still included in the final effect estimation. All five treatment comparators were included in the NMA, which produced a total of 66 direct comparisons. The node splitting results exhibited overall consistency, as both direct and indirect comparisons for all outcomes of interest exhibited a p value greater than 0.05.

Radiographic adjacent segment degeneration

The evidence network for the incidence of RASDeg included 15 studies, comparing 6 studies of Dynesys, 3 studies of Wallis, 3 studies of Coflex, and 4 studies of DIAM with spinal fusion surgery alone. Data from each of the individual studies are presented in Table 1. The forest plot (Fig. 4a) revealed that Coflex, DIAM, and Dynesys were associated with significantly lower odds of RASDeg than spinal fusion surgery alone (Fig. 5a). Wallis also had a lower OR of RASDeg than spinal fusion surgery, but no statistically significant difference was observed between the two ($p = 0.309$) (Figs. 4a, 5a).

The treatments were ranked from lowest to highest, according to the OR of the incidence of RASDeg, in the following order: DIAM (vs. fusion alone, OR = 0.235, 95% CI: 0.125 to 0.442, $p < 0.01$, I2 = 53.5%), Dynesys (vs. fusion alone, OR = 0.413, 95% CI: 0.248 to 0.689, $p < 0.01$, I2 = 0%), Coflex (vs. fusion alone, OR = 0.417, 95% CI: 0.218 to 0.798, $p < 0.01$, I2 = 0%), and Wallis (vs. fusion alone, OR = 0.572, 95% CI: 0.197 to 1.660, $p = 0.309$, I2 = 51.1%; Figs. 4a, 5a). DIAM was favored over Wallis, but the difference was nonsignificant ($p = 0.128$). The OR estimates for RASDeg from direct comparisons were consistent with the NMA OR estimates (Supplementary Table 1).

Clinical adjacent segment disease

The analysis for the incidence of CASD included 15 out of 17 studies, comparing 6 studies of Dynesys, 3 studies of Wallis, 3 studies of Coflex, and 4 studies of DIAM with spinal fusion surgery alone. The NMA pooled results revealed that all topping-off implants were associ-

