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Surgical Interventions for Cervical Radiculopathy without Myelopathy

A Systematic Review and Meta-Analysis

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Background: The effectiveness of surgical interventions for cervical degenerative disorders has been investigated in multiple systematic reviews. Differences in study population (e.g., patients with myelopathy and/or radiculopathy) were often neglected. Therefore, the objective of this study was to investigate the effectiveness of surgical interventions for patients with symptoms of cervical radiculopathy without myelopathy by conducting a systematic review and meta-analysis based on randomized controlled trials (RCTs).

Methods: A comprehensive systematic search was conducted in MEDLINE, Embase, and CENTRAL (Cochrane Central Register of Controlled Trials) to identify RCTs that investigated the effectiveness of surgical interventions using an anterior or posterior approach compared with other interventions for patients with pure cervical radiculopathy. Outcomes were success rates (Odom criteria, similar rating scales, or percentage of patients who improved), complication and reoperation rates, work status, disability (Neck Disability Index), and pain (arm and neck). The Cochrane risk-of-bias tool was used to assess the likelihood of the risk of bias. A random-effects model was used. Heterogeneity among study results ($I^2 \geq 50\%$ or $p < 0.05$) was explored by conducting subgroup analyses. Funnel plots were used to assess the likelihood of publication bias.

Results: A total of 21 RCTs were included, comprising 1,567 patients. For all outcomes, among all surgical techniques, only 1 pooled estimate showed a significant effect on success rate, which was in favor of anterior cervical discectomy with fusion compared with anterior cervical discectomy without an intervertebral spacer ($p = 0.02$; risk ratio [RR] = 0.87; 95% confidence interval [CI] = 0.77 to 0.98). Complication rates were higher when autologous bone graft from the iliac crest was used as an intervertebral spacer ($p < 0.01$; RR = 3.40; 95% CI = 1.56 to 7.43), related to donor-site morbidity.

Conclusions: This meta-analysis demonstrated consistent results regarding clinical outcome for pure cervical radiculopathy among all studied interventions. Complication and reoperation rates were also similar, with the exception of higher complication rates in patients in whom autologous bone grafts were used. On the basis of clinical outcome and safety, there is no superior surgical intervention for pure cervical radiculopathy.

Level of Evidence: Therapeutic Level I. See Instructions for Authors for a complete description of levels of evidence.

Degenerative changes in the cervical spine are common in the aging population[1-3]. When these changes cause symptoms, patients can present with myelopathy, radiculopathy, or a combination of both. These symptoms often correspond to localized compression resulting from the degenerative disease (i.e., centrally at the spinal cord and/or laterally at the exiting nerve root).

When conservative treatment for a herniated cervical disc fails, surgery is a viable option. The favored surgical strategy for a single-level, centrally herniated disc is an anterior approach[4-7]. However, for isolated lateral compression of the cervical nerve root, there is conflicting evidence regarding the most effective surgical technique. There are multiple surgical techniques available, from anterior discectomy with or without fusion to disc arthroplasty or posterior foraminotomy.

Multiple reviews and meta-analyses have been published comparing one surgical technique with another; however, in most studies, the localization of the degenerative disease was

not clearly stated. Furthermore, patients presenting with myelopathy and/or radicular symptoms were often combined, which may lead to undesired heterogeneity in the study population[8-22]. Therefore, a comprehensive systematic review investigating the effectiveness of surgery for patients with pure cervical radiculopathy is needed.

Two recent systematic reviews focused on the surgical treatment of cervical radiculopathy[23,24]. One compared anterior cervical discectomy with fusion (ACDF) and posterior cervical foraminotomy (PCF) in both prospective and retrospective studies; other techniques were not addressed. The other systematic review included randomized controlled trials (RCTs) that compared ACDF with PCF or cervical disc replacement (CDR). That paper found only 3 eligible studies and provided only a descriptive review of the data. To our knowledge, a systematic review and meta-analysis comparing RCTs on all available interventions for pure radiculopathy has not yet been performed and would provide evidence to help clinicians decide which intervention should be preferred.

The objective of this systematic review and meta-analysis was to investigate the effectiveness of surgical interventions for patients with cervical radiculopathy without signs of myelopathy. It was conducted according to the methods of the Cochrane Collaboration and reported according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement[25,26].

Materials and Methods

Systematic Search and Study Selection

A comprehensive systematic search was developed in consultation with an information specialist and conducted in MEDLINE, Embase, and CENTRAL (Cochrane Central Register of Controlled Trials) on January 1, 2019. Search strings included terms related to the pathology and surgical technique (Appendix 1). Two reviewers (A.E.H.B. and N.F.S.d.S.) independently screened the titles and abstracts of all records identified. The full text of potentially eligible publications was retrieved and read for final selection. In case of disagreement, a third reviewer (J.M.A.K.) was consulted to reach consensus. The reference lists of the included studies and relevant reviews on the topic were screened to identify additional articles. Eligible articles met the following criteria: (1) describing patients with pure cervical radiculopathy; (2) reporting anterior or posterior surgical interventions compared with control interventions (surgical or conservative); (3) reporting the success rate of the intervention, disability, or pain scores; and (4) utilizing an RCT design. Only full-text, peer-reviewed articles that were published in English or Dutch from January 1, 2000, to January 1, 2019, were included.
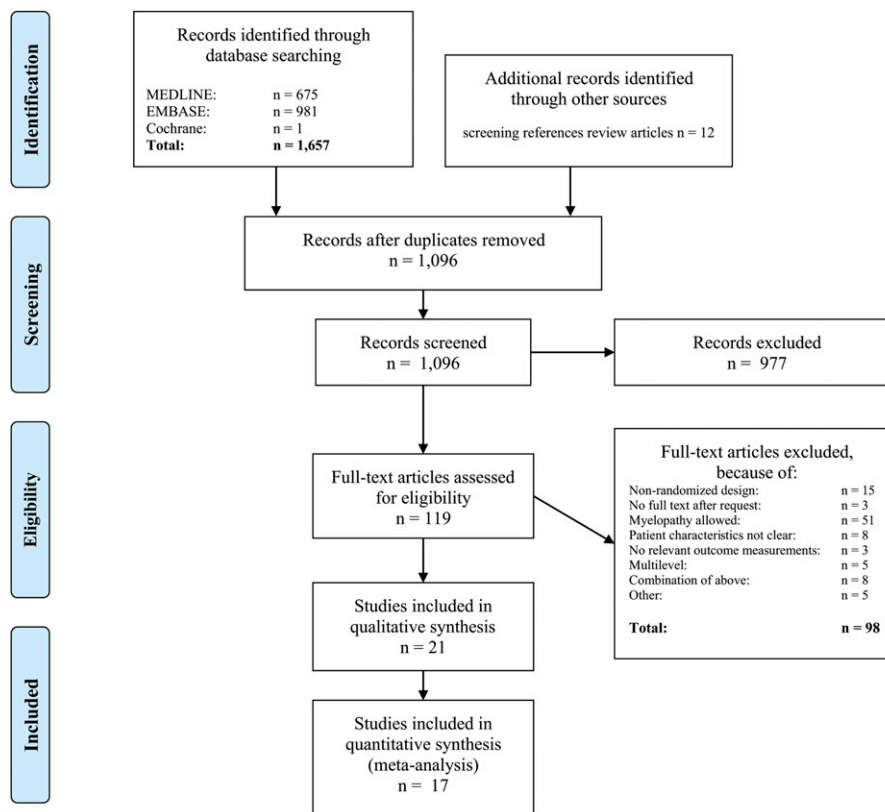

Fig. 1
Flow diagram of the included studies.

