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Comparison of cervical disc arthroplasty and anterior cervical discectomy and fusion for the treatment of cervical disc degenerative diseases on the basis of more than 60 months of follow-up: a systematic review and meta-analysis

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Abstract

Background: This meta-analysis was designed to investigate the long-term efficacy and safety between cervical disc arthroplasty (CDA) and anterior cervical discectomy and fusion (ACDF) in treating cervical disc degenerative diseases (CDDD).

Methods: Literature search was performed on Pubmed, Embase, Cochrane Library, and Web of Science before Jan 2019. Surgical details, clinical outcomes, range of motion (ROM), complications, and reoperation rates between CDA and ACDF groups were compared and analyzed. A fixed- or random-effects model was applied based on different heterogeneity. STATA (Version 11.0) software was used to perform data analysis.

Results: A total of 13 randomized controlled trial studies with more than 60 months of follow-up (mean 83.1 months) were enrolled in this meta-analysis. Pool results indicated that the CDA group exhibited significantly better outcomes in clinical scores (odds ratio [OR] = 1.54, 95% confidence interval [CI]: 1.15–2.08, $p = 0.004$) and preservation of ROM (mean difference = 1.77, 95% CI: 1.60–1.95, $p < 0.001$) than the ACDF group. Meanwhile, the incidence of adjacent segment disease (ASD) (OR = 0.51, 95% CI: 0.35–0.76, $p = 0.001$) and occurrence of reoperation (OR = 0.41, 95% CI: 0.25–0.69, $p = 0.001$) were lower in the CDA group than in the ACDF group.

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Conclusions: At long-term follow-up, CDA showed better efficacy in terms of clinical outcomes, ROM, ASD, and reoperation than ACDF for treating CDDDs. However, our results require further validation in large-sample and high-quality studies.

Keywords: Cervical disc arthroplasty, Anterior cervical discectomy and fusion, Cervical degenerative disc diseases, Long-term follow-up

Background

In the past several decades, anterior cervical discectomy and fusion (ACDF) has been applied to multiple cervical disorders, including cervical spondylotic myelopathy, cervical spondylotic radiculopathy, and cervical ossification of posterior longitudinal ligament, for its satisfactory clinical efficacy [1]. In the ACDF procedure, directed decompression of the nucleus pulposus and osteophyte can be performed under clear vision during operation [2]. Meanwhile, the physical sagittal alignment of cervical spine can be restored with the inserted cage in the intervertebral space, fixed screws, and anterior plates [3]. However, a solid bony fusion in this procedure can change the range of motion (ROM) and mechanical load of adjacent segments, which can cause subsequent adjacent segment disease (ASD) [4].

Therefore, to decrease the risk of ASD in cervical surgery, cervical disc arthroplasty (CDA) was introduced as an alternative treatment for cervical disc degenerative diseases (CDDDs) in the past 20 years [5]. With a mobile device between two contiguous vertebrae, the mobility of operated segments can be preserved, which may potentially decrease the incidence of ASD postoperatively [6]. Moreover, CDA was reported to show better improvement in clinical functions than fusion surgery because the normal kinematics of the involved segments are maintained [7]. Numerous studies have compared the clinical results and complications between CDA and ACDF, but the conclusions are inconsistent [8, 9].

Though several meta-analyses have compared CDA and ACDF, most of them are based on short-term follow-ups [10, 11]. To the best of our knowledge, few studies have examined the long-term efficacy between the two procedures. Hence, in the present study, we performed a systematic review and meta-analysis to investigate the long-term radiographic data, clinical outcomes, and other complications between CDA and ACDF for the treatment of CDDDs.

Methods

Literature search

The present meta-analysis was based on the guidelines listed in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement [12]. Electronic search was performed on PubMed, Embase, Scopus,

Cochrane Database, and Web of Science from the dates of inception to January 2019. In the search strategy, the following controlled vocabulary (Emtree of Embase and MeSH of PubMed) and keywords were used: (“cervical disc arthroplasty” OR “cervical disc replacement” OR “CDA” OR “CDR”) AND (“anterior cervical discectomy and fusion” OR “ACDF”). The reference lists of the enrolled studies were searched for missed eligible studies. The literature search was restricted to the English language.

Selection criteria

The inclusion criteria for identification of studies were as follows: (1) randomized controlled trials (RCTs), (2) comparison between two surgical procedures (CDA and ACDF), (3) follow-up time of more than 60 months, and (4) reporting at least one surgical related outcome. The studies that satisfied the following criteria were eliminated: (1) lack of comparative data, (2) insufficient follow-up, and (3) biomechanical or in vitro studies.