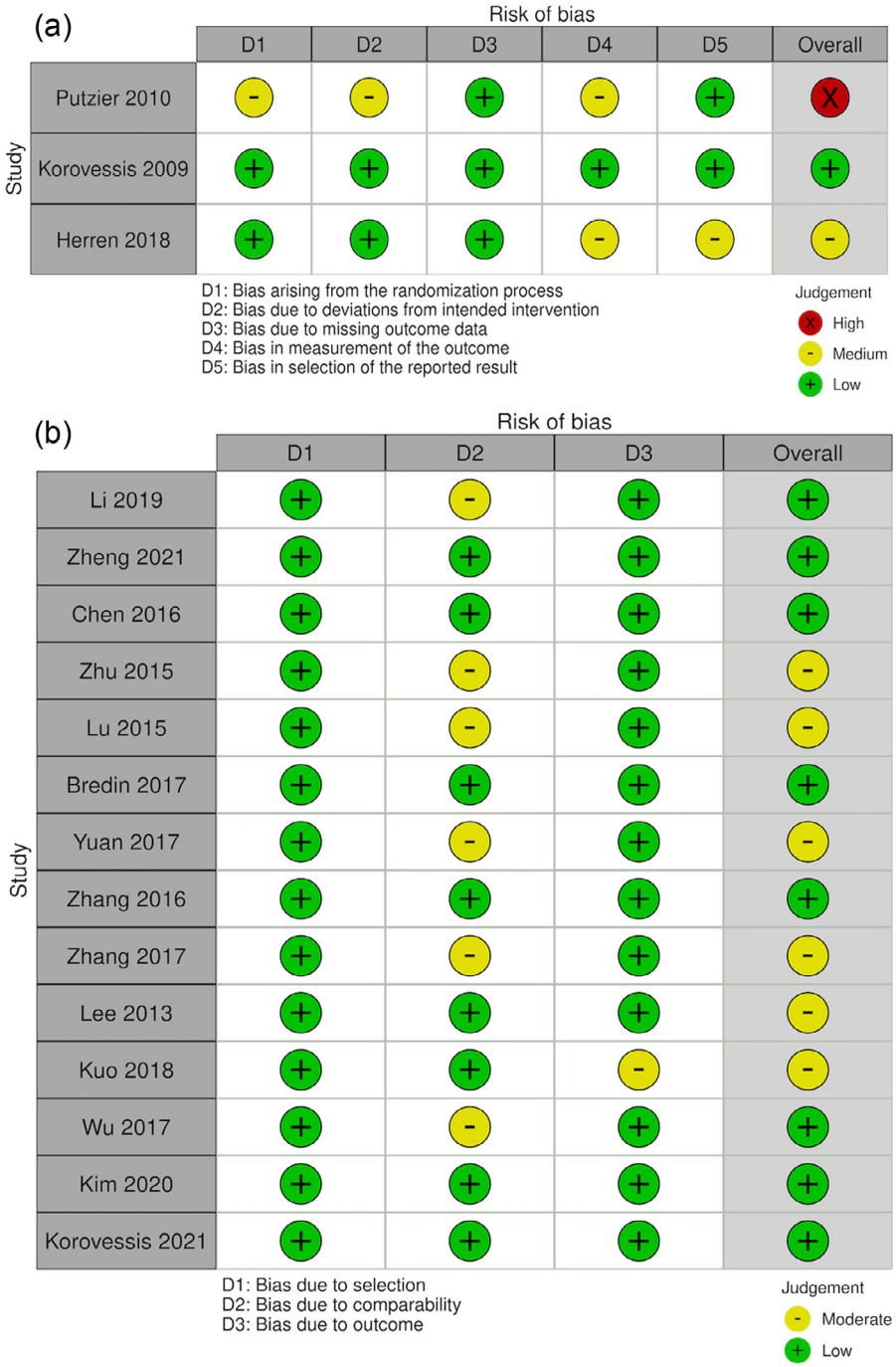


Fig. 2. a Risk of bias summary for randomized trials using the Cochrane risk of bias (RoB) 2.0 tool. Each domain was rated either low, medium, or high risk of bias. 2b. Risk of bias summary for retrospective studies using the Newcastle Ottawa Scale. Each domain was rated either low, medium, or high risk of bias.

ated with a lower incidence of CASD than spinal fusion alone. However, DIAM was the only topping-off implant that had significantly lower odds of CASD compared with spinal fusion alone ($p = 0.033$; Figs. 4b, 5a).

The topping-off implants compared to spinal surgery alone were ranked from lowest to highest, according to the OR of the incidence of CASD: DIAM (OR = 0.359, 95% CI: 0.140 to 0.919, $p = 0.033$, I2 = 0%), Coflex (OR = 0.473, 95% CI: 0.116 to 1.924, $p = 0.330$, I2 = 0%), Dynesys (OR = 0.474, 95% CI: 0.152 to 1.482, $p = 0.252$, I2 = 0%), and Wallis (OR = 0.605, 95% CI: 0.135 to 2.712, $p = 0.522$, I2 = 0%; Figs. 4b, 5a). The mixed NMA estimates of CASD between DIAM versus Wallis favored DIAM (OR= 0.592). However, overall, no significant differences were observed between the comparators of the topping-off devices.

Reoperations due to ASD

The NMA for reoperation rates due to ASD included 15 out of 17 studies, comparing 6 studies of Dynesys, 3 studies of Wallis, 3 studies of Coflex, and 4 studies of DIAM with spinal fusion surgery alone. Overall, the topping-off implants had lower odds of reoperation due to clinical ASD compared with spinal fusion surgery alone (Figs. 4c, 5b). However, the pooled results for reoperation rates due to symptomatic ASD did not exhibit significant ORs for comparisons between any topping-off device and spinal fusion.