TABLE I Characteristics of the Included Studies*

Study	No. of Centers	Sponsor	Total Participants	No. of Arms	Control Groups	Experimental Groups	Follow-up (mo)	Age† (yr)	Male/Female
Zoëga[38] (2000)	1	Noncommercial	27‡	2	ABG	ABGP	24	41 (25-60)	15/12
Wirth[28] (2000)	1	Unclear	72	3	ABG	PCF, ACD	60	43.5 (28-67)	36/36
Persson[47] (2001)	1	Unclear	81	3	ACDF	PT, cervical collar	12	47.5 ± 7.9 (28-64)	44/37
Bärlocher[31] (2002)	1	Unclear	125	4	ACDF	PMMA, ACD, ABG	12	50.5 ± 11.4 (24-84)	74/51
Xie[42] (2007)	Unclear	None	42	3	ABG	ACD, ABGP	24	43 ± 8 (26-59)	28/14
Nabhan[48] (2007)	1	Unclear	33	2	ACDFP	CDR	6	45 ± 11	19/14
Lind[35] (2007)	1	Unclear	24	2	ACDF	ABG	24	42 (29-57)	11/13
Oktenoglu[46] (2007)	>1	Unclear	20	2	ABGP	ACD	12	Median, 40.05	11/9
Schröder[40] (2007)	Unclear	Unclear	107	2	ACDF	PMMA	24	44.5 ± 8.5	62/45
Fernández-Fairen[37] (2008)	1	None	61	2	ABGP	ACDF	24	48.4 (22-65)	22/39
Hauerberg[33] (2008)	1	None	86	2	ACDF	ACD	24	Median, 45.5 (IQR, 10.5)	43/43
Ruetten[30] (2008)	Unclear	None	200	2	ACDF	PCF	24	43 (27-62)	68/132
Löfgren[36] (2010)	1	Unclear	80	2	ABG	ACDF	24	49 (27-70)	50/30
Orief[32] (2010)	1	Unclear	60	3	ABG	PMMA, ACDF	6	46.7 (28-68)	34/26
Ebrahim[29] (2011)	1	None	30	2	ACF	PCF	24	44.4 (29-62)	14/16
Engquist[39] (2013)	1	Noncommercial	63§	2	ACDF	PT	24	46.5 ± 8.5	33/30
Nemoto[34] (2015)	1	Unclear	46	2	ACDFP	ACDF (Zero-P)	24	41.3 ± 7.1 (31-54)	42/4
Li[44] (2015)	1	Unclear	23**	2	ACDFP	ACDF (Zero-P)	12	48.7 ± 7.1 (25-65)	11/12
Donk[41] (2017)	1	None	142	3	ACDF	ACD, CDR	60	44.9 ± 6.5	71/71
Sundseth[43] (2017)	5	DePuy Synthes	136	2	ACDF	CDR	24	44.1 ± 7	63/73
Vleggeert-Lankamp[45] (2019)	1	Unclear	109	3	ACDF	ACD, CDR	24	46.8 ± 8	51/58

*ABG = anterior cervical discectomy with autologous bone graft, ABGP = ABG with additional plating, PCF = posterior cervical foraminotomy, ACD = anterior cervical discectomy without intervertebral spacer ACDF = anterior cervical discectomy with fusion, PT = physiotherapy, PMMA = ACDF with polymethylmethacrylate as an intervertebral spacer, ACDFP = anterior cervical discectomy with fusion and additional plating, CDR = cervical disc replacement, IQR = interquartile range, ACF = anterior cervical foraminotomy, and Zero-P = ACDF with zero-profile cage as intervertebral spacer. Experimental and control groups in this table are as defined in the original studies, which may differ from the definitions used elsewhere in this meta-analysis. †Age is given as the mean, with or without the standard deviation, and with or without the range in parentheses, unless otherwise specified. ‡Zoëga included a total of 46 patients, of whom 27 were treated with 1-level surgery and were included for this review. §Engquist included 4 patients who had 2-level surgery, who were included since individual outcomes could not be determined. **Li included a total of 46 patients, of whom 23 had radicular symptoms and were included for this review.

Studies that included patients with symptoms of myelopathy, radiculomyelopathy, or pure axial neck pain were excluded. In addition, studies that did not differentiate between single-level and multilevel surgery were not eligible. The protocol of this systematic review was registered in PROSPERO, an international prospective register of systematic reviews (CRD42018091912).

Data Extraction
Data were extracted from the included articles regarding study characteristics, selection criteria, participant characteristics, and the results for the relevant outcome parameters. Extraction was independently performed by the same reviewers (A.E.H.B. and N.F.S.d.S.). The primary outcome was the success rate of the intervention (based on the Odom criteria or a similar rating scale, or described as the percentage of patients who improved). Secondary outcomes were work status, reoperation and complication rates, disability (Neck Disability Index [NDI]), and pain (numeric or visual rating scales for arm and neck pain).

Adjacent-segment disease and pseudarthrosis were considered complications even when asymptomatic or when symptoms were not described. Temporary dysphagia and hoarseness, when noted, were also considered complications.

Risk of Bias and Synthesis of Results
The Cochrane risk-of-bias tool[27] was used to assess the likelihood of risk of bias for each included study. This tool evaluates risk of bias on the following 6 domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, and selective reporting. The result for each domain was scored as "low risk of bias," "high risk of bias," or "unclear risk of bias." The overall percentage agreement and Cohen kappa were calculated to evaluate interrater agreement regarding the risk-of-bias assessment of the included studies.

Statistical Analysis
The meta-analysis was conducted using RevMan 5.3.01 for Windows (Cochrane Collaboration). The risk ratio (RR) with 95% confidence interval (CI) was extracted or calculated for each individual study. If studies reported zero events (e.g., a complication rate of zero), +1 was added to all study data within that outcome to be able to include studies with zero events in the meta-analysis. A random-effects method was used to pool effect estimates. If the same patient cohorts were used in various publications, the most recent or complete publication was used for the meta-analysis.