Assessment of quality

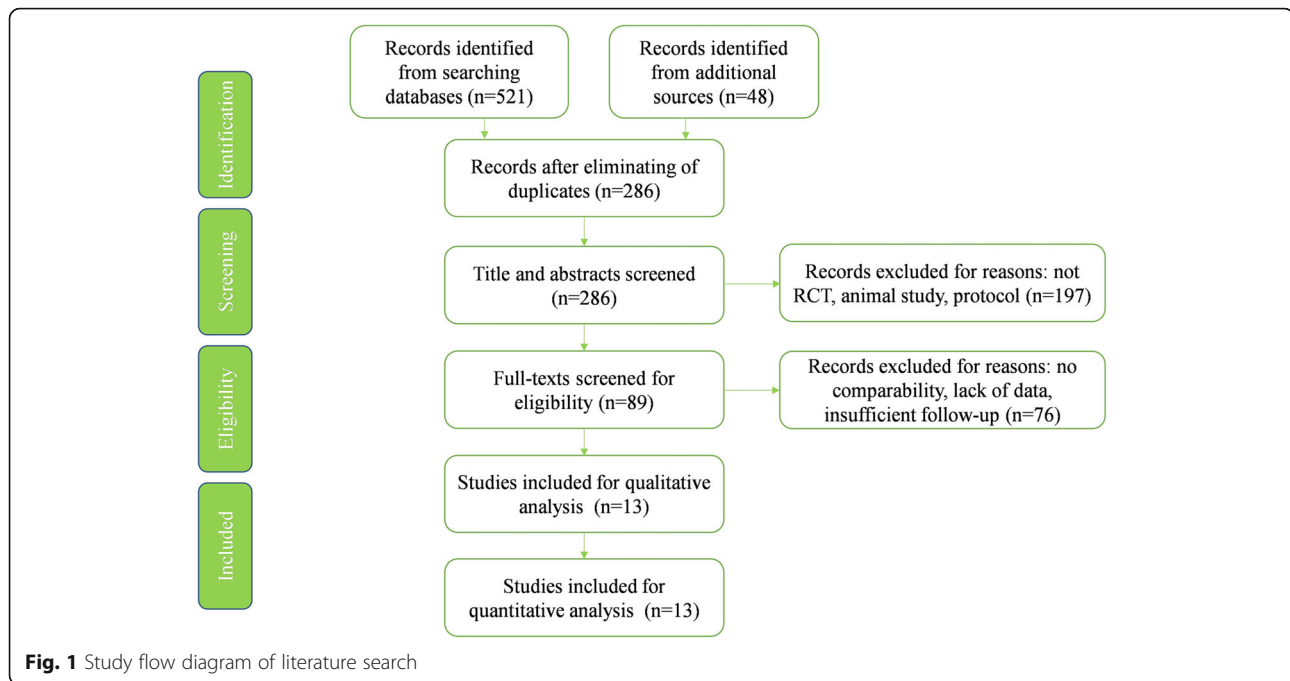
To evaluate the quality of evidence of the identified studies, the Cochrane Collaboration tool was used to assess the RCTs [13]. Each identified trial was reviewed and scored as high, low, and unclear risks according to selection, performance, detection, attribution, reporting, and other potential biases. Two reviewers (YJ Z and B P) reviewed and assessed each study independently, and a third reviewer (HL Y) was consulted to solve disagreements.

Data extraction

The data extracted from the enrolled studies for synthesis and analysis included authors, date of publication, study design, study country, patient characteristics (distribution of sex and age), surgical prosthesis, follow-up, neurological success, overall success, neck disability index (NDI), short-form questionnaire for physical health (SF-PCS), arm pain, neck pain, ROM, ASD, adverse events, reoperation at index level, and reoperation at adjacent level.

Statistical analysis

Meta-analysis was performed using the STATA (Version 11.0) software. For binary variables, the odds ratio (OR)



was used for evaluation, while mean difference (MD) was applied for continuous variables. The heterogeneity of studies was estimated using the I^2 tests: low heterogeneity ($I^2 < 30\%$), moderate heterogeneity ($30\% < I^2 < 50\%$), and substantial heterogeneity ($I^2 > 50\%$). The fixed-effects model was adopted when $I^2 < 50\%$, and the random-effects model was applied when $I^2 > 50\%$. The minimal clinically important difference (MCID) for NDI, SF-PCS, arm pain and neck pain was set as 2.5 according to previous studies [14, 15]. Publication bias was assessed by Egger's test, and sensitivity analysis was used

to confirm the stability of results. A two-tail p -value of less than 0.05 was considered significant.

Results

Search results

A total of 569 studies were searched at the initial searching process. After eliminating of duplicate studies, 286 studies were screened based on titles and abstracts. The 89 potential eligible studies that remained were full-text reviewed. Ultimately, 13 articles were enrolled in this

Table 1 Characteristics of 13 enrolled RCT studies

Authors	Year	CDA (N)	CDA (Age)	CDA (Male %)	ACDF (N)	ACDF (Age)	ACDF (Male %)	Prosthesis	Follow-up
Burkus et al.	2014	276	43.3	46.4	265	43.9	46.0	Prestige	84 months
Coric et al.	2013	41	49.5	39.0	33	49.3	42.4	Bryan and KineflexC	72 months
Ghobrial et al.	2018	242	Not provided	Not provided	221	Not provided	Not provided	Bryan	120 months
Gornet et al.	2016	280	44.5 ± 8.8	46.1	265	43.9 ± 8.8	46	Prestige LP	84 months
Hisey et al.	2016	164	43.3 ± 9.2	47.6	81	44.0 ± 8.2	44.4	Mobi-C	60 months
Jackson et al.	2016	413	Not provided	Not provided	186	Not provided	Not provided	Mobi-C	60 months
Janssen et al.	2015	103	42.1 ± 8.4	45	106	43.5 ± 7.2	46	ProDisc-C	84 months
Lanman et al.	2017	209	47.1 ± 8.3	44	188	47.3 ± 7.7	47.9	Prestige LP	84 months
Loimeau et al.	2016	22	Not provided	Not provided	22	Not provided	Not provided	ProDisc-C	84 months
Miller et al.	2018	34	Not provided	Not provided	36	Not provided	Not provided	Bryan	84 months
Philips et al.	2015	224	Not provided	Not provided	192	Not provided	Not provided	PCM	60 months
Radcliff et al.	2017	389	44.5 ± 8.6	49	186	45.2 ± 8.1	43.5	Mobi-C	84 months
Sasso et al.	2016	22	Not provided	Not provided	25	Not provided	Not provided	Bryan	120 months

meta-analysis for qualitative and quantitative analyses (Fig. 1).

Demographic data

Thirteen RCT studies published between 2013 and 2018 were included in the present study. The distributions of prosthesis in CDA were Bryan (3 studies), Bryan and KineflexC (1 study), Prestige (1 study), Prestige LP (2 study), ProDisc-C (2 studies), Mobi-C (3 studies), and PCM (1 study). The mean follow-up of the enrolled studies was 83.1 months, ranging from 60 months to 120 months. The specific characteristics of all included studies are listed in Table 1.