Compared with spinal fusion surgery alone, Wallis exhibited the lowest odds of reoperation rates due to ASD (OR = 0.360, 95% CI: 0.050

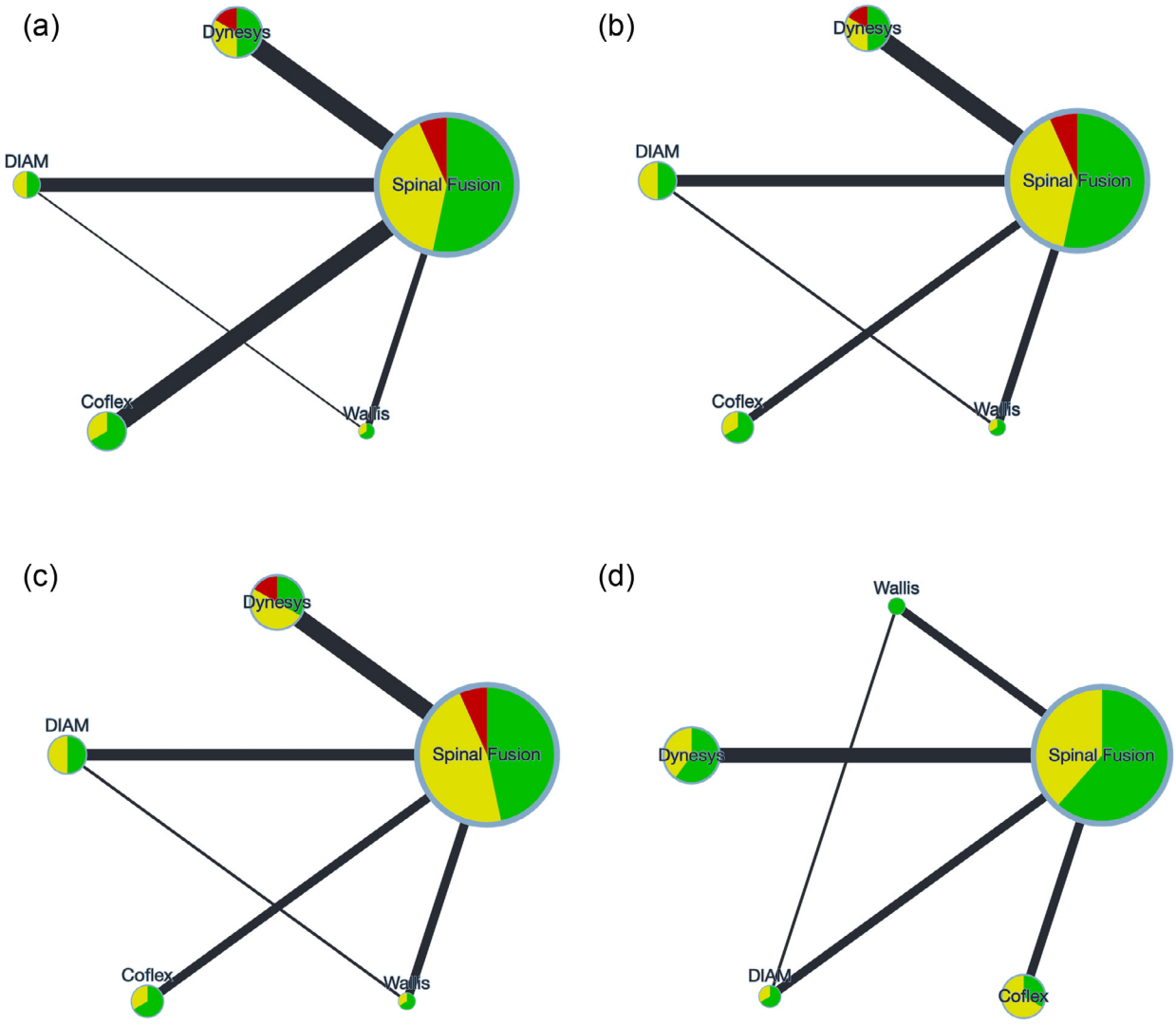


Fig. 3. a Network plot for radiographic adjacent segment degeneration. Each node represents a treatment modality, while the lines between the nodes show a direct comparison between the treatments. The node size represents the sample size, while the node color indicates risk of bias with low (green), moderate (yellow), and high (red) according to the proportion of studies. Thicker lines indicate more studies. 3b. Network plot for clinical adjacent segment disease. Each node represents a treatment modality, while the lines between the nodes show a direct comparison between the treatments. The node size represents the sample size, while the node color indicates risk of bias with low (green), moderate (yellow), and high (red) according to the proportion of studies. Thicker lines indicate more studies. 