Study	Primary Outcome	Secondary Outcomes
Zoëga[38]	Unclear	VAS arm/neck, work status, Odom, radiographic outcome, reoperations, complications
Wirth[28]	Unclear	Pain improvement, work status, Odom, reoperations, complications
Persson[47]	Unclear	VAS arm/neck†, NDI, HADS, MACL, DRI, coping
Bärlocher[31]	Unclear	VAS arm/neck, work status, Odom, radiographic outcome, reoperations, complications
Xie[42]	Unclear	VAS arm/neck, work status, McGill Pain Score‡, SF-36, radiographic outcome, reoperations, complications
Nabhan[48]	Radiographic outcome	VAS arm/neck
Lind[35]	Radiographic outcome	VAS arm/neck, Odom, complications
Oktenoglu[46]	Unclear	VAS arm/neck, radiographic outcome
Schröder[40]	Unclear	Odom, radiographic outcome, complications
Fernández-Fairen[37]	Radiographic outcome	VAS general pain, Odom, Zung depression scale, NDI, reoperations, complications
Hauerberg[33]	Recovery rate	VAS arm/neck, work status, Odom, reoperations, complications
Ruetten[30]	Unclear	VAS arm/neck, Hilibrand criteria§ (success rate), reoperations, complications
Löfgren[36]	Unclear	VAS arm/neck, Odom, NDI, radiographic outcome
Orief[32]	Unclear	VAS arm/neck, Odom, radiographic outcome, complications
Ebrahim[29]	Unclear	VAS arm/neck, work status, Odom, satisfaction score, radiographic outcome
Engquist[39]	Self-reported disability	VAS arm/neck, global assessment, NDI, Odom, complications
Nemoto[34]	Radiographic outcome	VAS arm/neck, Odom
Li[44]	Postop. dysphagia	VAS general pain, radiographic outcome, JOA, complications
Donk[41]	NDI	MPQ-DLV, SF-36, McGill Pain Score, NRS arm/neck, reoperations, complications
Sundseth[43]	NDI	NRS arm/neck, work status, SF-36, EQ-5D-3L, complications, Dysphagia Short Questionnaire, reoperations
Vleggeert-Lankamp[45]	NDI	VAS arm/neck, EQ-5D, SF-36, radiographic outcome, complications

*VAS = visual analog scale, NDI = neck disability index, HADS = Hospital Anxiety and Depression Scale, MACL = Mood Adjective Check List, DRI = Disability Rating Scale, SF-36 = Short Form-36, JOA = Japanese Orthopaedic Association score, MPQ-DLV = McGill Pain Score–Dutch language version, NRS = numeric rating scale, and EQ-5D-3L = EuroQol-5 Dimensions-3 Levels. †Persson reported VAS scores for combined arm and neck pain. ‡Xie included the McGill Pain Score as an Odom score. §Ruetten used the Hilibrand criteria as an Odom score.

In case of heterogeneity ($I^2 \geq 50\%$ or $p < 0.05$), subgroup analyses were conducted to investigate the sources of heterogeneity. Subgroups were constructed for surgical technique, year of publication, outcome reporting (e.g., considering temporary dysphagia to be a complication or not), sponsorship, and the risk-of-bias assessment (per item).

In order to assess the likelihood of publication bias, funnel plots were constructed for the different outcomes (if ≥10 studies were available).

Results

A total of 1,669 records were identified, which led to inclusion of 21 RCTs[28-48] (Fig. 1).

Study Characteristics

Details regarding study characteristics are summarized in Tables I and II. The included studies were conducted between 2000 and 2018 and included a total of 1,567 patients. The mean age of the included patients was 43.8 years, with a male:female ratio of 1: 0.95. Mean follow-up was 23.8 months (range, 6 to 60 months).

The experimental groups, as originally defined in the studies, included anterior cervical discectomy without intervertebral spacer (ACD), ACD with polymethylmethacrylate (PMMA) as an intervertebral spacer, ACDF with a zero-profile cage, ACDF with a polyetheretherketone (PEEK) or titanium cage, ACDF with autologous bone graft (ABG), CDR, and (endoscopic) PCF. Two studies used a conservative treatment involving physiotherapy and/or a cervical collar as the experimental group. Control groups included anterior cervical foraminotomy (ACF), ACDF with a cage or ABG, and the latter 2 treatments with additional plating (ACDFP or ABGP). ABGP was used as the experimental group as well, when compared with ACDF without plating.

Risk-of-Bias Assessment

The risk of bias showed great variation between the included studies (Appendix 2). A low risk of bias was most often scored for the incomplete outcome data domain (18 [86%] of 21 studies were rated low). For blinding of participants and personnel, only 3 of 21 studies had a low risk of bias (14%). Interrater agreement was 88%, with a Cohen kappa of 0.80.
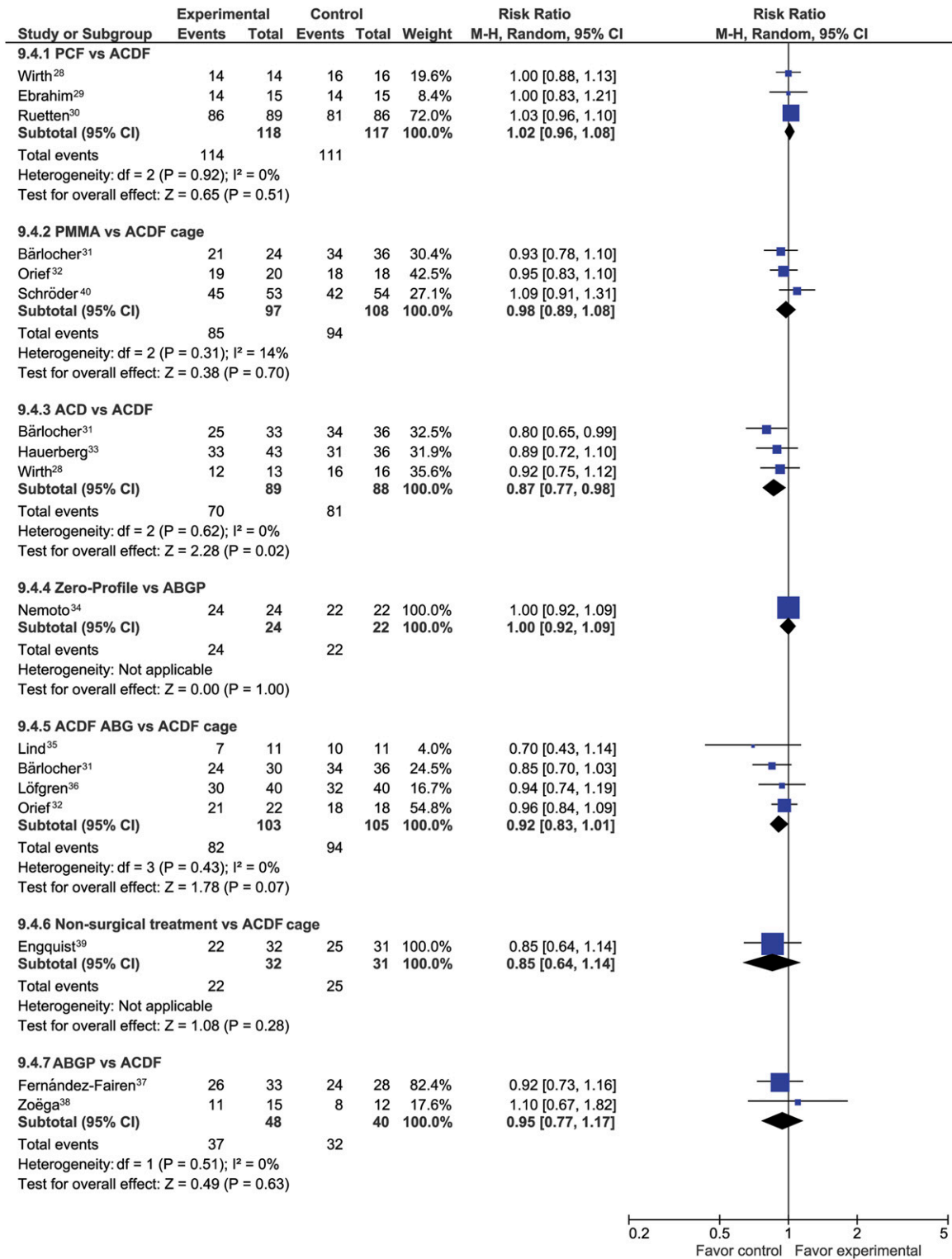
Fig. 2