Quality assessment

The majority of the 13 eligible studies were well designed and of high quality. All studies were rated as “low risk of bias” according to the Cochrane Handbook for Systematic Review of Interventions (Fig. 2).

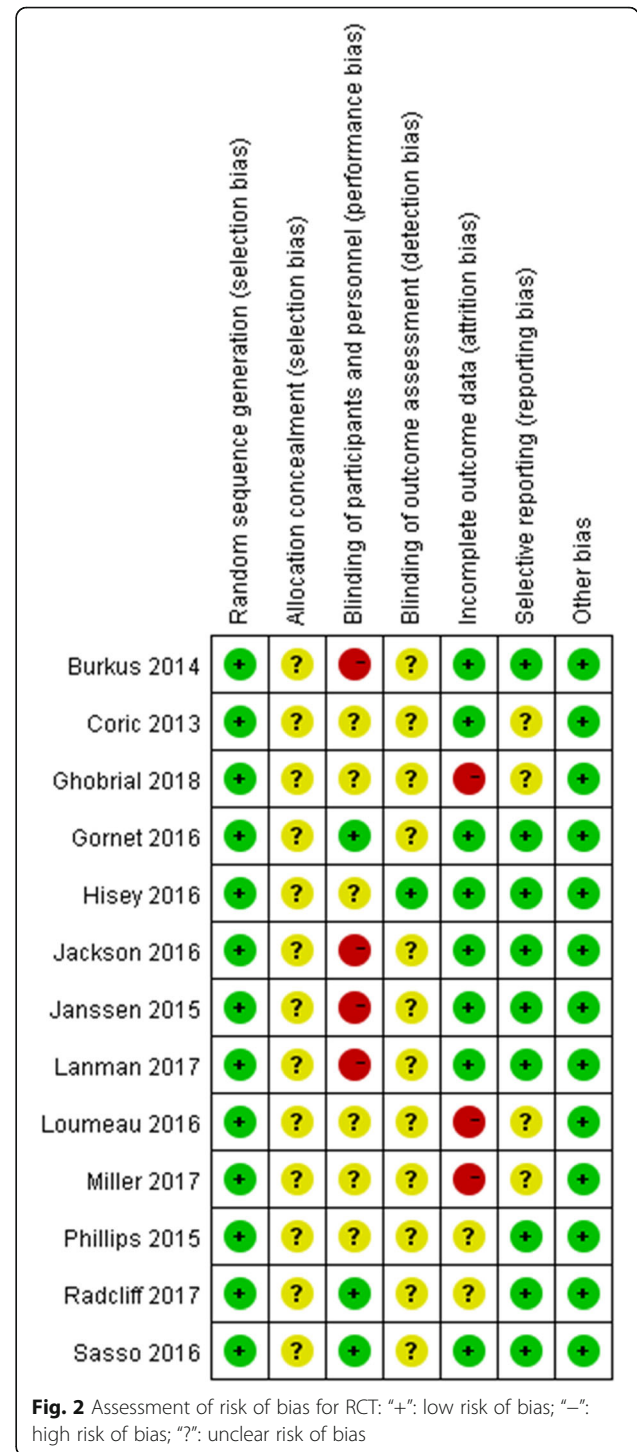
Meta-analysis outcome

Neurological success was reported in six studies [16–21] that comprised 944 patients in the CDA group and 747 patients in the ACDF group. The pooled results indicated that the neurological success rate in the CDA group was significantly higher than that in the ACDF group (OR = 1.54, 95% confidence interval [CI]: 1.14–2.08, $p = 0.004$) with moderate heterogeneity ($I^2 = 34.0%$, $p = 0.18$) (Fig. 3). Overall success was reported in four studies [16, 20–22] that comprised 620 patients in the CDA group and 418 patients in the ACDF group. The pooled results indicated that the overall success rate in the CDA group was also significantly higher than that in the ACDF group (OR = 1.68, 95% CI: 1.29–2.19, $p < 0.001$) with low heterogeneity ($I^2 = 0%$, $p = 0.62$) (Fig. 4).

NDI was provided in three studies [16, 20, 23] that comprised 398 patients in the CDA group and 305 patients in the ACDF group. The pooled results indicated that the NDI in the CDA group was significantly lower than that in the ACDF group (MD = - 0.20, 95% CI: - 0.36 to - 0.05, $p = 0.009$), with moderate heterogeneity ($I^2 = 37.8%$, $p = 0.20$) while the effective size of NDI did not exceed the MCID. SF-PCS was obtained from two studies [16, 20] that comprised 376 patients in the CDA group and 264 patients in the ACDF group. The pooled results indicated that the SF-PCS scores were higher in the CDA group than in the ACDF group, with a clear tendency to significance (MD = 0.16, 95% CI: - 0.00–0.32, $p = 0.05$) and an inconspicuous heterogeneity ($I^2 = 0%$, $p = 0.995$) while the effective size of SF-PCS did not exceed the MCID (Fig. 5).

Arm and neck pains were provided in three studies [16, 20, 23] that comprised 398 patients in the CDA group and 305 patients in the ACDF group. The pooled

results indicated that both neck and arm pains were significantly better in the CDA group than in the ACDF group (MD = - 0.20, 95% CI: - 0.35 to - 0.05, $p = 0.01$ and MD = - 0.23, 95% CI: - 0.38 to - 0.07, $p = 0.004$, respectively), with inconspicuous heterogeneity ($I^2 = 31.6%$, $p = 0.23$ and $I^2 = 24.3%$, $p = 0.27$, respectively). The