3c. Network plot for reoperations due to adjacent segment disease. Each node represents a treatment modality, while the lines between the nodes show a direct comparison between the treatments. The node size represents the sample size, while the node color indicates risk of bias with low (green), moderate (yellow), and high (red) according to the proportion of studies. Thicker lines indicate more studies. 3d. Network plot for visual analogue scale back pain score. Each node represents a treatment modality, while the lines between the nodes show a direct comparison between the treatments. The node size represents the sample size, while the node color indicates risk of bias with low (green), moderate (yellow), and high (red) according to the proportion of studies. Thicker lines indicate more studies. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

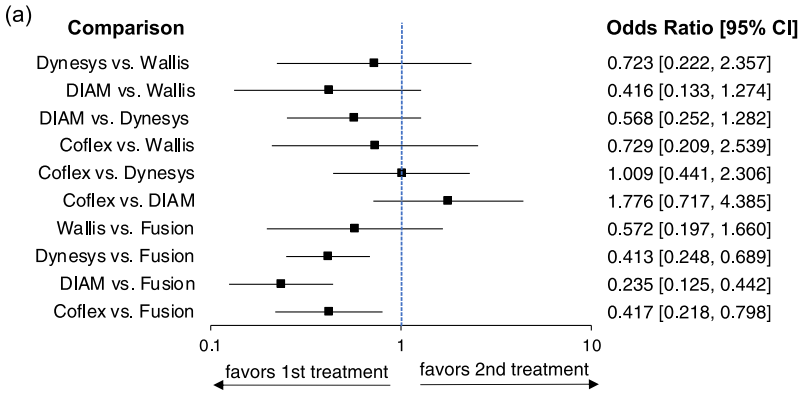
to 2.606, $p = 0.316$, I2 = 0%), followed by DIAM (OR = 0.473, 95% CI: 0.143 to 1.566, $p = 0.222$, I2 = 0%), Coflex (OR = 0.473, 95% CI: 0.116 to 1.650, p = 0.300, I2 = 0%), and Dynesys (OR= 0.482, 95% CI: 0.151 to 1.542, p = 0.220, I2 = 0%) (Figs. 4c, 5b).