Forest plots of postoperative success rates. In each section, the first group listed is referred to as the experimental group. M-H = Mantel-Haenszel, CI = confidence interval, PCF = posterior cervical foraminotomy, ACDF = anterior cervical discectomy with fusion (when not further specified as with cage or autologous bone graft [ABG]), df = degrees of freedom, PMMA = ACDF with polymethylmethacrylate as an intervertebral spacer, ACD = anterior cervical discectomy without intervertebral spacer, Zero-Profile = ACDF with a zero-profile cage, ACDF ABG = ACDF with ABG, and ABGP = anterior cervical discectomy with ABG and additional plating. Ebrahim et al.[29] compared PCF with anterior cervical foraminotomy (ACF).

Fig. 3

Forest plots of postoperative complication rates. In each section, the first group listed is referred to as the experimental group. M-H = Mantel-Haenszel, CI = confidence interval, PCF = posterior cervical foraminotomy, ACDF = anterior cervical discectomy with fusion (when not further specified as with cage or autologous bone graft [ABG]), df = degrees of freedom, ACD = anterior cervical discectomy without intervertebral spacer, PMMA = ACD with polymethylmethacrylate as an intervertebral spacer, CDR = cervical disc replacement, ACDF ABG = ACDF with ABG, ABGP = anterior cervical discectomy with ABG and additional plating. Ebrahim et al.[29] compared PCF with anterior cervical foraminotomy (ACF).
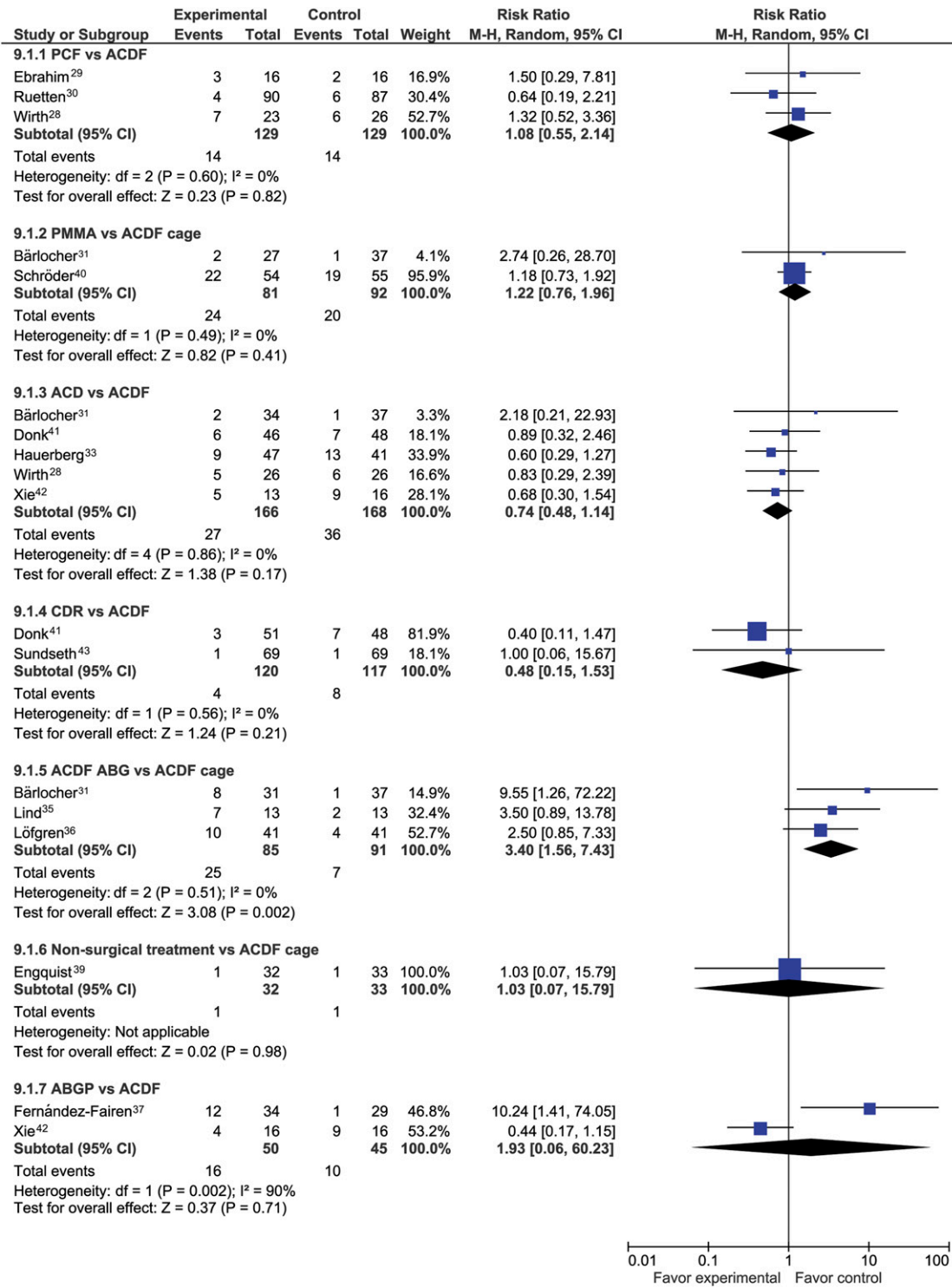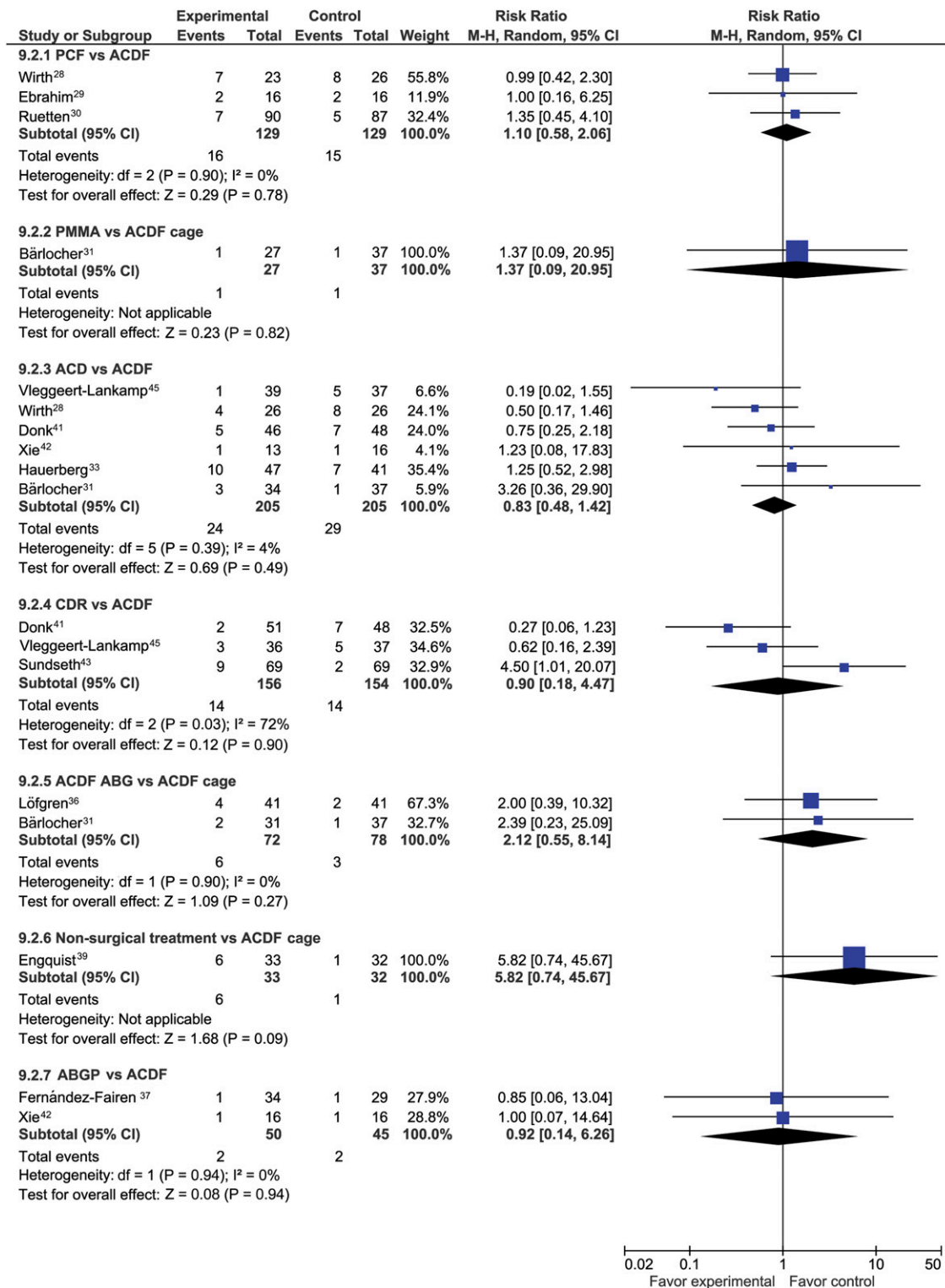
Fig. 4