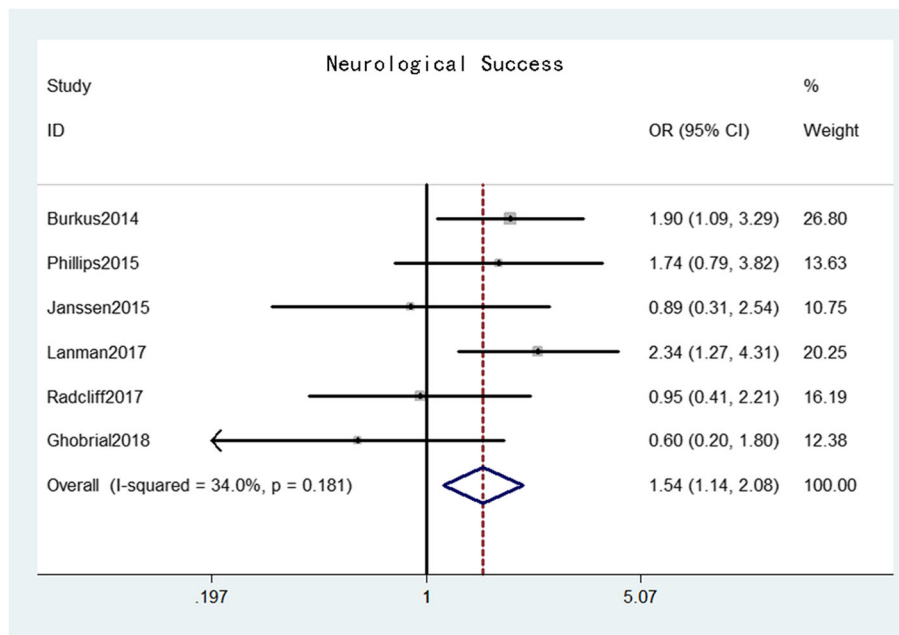


Fig. 3 Forest plot of neurological success between CDA and ACDF groups

effective size of arm and neck pains did not exceed the MCID (Fig. 6).

ROM was reported in three studies [17, 18, 20] that comprised 400 patients in the CDA group and 274 patients in the ACDF group. The pooled results indicated that the ROM in the CDA group was significantly larger

than that in the ACDF group (MD = 1.76, 95% CI: 1.57–1.94, $p < 0.001$) with low heterogeneity ($I^2 = 0\%$, $p = 0.38$). ASD was provided from three studies [20, 22, 24] that comprised 302 patients in the CDA group and 160 patients in the ACDF group. The pooled results indicated that the ASD rate in the CDA group was