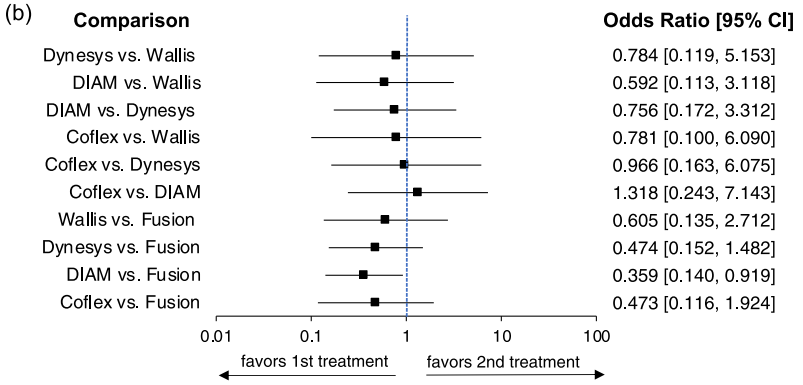
VAS back pain

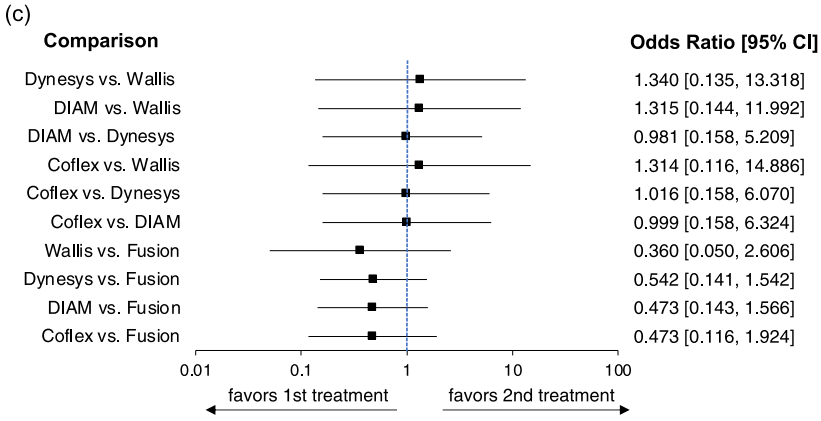
The analysis for back pain score included 13 studies, comparing 5 studies of Dynesys, 3 studies of Wallis, 3 studies of Coflex, and 3 studies of DIAM with spinal fusion surgery alone. The MDs of the VAS back pain score favored all topping-off implants compared with spinal fusion alone, but the results were nonsignificant (Figs. 4d, 5b). Compared with spinal fusion, Wallis resulted in the greatest improvement of the VAS of back pain (MD= −0.537, 95% CI: −1.104 to 0.030, $p = 0.063$), followed by Coflex (MD = −0.482, 95% CI: −1.1051 to 0.086, $p = 0.096$), DIAM (MD = −0.469, 95% CI: −1.030 to 0.092, $p = 0.101$), and Dynesys (MD = −0.141, 95% CI: −0.585 to 0.303, $p = 0.544$; Fig. 5b). No significant difference in the change of the VAS back pain score was observed in the comparisons of other topping-off implants with spinal fusion surgery alone.

IPD-related or HSD-related complications

Thirteen studies reported complications [7,19,31-40, 42], and four studies reported no intraoperative or postoperative complications [19,34,39,40]. Three studies reported screw or rod breakage in three patients of the Dynesys group and two patients of the spinal fusion surgery–alone group [31,33,36]. Moreover, four studies reported screw loosening occurred in 21 cases, with 11 in the Dynesys group and 10 in the fusion-only group [33,36,38,42]. Four studies reported dura mater







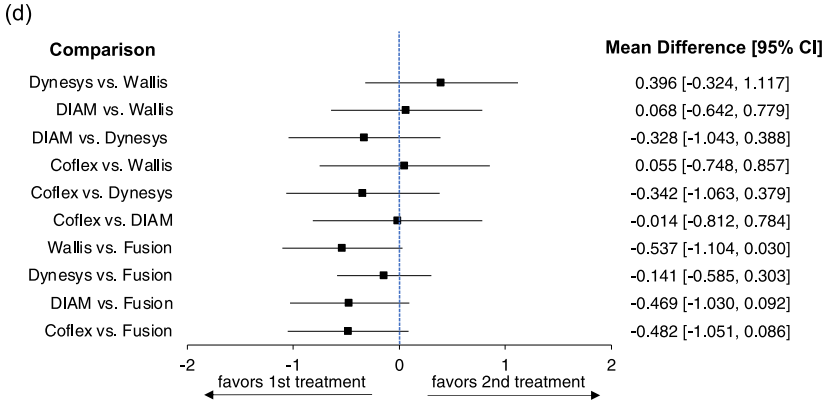


Fig. 4. a Forest plot for radiographic adjacent segment degeneration. "Topping-off" implant devices compared with other implant treatments. Results are presented as an odds ratio with 95% confidence intervals (CI). 4b. Forest plot for clinical adjacent segment disease. "Topping-off" implant devices compared with other implant treatments. Results are presented as an odds ratio with 95% confidence intervals (CI). 4c. Forest plot for reoperations due to adjacent segment disease. "Topping-off" implant devices compared with other implant treatments. Results are presented as an odds ratio with 95% confidence intervals (CI). 4d. Forest plot for back pain score. "Topping-off" implant devices compared with other implant treatments. Results are presented as difference in mean pain score with 95% confidence intervals (CI).