Forest plots of postoperative reoperation rates. In each section, the first group listed is referred to as the experimental group. M-H = Mantel-Haenszel, CI = confidence interval, PCF = posterior cervical foraminotomy, ACDF = anterior cervical discectomy with fusion (when not further specified as with cage or autologous bone graft [ABG]), df = degrees of freedom, ACD = anterior cervical discectomy without intervertebral spacer, PMMA = ACD with polymethylmethacrylate as an intervertebral spacer, CDR = cervical disc replacement, ACDF ABG = ACDF with ABG, and ABGP = anterior cervical discectomy with ABG and additional plating. Ebrahim et al.[29] compared PCF with anterior cervical foraminotomy (ACF).
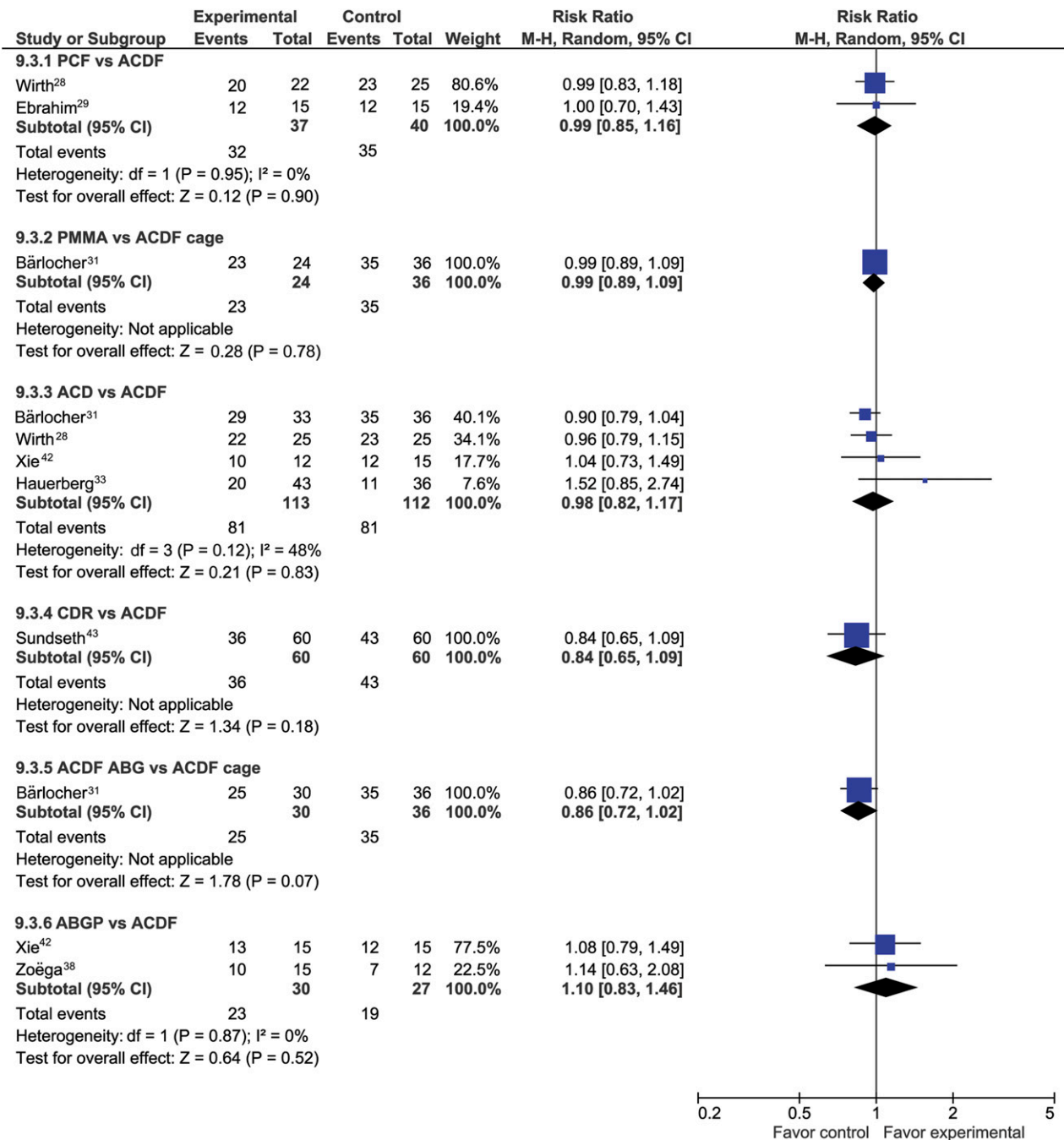
Fig. 5