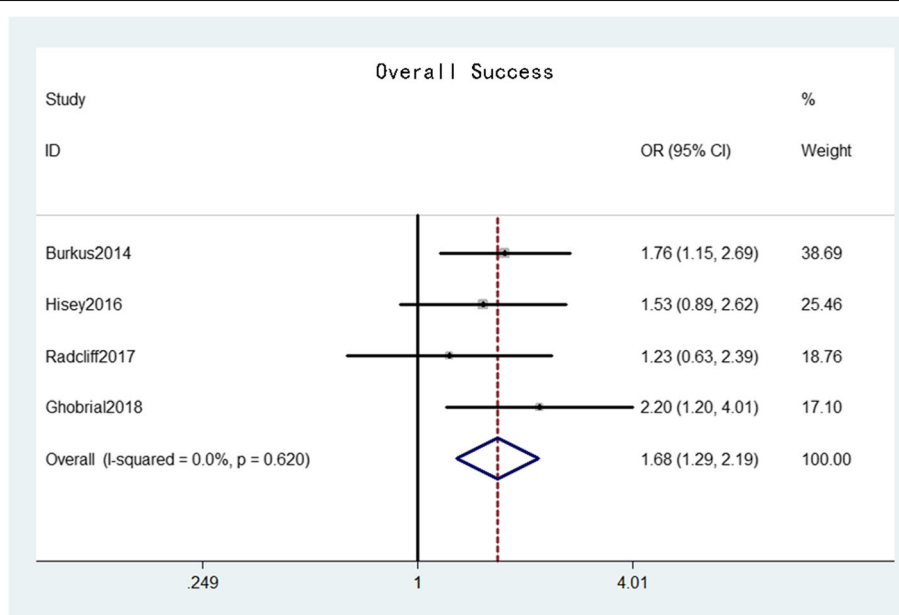


Fig. 4 Forest plot of overall success between CDA and ACDF groups

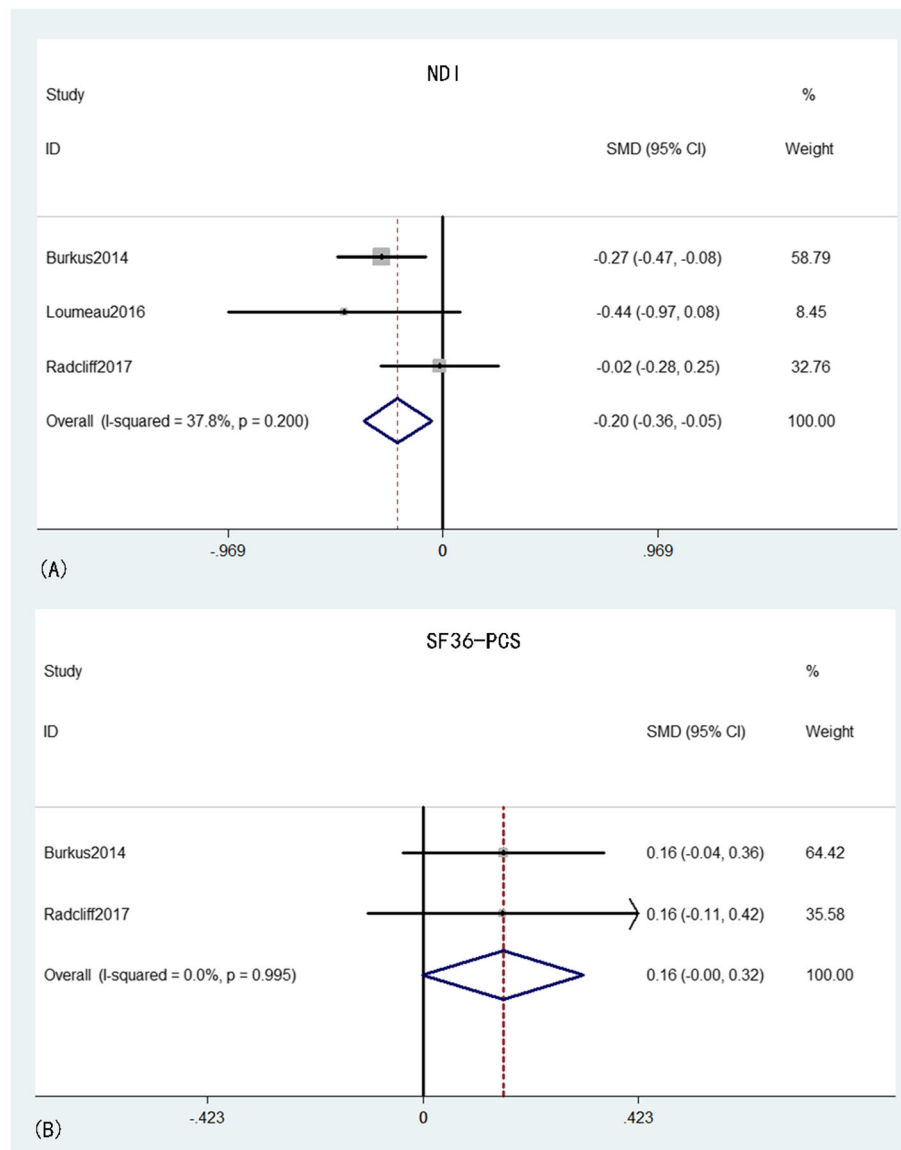


Fig. 5 Forest plot of NDI (A) and SF-36 PCS (B) between CDA and ACDF groups

significantly lower than that in the ACDF group (OR = 0.51, 95% CI: 0.35–0.76, $p = 0.001$), with moderate heterogeneity ($I^2 = 32.9%$, $p = 0.23$) (Fig. 7).

The adverse event rate was derived from seven studies [17–20, 22, 25, 26] that comprised 1145 patients in the CDA group and 901 patients in the ACDF group. The pooled results indicated the adverse event rate was not significant between the two groups (OR = 1.01, 95% CI: 0.77–1.32, $p = 0.96$), with low heterogeneity ($I^2 = 8.4%$, $p = 0.37$) (Fig. 8).

Reoperation at the index level was provided from 11 studies [16–20, 22, 23, 25–28] that comprised 1811 patients in the CDA group and 1330 patients in the ACDF

group. The pooled results indicated that reoperation at the index level rate was significantly lower in the CDA group than in the ACDF group (OR = 0.41, 95% CI: 0.25–0.69, $p = 0.001$), with substantial heterogeneity ($I^2 = 61.0%$, $p = 0.004$) (Fig. 9).

Reoperation at the adjacent level was provided from 11 studies [16–23, 25, 27, 28] that comprised 1773 patients in the CDA group and 1286 patients in the ACDF group. The pooled results indicated that reoperation at the adjacent level rate was significantly lower in the CDA group than in the ACDF group (OR = 0.34, 95% CI: 0.26–0.46, $p < 0.001$), with low heterogeneity ($I^2 = 23.4%$, $p = 0.22$) (Fig. 10).