(a)

Radiographic Adjacent Segment Degeneration (RASDeg)

Clinical Adjacent Segment Disease (CASD)				
Fusion + Coflex	1.773 (0.717, 4.385)	1.009 (0.441, 2.306)	0.729 (0.209, 2.539)	0.417 (0.218, 0.798)
1.318 (0.243, 7.143)	Fusion + DIAM	0.569 (0.252, 1.282)	0.411 (0.133, 1.274)	0.235 (0.125, 0.442)
0.966 (0.163, 6.075)	0.756 (0.172, 3.312)	Fusion + Dynesys	0.723 (0.222, 2.357)	0.413 (0.248, 0.689)
0.781 (0.100, 6.090)	0.592 (0.113, 3.118)	0.784 (0.119, 5.513)	Fusion + Wallis	0.572 (0.197, 1.660)
0.473 (0.116, 1.924)	0.359 (0.140, 0.919)	0.474 (0.152, 1.482)	0.605 (0.135, 2.712)	Fusion only

(b)

Reoperations due to ASD

VAS Back Pain Score				
Fusion + Coflex	0.999 (0.116, 1.924)	0.981 (0.158, 6.070)	1.314 (0.116, 14.886)	0.473 (0.116, 1.924)
-0.014 (-0.812, 0.784)	Fusion + DIAM	0.981 (0.185, 5.209)	1.315 (0.144, 11.992)	0.473 (0.143, 1.566)
-0.342 (-1.063, 0.379)	-0.328 (-1.043, 0.388)	Fusion + Dynesys	1.340 (0.135, 13.318)	0.482 (0.151, 1.542)
0.055 (-0.748, 0.857)	0.068 (-0.642, 0.779)	0.396 (-0.324, 1.117)	Fusion + Wallis	0.360 (0.050, 2.606)
-0.482 (-1.051, 0.086)	-0.469 (-1.030, 0.092)	-0.141 (-0.585, 0.303)	-0.537 (-1.104, 0.030)	Fusion only

Fig. 5. a Merged league table for RASDeg and CASD by surgical treatment. The blue cells represent the odds ratio (OR) of RASDeg, while the green cells represent the odds ratio of CASD, with the corresponding 95% confidence intervals shown in parentheses. *RASDeg: radiographic adjacent segment degeneration; CASD: clinical adjacent segment disease.* 5b. Merged league table for reoperations due to ASD and VAS back pain score by surgical intervention. The blue cells represent the odds ratio (OR) of re-operations due to ASD with corresponding 95% confidence intervals shown in parentheses. The green cells represent the mean difference (MD) of back pain score with corresponding 95% confidence intervals shown in parentheses. *ASD: adjacent segment disease; VAS: visual analogue scale*(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

violations in 9 cases, including 2 cases in the Wallis group, 2 in the DIAM group, 1 in the Dynesys group, and 4 in the spinal fusion surgery–alone group [7,32,35,38].

Additionally, two studies reported postoperative deep wound infection in 3 cases of the fusion-only group [7,42]. Superficial wound infection was more common, as three studies reported a total of 9 cases, with 1 in the DIAM group, 1 in the Coflex group, 1 in the Dynesys group, and 6 in the spinal fusion surgery–alone group [35,37,38].

Discussion

Traditional spinal fusion surgery has long been used to treat lumbar degenerative diseases but has also been observed to accelerate the degeneration of the adjacent segment. ASDeg (asymptomatic) and ASD (symptomatic) are common complications that occur postoperatively after spinal fusion surgeries. Risk factors such as the narrowing of disc space, segmental instability, and fatty degeneration of paraspinal muscles were reported to be significantly associated with the development of radiologic ASD [44].