Forest plots of postoperative work status. In each section, the first group listed is referred to as the experimental group. M-H = Mantel-Haenszel, CI = confidence interval, PCF = posterior cervical foraminotomy, ACDF = anterior cervical discectomy with fusion (when not further specified as with cage or autologous bone graft [ABG]), df = degrees of freedom, ACD = anterior cervical discectomy without intervertebral spacer, PMMA = ACD with polymethylmethacrylate as an intervertebral spacer, CDR = cervical disc replacement, ACDF ABG = ACDF with ABG, and ABGP = anterior cervical discectomy with ABG and additional plating. Ebrahim et al.[29] compared PCF with anterior cervical foraminotomy (ACF).

Meta-Analysis Outcomes

Success Rate

Thirteen studies (981 patients) investigated the effectiveness of ACDF compared with PCF[28-30], PMMA[31,32,40], ACD[28,31,33], ABG[31,32,35,36], ABGP[37,38], or a nonsurgical intervention[39], or ABGP was compared with a zero-profile cage[34], on the basis of the success rate. Meta-analyses could be conducted for 7 subgroup comparisons (Fig. 2). The only significant effect was observed in the comparison between ACDF and ACD, with a lower success rate in ACD (p = 0.02; RR = 0.87; 95% CI = 0.77 to 0.98).

TABLE III Neck Disability Index (NDI) Scores*

Study	Follow-up (mo)	Arms	Sample Size	NDI Score Preop.	NDI Score Postop.	P Value
Donk[41] † ‡	60	ACD	45	34.2 ± 12.8	16.6 ± 16.9	0.33
		CDR	50	37.1 ± 14.9	13.0 ± 17.1	
		ACDF	47	37.6 ± 14.7	13.9 ± 16.5	
Engquist[39] † §	24	PT	32	40.0	29.0	0.42
		ACDF	31	38.0	24.0	
Vleggeert-Lankamp[45] †	24	ACD	38	45.2 ± 15.6	19.0 ± 15	0.93
		ACDF	36	41.0 ± 13.2	19.0 ± 18	
		CDR	35	46.5 ± 17.2	20.0 ± 22	
Fernández-Fairen[37] †	24	ACDF	28	46.8 (38-56)	19.0 (10-34)	>0.10
		ABGP	33	48.9 (32-66)	20.9 (10-40)	
Sundseth[43] †	24	CDR	60	45.7 (43-48)	25.0 (20.1-29.9)	0.25, 0.049 favoring ACDF#
		ACDF	60	51.2 (48-54)	21.2 (16.7-25.6)	
Löfgren[36] †	24	ABG	40	44.0 (30-51)	25.0 (8-44)	0.8
		ACDF	40	36.0 (25-47)	30.0 (12-47)	

*ACD = anterior discectomy without fusion, CDR = cervical disc replacement, ACDF = anterior cervical discectomy with fusion, PT = physiotherapy, ABGP = ACDF with autologous bone graft (ABG) and additional plating, and ABG = ACDF with ABG. †NDI scores are given as the mean, with or without the standard deviation, and with or without the range in parentheses. ‡Donk gave NDI values on a scale from 0 to 50 points in the original article. The NDI in the table was converted to a scale of 100 points. Postoperative NDI values were calculated from the available online database but not reported in the manuscript. §Engquist did not report a preoperative NDI value; therefore, these values were estimated from a figure. The postoperative values were calculated by subtracting the postoperative reduction in score from the estimated preoperative value. #No significant difference was initially observed between subgroups (p = 0.25); however, when a linear mixed model was used, the outcome was in favor of the ACDF group (p = 0.049).

Complication Rate

Thirteen studies (1,168 patients) investigated the effectiveness of ACDF compared with PCF[28-30], PMMA[31,40], ACD[28,31,33,41,42], CDR[41,43], ABG[31,35,36], ABGP[37,42], or a nonsurgical intervention[39] on the basis of the complication rate. Meta-analyses could be conducted for 7 subgroup comparisons (Fig. 3).

The only significant effect was observed in the comparison between ACDF with ABG and ACDF with a cage, with a higher postoperative complication rate in the group with ABG from the iliac crest (p < 0.01; RR = 3.40; 95% CI = 1.56 to 7.43). This effect disappeared when donor-site complications were left out (p = 0.47; RR =1.30; 95% CI = 0.49 to 3.44).

Heterogeneity was observed in the ABGP versus ACDF subgroup comparison (p < 0.01, I^2 = 90%)[37,42]. Both studies were conducted in the same time period with a comparable follow-up period. Interstudy differences that could have contributed to the heterogeneity include the sample size of the subgroups (n = 61 versus n = 30), primary outcome measure (radiographic versus clinical), and type of spacer (ABG versus tantalum cage).

Reoperation Rate

Twelve studies (1,146 patients) investigated the effectiveness of ACDF compared with PCF[28-30], PMMA[31], ACD[28,31,33,41,42,45], CDR[41,43,45], ABG[31,36], ABGP[37,42], or a nonsurgical intervention[39] on the basis of the reoperation rate. No significant effects were

observed in the 7 subgroup comparisons. Heterogeneity was found in the subgroup comparing CDR and ACDF (p = 0.03, I^2 = 72%) (Fig. 4). The 3 included studies had an overall low risk of bias and were recently published[41,43,45]. The study by Donk et al. had a substantially longer follow-up than the other studies (60 versus 24 months)[41]. Two studies[41,45] were performed in the Netherlands, and 1[43] was performed in Norway. Furthermore, the Norwegian study described only index-level reoperations whereas the other studies included additional surgery for adjacent-segment disease as well. A subgroup analysis revealed that by omitting the study by Sundseth et al.[43], the heterogeneity disappeared (p = 0.42, I^2 = 0%).

Work Status

Seven studies (518 patients) investigated the effectiveness of ACDF compared with PCF[28,29], PMMA[31], ACD[28,31,33,42], CDR[43], ABG[31], or ABGP[38,42] on the basis of work status. No significant effects were observed for work status in the 6 subgroup comparisons (Fig. 5).

Disability

The NDI was reported in 6 of 21 studies[36,37,39,41,43,45]. It was not possible to conduct a reliable meta-analysis because of variations in reporting of outcome data. The only significant difference between interventions was found using a linear mixed model, favoring ACDF over CDR (p = 0.049) (Table III)[43].