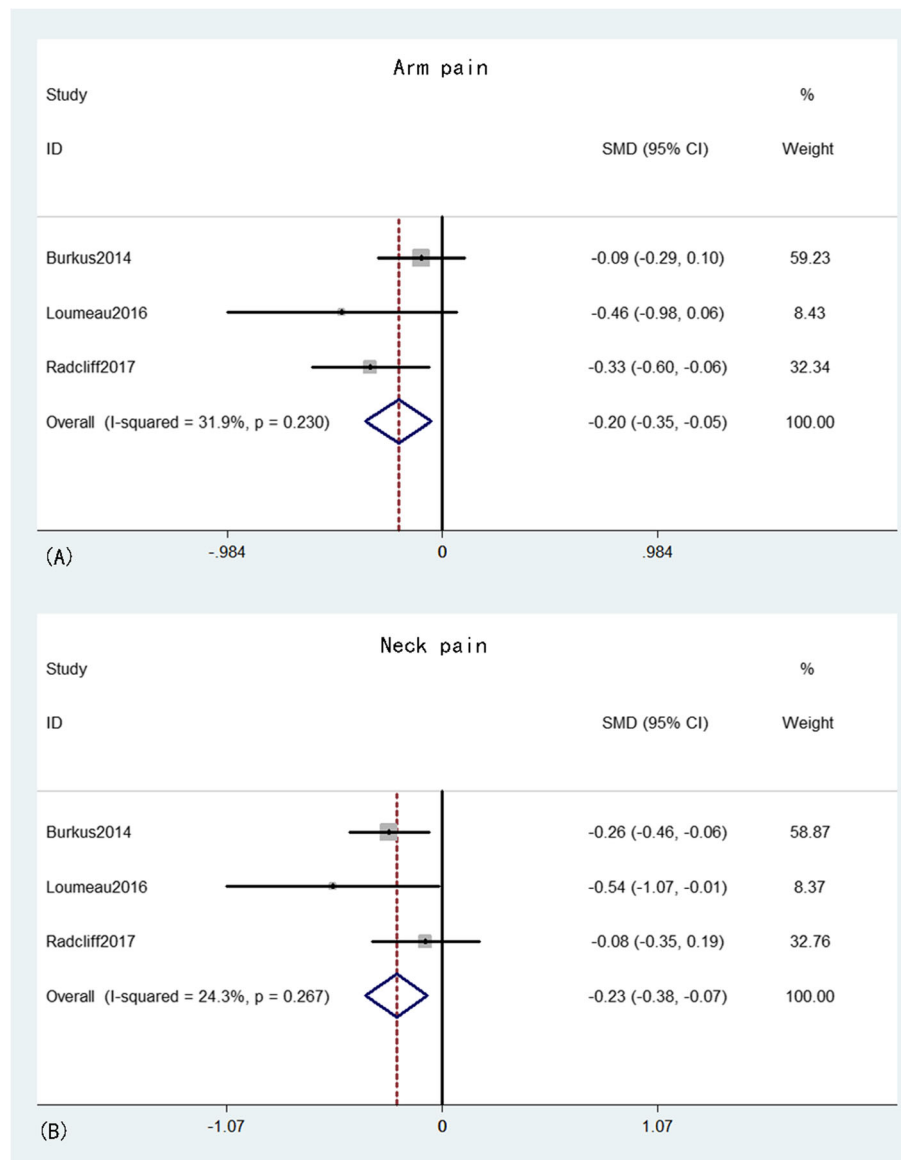


Fig. 6 Forest plot of arm pain (A) and neck pain (B) between CDA and ACDF groups

Publication bias

Publication bias was investigated using Begg's test, and Begg's funnel plot was constructed to evaluate the publication bias of the included studies. No studies showed obvious asymmetry on two sides, indicating a low publication bias in the present study (Supplement 1).

Sensitivity analysis

Sensitivity analysis was performed to examine whether removing each study would make a significant change on the overall trend. No altered results were observed after each study was eliminated, suggesting the reliability and stability of results in this meta-analysis (Supplement 2).

Discussion

ACDF has been applied as an optimal surgical procedure for treating cervical degenerative diseases since it was first reported in 1958 by Robinson and Smith [29]. However, with the widespread use of this procedure, some complications, including decrease of ROM, emergence of ASD, and reoperation, have drawn significant attention. Previous studies reported that the loss of mobility of surgical segments caused by fusion may be a potential reason for ASD and reoperation. By contrast, as a non-fusion decompression method, CDA can preserve the motion of index segments and the natural cervical alignment. ROM, at either operative or adjacent levels, can be maintained effectively after CDA [30]. In recent years,

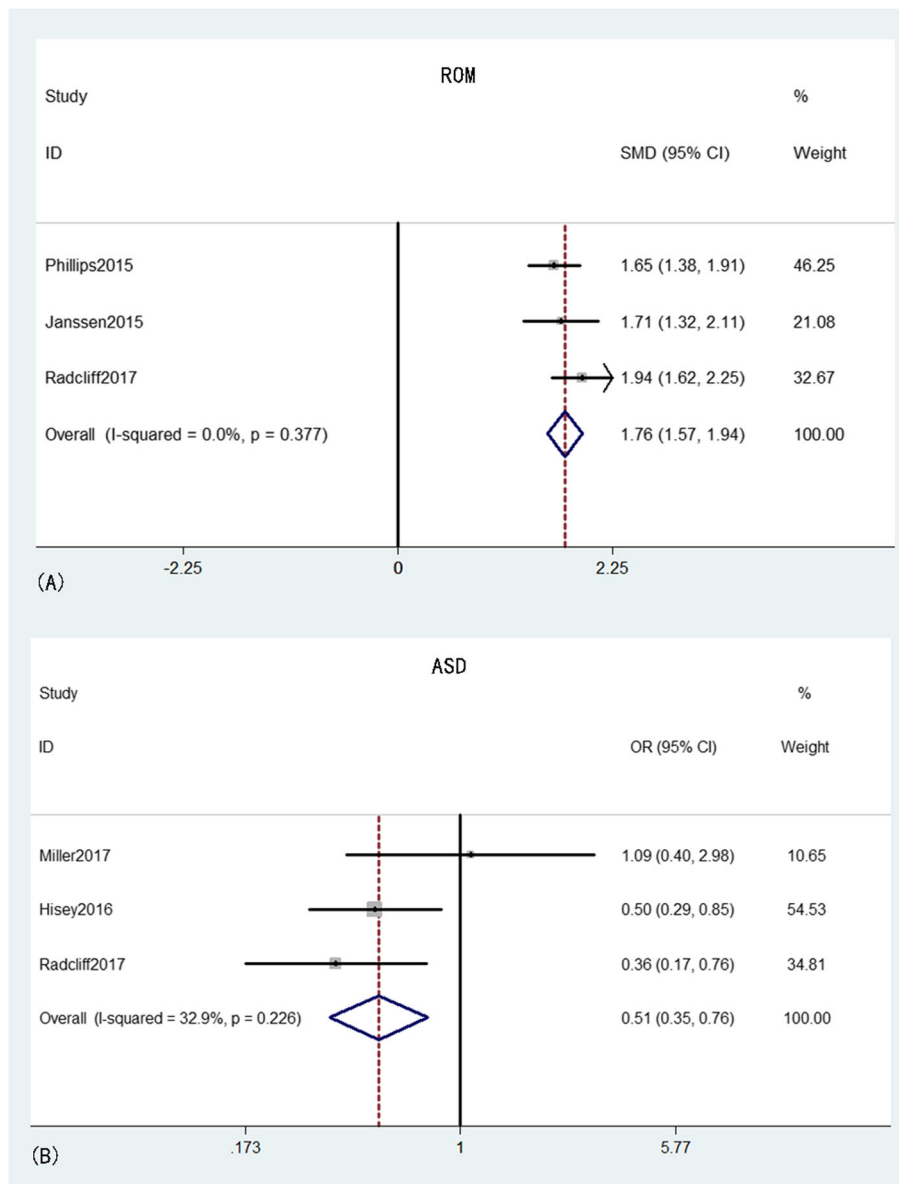


Fig. 7 Forest plot of ROM (A) and ASD (B) between CDA and ACDF groups

numerous meta-analyses compared the clinical and radiological outcomes between ACDF and CDA to evaluate whether the latter is better at reducing related complications. Luo et al. reported that CDA has significantly lower incidence of ASD and adjacent segment reoperations in cervical degenerative diseases than ACDF [31]. Similar results were also verified in another study, indicating the superior effect of CDA through the fewer adjacent segmental complications [32]. Meanwhile, some studies demonstrated that CDA may show better clinical outcomes and fewer postoperative adverse events than ACDF [33]. Unfortunately, most of them reported short- or mid-term outcomes between the two procedures, while long-term results were still unclear.