Therefore, the topping-off technique was introduced as an alternative approach using dynamic or less rigid fixation as an active buffer between the caudal rigid fused segment and the cephalad mobile unfused segment. Combining conventional spinal fusion surgery with posterior IPDs or HSDs gradually reduces stress on the fused segments while stabilizing the pathologically unstable vertebral level [45]. HSDs such as the Dynesys system limit the impact of biomechanical stress on adjacent levels, whereas posterior IPDs are designed to distract interspinous processes and flex the spinal canal and neural foramina [46].

A finite element study by Fan et al. reported that PLIF increased torsional rigidity compared with Coflex, placing a higher load burden on the adjacent disc and facet joint in rotational activity [22]. Likewise, the Wallis implant consists of an interspinous spacer and two bands to secure the implant in the interspinous space and limit flexion and extension [47,48].

In this study, we compared various hybrid topping-off constructs along with fusion-only constructs and examined the long-term effectiveness of ASD incidence, reoperation rate due to ASD, and pain relief. This is the first study, to the best of our knowledge, that uses NMA in a systematic review to compare fusion-only constructs and topping-off constructs for lumbar degenerative diseases.

Our results demonstrate that the integration of posterior dynamic topping-off devices into spinal fusion surgery was more favorable in lowering the incidence of both radiographic and clinical ASD than was spinal fusion surgery alone. The topping-off implants DIAM, Dynesys, and Coflex exhibited significant effects for lowered incidence of RASDeg, while Wallis had the same effect as spinal fusion surgery alone.

These results are somewhat contrary to Mo et al. who suggested that all IPDs—Wallis, X-stop, and Coflex—were associated with a significantly greater degree of range of motion in the surgical segment than PLIF and may slow down the development of adjacent segment degeneration [24]. One explanation for this may be because only three studies of Wallis were included in our NMA.

As another primary outcome, CASD incidence was evaluated, which was defined as the presence of symptomatic low back or radicular pain attributed to RASDeg. The results of our NMA were consistent with those of previous studies and revealed a trend of DIAM performing superior to Wallis in lowered incidence of CASD [32]. DIAM was ranked best among the five treatments for significantly lowering the incidence of RASDeg and CASD. Similarly, Cho et. al suggested that IPD treatments had the greatest effect among hybrid constructs for decreasing the incidence of early-onset ASDeg [18].

All four topping-off implants in the study were able to provide the same effects in lowering the incidence of ASD, reoperation rate due to ASD, and back pain intensity. DIAM was the only topping-off device that demonstrated significant favorable outcomes in reduced incidence of radiographical and clinical ASD. The spinal fusion surgery–alone group was observed to be the least favorable intervention for all measured outcomes.

One of the main intentions of the topping-off method is to prevent the occurrence of ASDeg and ASD. However, although the incidence of ASD in the topping-off group was lower than it was in the spinal fusion surgery–alone group, ASD could not be fully prevented. This demonstrates that causes for ASD are multifactorial and are largely dependent on the patient's preoperative condition as well as intraoperative findings and/or complications [49,50].

Limitations

Our study had several limitations. First, the quality of the included trials was mostly moderate to high, with older trials more prone to bias than newer trials. Second, apparent asymmetry was also present due to the small sample size and number of studies in each intervention group compared with the control group. The network could be expanded to include more specific topping-off implants, including total facet replacement systems, because our NMA only compared HSDs and IPDs in the topping-off intervention group. Third, more clinical trial data are required to confirm the study findings.

Conclusion

This NMA demonstrated that compared with other topping-off implants and fusion-only surgery, spinal fusion supplemented with DIAM substantially reduced the incidence of RASDeg and CASD. However, the effectiveness of all treatment comparators for reoperation due to ASD and back pain relief was consistently similar.

Funding Disclosure Statement

No external funding was received for the completion of this study.

Declaration of Competing Interest

One or more of the authors declare financial or professional relationships on ICMJE-NASSJ disclosure forms.

Acknowledgments

The authors wish to thank Nai-Hsuan Ko, Department of Orthopedics, Taipei Medical University Hospital, and Yu-Yin Wei, Office of Research and Development, Taipei Medical University for their assistance in the preparation of related documents.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2022.100177.

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