TABLE IV Rating Scale Scores for Arm Pain*

Study	Follow-up (mo)	Arms	Sample Size	Arm Pain Preop.	Arm Pain Postop.	P Value
Engquist[39] † ‡	24	PT	32	4.7	2.6	0.81
		ACDF	31	4.2	2.5	
Donk[41] † §	60	ACD	47	NR	1.9 ± 2.4	>0.05
		CDR	49	NR	1.5 ± 2.5	
		ACDF	44	NR	2.0 ± 2.6	
Lind[35] † #	24	ABG	12	5.2 (0.5-9.3)	3.4	Significant in favor of ACDF
		ACDF	12	7.0 (2.3-8.9)	2.2	0.03
Nabhan[48] †	6	CDR	16	7.6 ± 1.4	1.4 ± 0.2	>0.05
		ACDFP	17	7.2 ± 1.7	1.7 ± 0.3	
Nemoto[34] †	24	ACDF (Zero-P)	24	6.4 ± 1.2	0.5 ± 0.5	0.342
		ACDFP	22	6.5 ± 1.1	0.3 ± 0.5	
Oktenoglu[46] †	12	ACD	11	8.2	3.3	NS
		ABGP	9	8.0	3.1	
Ruetten[30] †	24	PCF	89	8.4	0.8	NS
		ACDF	86	8.1	0.7	
Sundseth[43] †	24	CDR	60	6.0 (1-10)	2.0 (0-10)	0.06, 0.03 favoring ACDF**
		ACDF	60	6.5 (1-10)	1.5 (0-8)	
Vleggeert-Lankamp[45] †,††	24	ACD	38	6.4 ± 2.2	1.8 ± 2.5	0.880
		ACDF	36	5.7 ± 2.0	1.5 ± 2.3	
		CDR	35	6.0 ± 2.2	1.7 ± 3.0	
Hauerberg[33] ‡‡	24	ACDF	36	7 (2)	2 (4)	0.46
		ACD	43	6 (3)	3 (5)	
Löfgren[36] ‡‡	24	ABG	40	6.0	2.8	0.8
		ACDF	40	4.5	2.4	
Zoëga[38] ‡‡	24	ABG	12	6.3 (2.9-8.6)	6.0 (0-7.8)	0.58
		ABGP	15	4.0 (1-9.5)	4.5 (0-8)	
Bärlocher[31] §§	12	ACD	33		81.9%	<0.05 favoring ACDF vs. ACD
		ABG	30		86.7%	
		PMMA	24		87.5%	
		ACDF	36		97.3%	
Ebrahim[29] §§	24	ACF	15		93.3%	NR
		PCF	15		93.3%	
Orief[32] §§	6	PMMA	20		91.5%	NS
		ABG	22		90.8%	
		ACDF	18		91.6%	
Xie[42] §§	12	ACD	12		92.0%	0.36
		ABG	15		93.0%	
		ABGP	15		100.0%	

*PT = physiotherapy, ACDF = anterior cervical discectomy with fusion, ACD = anterior cervical discectomy without intervertebral spacer, NR = not reported, CDR = cervical disc replacement, ABG = ACDF with autologous bone graft, ACDFP = ACDF with additional plating, Zero-P = ACDF with zero-profile cage as intervertebral spacer, NS = not significant, ABGP = ACDF with autologous bone graft and additional plating, PCF = posterior cervical foraminotomy, PMMA = ACDF with polymethylmethacrylate as an intervertebral spacer, and ACF = anterior cervical foraminotomy. †Pain values are given as the mean, with or without the standard deviation, and with or without the range in parentheses. ‡Engquist calculated the VAS scores on a scale from 0 to 100 mm. These values were converted to a centimeter scale. §The postoperative scores are calculated from the available online database but were not reported in the original manuscript of Donk. #Lind did not report postoperative VAS arm scores, nor a standard deviation or range. Therefore, the postoperative VAS scores were estimated from a figure reporting the change in VAS score. **No significant difference was initially observed between subgroups (p = 0.06); however, when a linear mixed model was used, the outcome was in favor of the ACDF group (p = 0.03). ††Vleggeert-Lankamp calculated the VAS scores on a scale from 0 to 100 mm. These values were converted to a centimeter scale. ‡‡Pain values are given as the median, with or without the extent of the interquartile range or the interquartile range in parentheses. §§Pain values are given as the percentage of patients with improvement.

TABLE V Rating Scale Scores for Neck Pain*

Study	Follow-up (mo)	Arms	Sample Size	Neck Pain Preop.	Neck Pain Postop.	P Value
Engquist[39] †	24	PT	32	4.8	3.0	0.09
		ACDF	31	5.0	1.9	
Donk[41] † ‡	60	ACD	47	NR	2.0 ± 2.6	>0.05
		CDR	49	NR	1.5 ± 2.5	
		ACDF	44	NR	2.2 ± 2.7	
Lind[35] † §	24	ABG	12	5.9 (3.9-9.5)	NR	0.15
		ACDF	12	7.2 (3.3-9.8)	NR	
Nabhan[48] †	6	CDR	16	6.2 ± 1.2	2.8 ± 0.4	>0.05
		ACDFP	17	6.4 ± 0.9	2.0 ± 0.5	
Nemoto[34] †	24	ACDF (Zero-P)	24	4.3 ± 1.4	0.9 ± 0.8	0.43
		ACDFP	22	4.5 ± 1.3	1.1 ± 0.7	
Oktenoglu[46] †	12	ACD	11	3.2	2.8	NS
		ABGP	9	3.2	2.0	
Ruetten[30] †	24	PCF	89	1.7	1.6	NS
		ACDF	86	1.5	1.7	
Sundseth[43] †	24	CDR	60	7.0 (0-10)	3.0 (0-10)	0.64#
		ACDF	60	7.0 (1-10)	3.0 (0-10)	
Vleggeert-Lankamp[45] † **	24	ACD	38	5.7 ± 3.1	2.1 ± 2.3	0.93
		ACDF	36	5.3 ± 2.6	2.3 ± 2.7	
		CDR	35	5.0 ± 2.7	2.3 ± 3.2	
Hauerberg[33] ††	24	ACDF	36	7 (2)	4 (6)	0.48
		ACD	43	6 (3)	3 (6)	
Löfgren[36] ††	24	ABG	40	6.6	2.4	0.60
		ACDF	40	5.7	4.1	
Zoëga[38] ††	24	ABG	12	6.3 (4.4-9.1)	5.6 (0-8.2)	0.72
		ABGP	15	5.4 (3.1-8.8)	5.9 (1.7-8.8)	
Bärlocher[31] ‡‡	12	ACD	33		64.0%	NR
		ABG	30		50.0%	
		PMMA	24		62.5%	
		ACDF	36		72.3%	
Ebrahim[29] ‡‡	24	ACF	15		90.9%	NR§§
		PCF	15		90.0%	
Orief[32] ‡‡	6	PMMA	20		86.4%	NS
		ABG	22		90.4%	
		ACDF	18		89.5%	
Xie[42] ‡‡	12	ACD	12		83.0%	0.33
		ABG	15		80.0%	
		ABGP	15		73.0%	