In this meta-analysis, the authors conducted a comparison between the surgical successes, clinical outcomes, ROMs, ASDs, and reoperations between CDA and ACDF on the basis of more than 60 months follow-up and obtained meaningful results. For clinical outcomes, at a mean of 83.1 months of follow-up, the NDI, SF-PCS, and neck and arm pains in the CDA group were better than those in the ACDF group, indicating that dynamic implant can achieve better clinical outcomes. However, for the clinical relevance, none of these parameters met the MCID. Therefore, we considered the superior curative outcomes for pain management need more studies to verify. The rates of neurological and overall successes were also higher in the CDA group

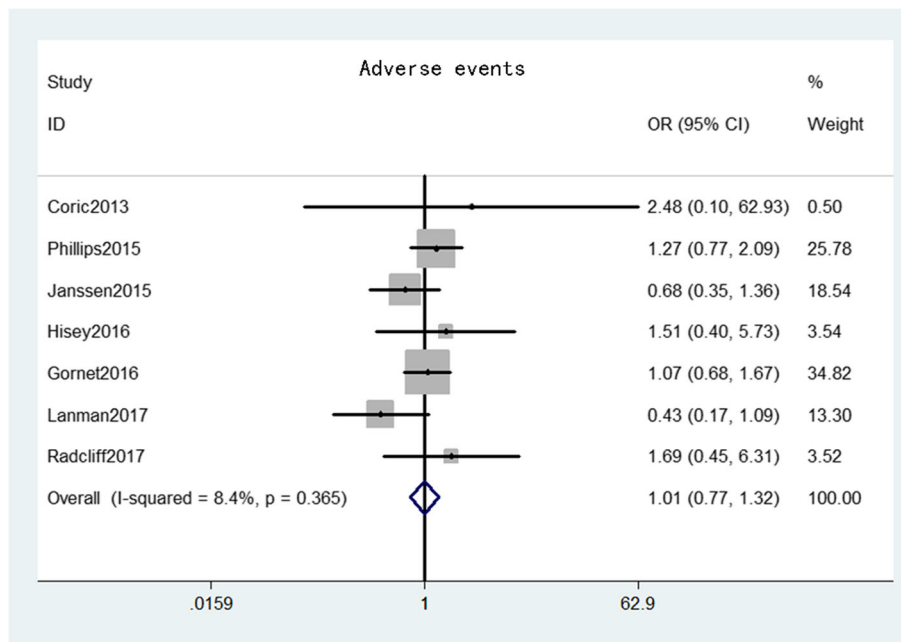


Fig. 8 Forest plot of adverse events between CDA and ACDF groups

than in the ACDF group. Both CDA and ACDF can relieve pain symptoms by the adequate decompression of the herniated disc or osteophyte under direct vision through the anterior approach. Meanwhile, compared with ACDF, CDA can preserve the cervical mobility and

provide a normal motion pattern of the intact spine, which may be a potential cause of the superior clinical outcomes in the CDA group [34].

As a dynamic device, CDA was designed to preserve the activity of surgical segments, which prevents long-

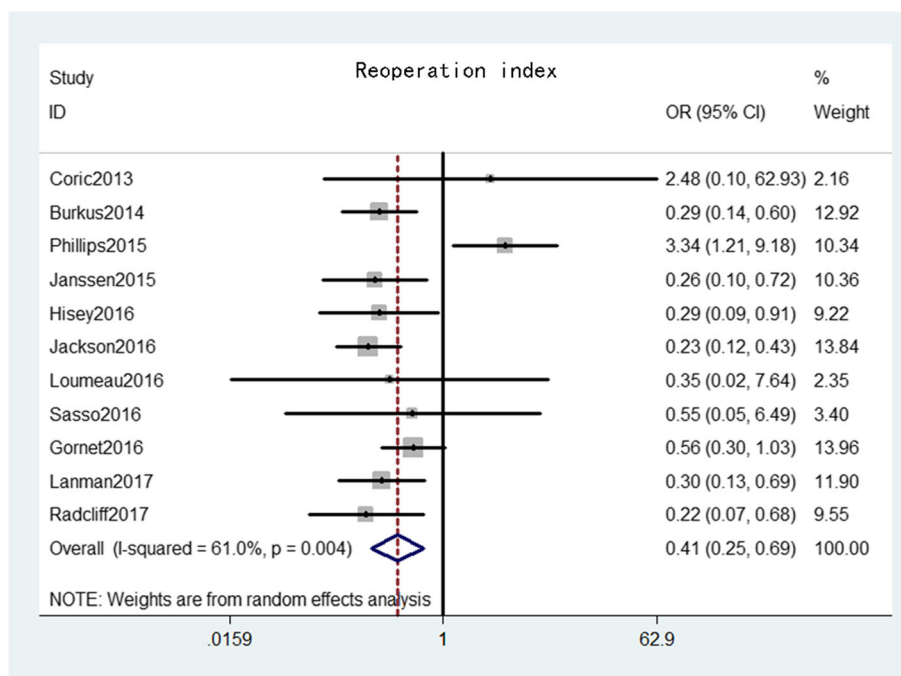


Fig. 9 Forest plot of reoperation at index level between CDA and ACDF groups

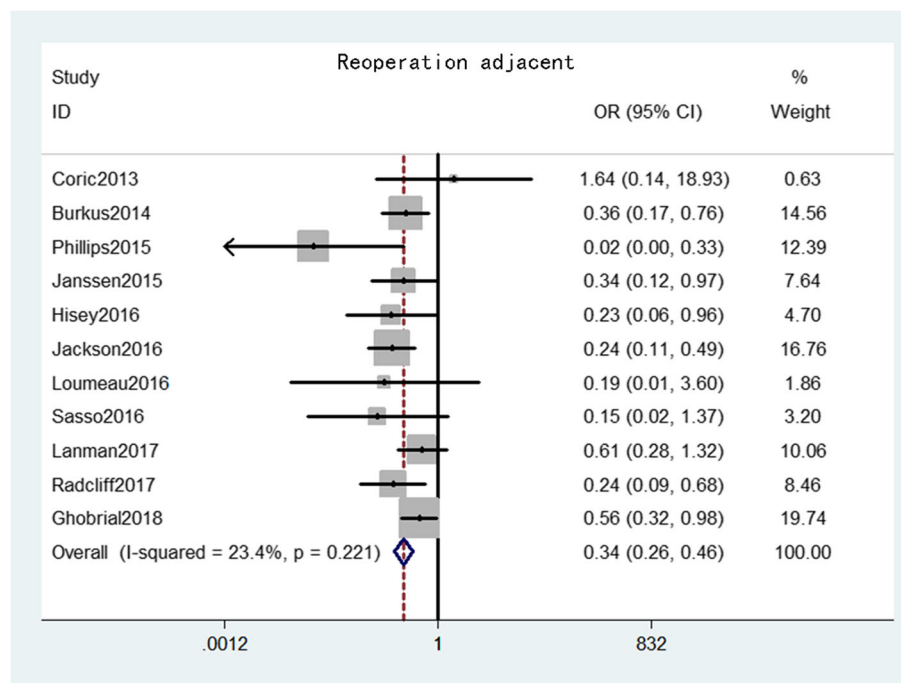


Fig. 10 Forest plot of reoperation at adjacent level between CDA and ACDF groups

term complications, such as ASD, neck stiffness, and revision. Zeng et al. conducted a seven-year follow-up and observed that the segment motion in the Prestige-LP Disc can be preserved effectively at the final follow-up [35]. Tian et al. performed a comparative study between Bryan disc and anterior fusion surgery, and their results corroborated that the ROM of the former is explicitly better and the mobility can be maintained after 6 years of follow-up [36]. In the present study, as theoretically predicted, the ROM in the CDA group was significantly higher than that in the ACDF group at long-term follow-up, which is consistent with previous studies [17, 18]. Additionally, we observed from the included studies that the ROM can be maintained well and even improved slightly in CDA patients, indicating the satisfactory effect of CDA on the preservation of segmental motion. For patients who demand normal working and mild activity, such maintenance of cervical mobility may benefit the quality of life.

As for complications, though no significant difference in the adverse events was observed between CDA and ACDF. It was worth noting that as a common complication after cervical surgery, the incidence of ASD was seem lower in the CDA group than in the ACDF group with our statistical results, which reveals that CDA may have a potential positive impact on reducing postoperative ASD at long-term follow-up. As mentioned above, due to the loss of segmental motion, patients after ACDF may have abnormal mobility at adjacent levels

that can alter the biomechanical load and exacerbate degeneration of adjacent vertebrae [37]. Compared with fusion surgery, the mobility and flexibility of operative levels can be preserved in the CDA group, and a physiological functional spinal unit (FSU) can be conserved, which may benefit the natural degenerative process. Finally, the reoperation rates of the two groups were compared, and CDA exhibited a favorable effect due to the lower reoperation rate, whether at index or adjacent segments [21, 24]. Without doubt, a second operation is another trauma for patients, and prior tissue and scar formation will increase the difficulty and risk of reoperation. Previous studies demonstrated that symptomatic pseudarthrosis is the main cause of reoperation at the treated level, while symptomatic ASD is responsible for reoperation at adjacent levels [38]. Hence, we inferred that the preservation of segmental motion can provide a physical FSU and avoid the generation of pseudarthrosis, which can reduce the reoperation rate at the index level. Meanwhile, a normal segmental mobility after surgery can decrease the excessive motion of adjacent levels and avert the occurrence of ASD, which leads to a low rate of reoperation at adjacent segments.

Limitation

We considered that the results of the present meta-analysis may be affected by the following reasons: First, the number of included studies was small, which may lead to insufficient evidence. Meanwhile, some included

studies were sponsored by companies, which may have introduced some confounding factors. Second, some results have moderate heterogeneity, which may introduce bias. Though we conducted publication bias and sensitivity assessment to consolidate the stability, these results still need to be interpreted with caution. Third, the use of cervical prosthesis in different studies was not coincident. Given the limited data, subgroup analysis is difficult to perform according to different devices. Fourth, the reasons for reoperation may sometimes depend on the surgeon's preference, which will also bring bias to the results. Fifth, though some variables showed significant differences between two groups, the overall effects did not across the MCID. Hence, the clinical reference for these data should be considered prudently. Based on the above limitations, we believe that the combined results of the present study should be accepted carefully, and more high-quality studies with larger samples and detailed data are needed.

Conclusion

For the treatment of CDDD, CDA is superior than ACDF in terms of improving clinical outcomes, preserving the ROM, ASD incidence, and reoperation rate at long-term follow-up. However, more high-quality, large-sample, and strong-evidenced studies are needed to verify our results.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s12883-020-01717-0>.

Additional file 1.

Additional file 2.

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Authors' contributions

YJ Z and NN L contributed equally to this work. YJ Z and XS Z designed the study and did the literature search, study quality assessment and data extraction. F H, B P, H L, and A C performed the statistical analysis and drafted the tables and Figs. YJ Z wrote the first draft of this analysis, HL Y, MM L helped to finish the final version. NN L and MM L helped with revision of the manuscript. All authors approved the conclusions of our study.

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Availability of data and materials

All data generated or analyzed in this work are included in the published version.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

All authors confirmed no competing interest in this work.

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