*PT = physiotherapy, ACDF = anterior cervical discectomy with fusion, ACD = anterior cervical discectomy without intervertebral spacer, NR = not reported, CDR = cervical disc replacement, ABG = ACDF with autologous bone graft, ACDFP = ACDF with additional plating, Zero-P = ACDF with zero-profile cage as intervertebral spacer NS = not significant, ABGP = ACDF with autologous bone graft and additional plating, PCF = posterior cervical foraminotomy, PMMA = ACDF with polymethylmethacrylate as an intervertebral spacer, and ACF = anterior cervical foraminotomy. †Pain values are given as the mean, with or without the standard deviation, and with or without the range in parentheses. ‡The postoperative scores are calculated from the available online database but were not reported in the original manuscript of Donk. §Lind did not report postoperative VAS neck pain scores, nor a standard deviation or range. Therefore, the postoperative VAS score was estimated from a figure reporting the change in VAS score. #No significant difference was observed between subgroups, regardless of whether a linear mixed model was used (p = 0.44) or not (p = 0.64). **Vleggeert-Lankamp calculated the VAS scores on a scale from 0 to 100 mm. These values were converted to a centimeter scale. ††Pain values are given as the median, with or without the extent of the interquartile range, and with or without the range in parentheses. ‡‡Pain values are given as the percentage of patients with improvement. §§Ebrahim also reported neck pain scores at time of discharge from the hospital, in which they found a favorable result for ACF (p < 0.05).

TABLE VI Rating Scale Scores for General or Combined Pain*				Pain		
Study	Follow-up (mo)	Arms	Sample Size	Preop.	Postop.	P Value
Fernández-Fairen[37] †	24	ACDF	28	6.8 (5-8)	4.1 (2-7)	>0.1
		ABGP	33	6.8 (5-9)	4.7 (2-8)	
Li[44] † ‡	6	ACDF (Zero-P)	11	7.9	0.8	NS
		ACDFP	12	7.4	1.3	
Persson[47] †	12	ACDF	27	7.2 ± 2.1	4.2 ± 2.8	NS
		PT	27	7.0 ± 1.8	5.3 ± 2.9	
		Collar	27	6.8 ± 1.7	5.2 ± 2.2	

*ACDF = anterior cervical discectomy with fusion, ABGP = ACDF with autologous bone graft and additional plating, Zero-P = ACDF with zero-profile cage as intervertebral spacer, NS = not significant, ACDFP = ACDF with additional plating, and PT = physiotherapy. †Pain values are given as the mean, with or without the standard deviation, and with or without the range in parentheses. ‡Preoperative and postoperative values in the study by Li were estimated from figures.

Pain

A visual analog scale (VAS) or numeric rating scale was used in almost all (19 of 21) studies for arm or neck pain, or for a general pain score[29-39,41-48]. However, the means of reporting the outcome varied considerably. Therefore, it was not possible to conduct a meta-analysis. Sixteen studies reported rating scales for arm pain and for neck pain[29-36,38,39,41-43,45,46,48] and 3 studies reported a general or combined pain score (Tables IV, V, and VI)[37,44,47]. A significant difference was observed in 3 studies, all involving the improvement in arm pain; 1 study showed results in favor of ACDF with a cage over ACDF with ABG (p = 0.03)[35]; 1, in favor of ACD over ACDF with a cage (p < 0.05)[31]; and 1, in favor of ACDF over CDR (p = 0.03)[43].

Publication Bias

Funnel plots could be constructed for success, complication, and reoperation rates (see Appendix). Visual inspection did not indicate that publication bias was likely.

Discussion

This systematic review and meta-analysis was conducted to investigate the effectiveness of surgical interventions for cervical radiculopathy without myelopathy. We included 21 RCTs that evaluated a variety of surgical interventions. Overall, our results suggest that none of the interventions is superior.

ABG

We observed a higher complication rate (p < 0.01; RR = 3.40; 95% CI = 1.56 to 7.43) in the ACDF with ABG subgroup, most likely related to donor-site morbidity. This is consistent with earlier reports[5,24,49-51]. Because of the additional complications together with longer operative time and recovery time, other intervertebral spacers should be recommended.

ACD

In this meta-analysis, we found a lower success rate after ACD compared with ACDF (p = 0.02; RR = 0.87; 95% CI = 0.77 to 0.98). The studies comparing ACD with ACDF that did not use success rate as an outcome[41,42,45] reported no significant differences regarding improvement in arm pain, neck pain, and NDI scores. In reviews comparing ACD with ACDF in general cervical degenerative disorders, there is conflicting evidence[52,53].

CDR

Unfortunately, no success rates were reported in the included RCTs that compared ACDF with CDR. The primary outcome measure (NDI) for these trials demonstrated no significant differences between the treatment arms. One study reported a significant difference (p = 0.049) in favor of ACDF after performing a linear mixed-model analysis that corrected for baseline differences, drop-outs, and missing data. There was no significant difference in complication rates between CDR and ACDF (p = 0.21). There was conflicting evidence for reoperation rates. In meta-analyses regarding CDR and ACDF in general cervical degenerative disorders, comparable or more favorable results have been reported for CDR[8,10,11,14,16,18,20,22,50].

PMMA

No significant difference was found in any outcome parameter. Although PMMA is known to yield lower fusion rates compared with ACDF with a cage or bone graft[54-56], we did not identify any differences in clinical outcome parameters. The included studies had a relatively short follow-up period (6, 12, and 24 months), so we cannot draw conclusions about the longer-term results of PMMA[31,32,40].

PCF

There were no significant differences in success, complication, and reoperation rates between PCF and anterior approaches for cervical radiculopathy. Reoperation rates are believed to be higher in PCF, although this meta-analysis as well as previous literature did not reveal any significant difference[23,24,57]. One study demonstrated higher neck pain scores at the time of discharge[29]. Although that study comprised only 30 patients,

this is a finding that confirms our clinical experience and has also been reported in the literature[58]. However, there were no significant differences in reported neck pain, NDI, or work status at the time of follow-up. Therefore, given the potential benefits of PCF, it is questionable whether the amount of neck pain in the short term, directly postoperatively, should be decisive in favoring an anterior approach for patients with pure cervical radiculopathy[59].

Quality of Included Studies

The 21 included RCTs varied substantially in sample size, and it is likely that some studies were underpowered to detect a difference between interventions. The studies also varied substantially in risk of bias. However, because of the similarity of outcomes among the studies in this review, it is unlikely that the inclusion of studies with a high risk of bias has introduced systematic bias in the overall conclusions in this review.

Strengths and Limitations

This meta-analysis was reported according to the PRISMA statement and was performed according to current standards[26]. We categorized the included RCTs into several subgroups, which made the results easier to interpret. This subgroup division can also serve as a limitation, since some control groups were used twice for different comparisons, making it impossible to calculate an overall pooled estimated effect.

Furthermore, although all RCTs included patients with pure cervical radiculopathy, the localization of the degenerative disease (e.g., central, paracentral, foraminal) was not stated in most of the included studies. This is an important factor in the decision-making process for surgeons, as some of the surgical techniques have specific contraindications. For instance, PCF is less suitable for a paracentral disc herniation with compression of the spinal cord and CDR is less suitable in patients with circumscribed narrowing of the spinal canal. Therefore, patient-specific contraindications for some techniques should always be taken into account when interpreting the results of this study.

Clinical Implications

For years, there has been controversy regarding the best surgical treatment for cervical radiculopathy. Besides the clinical outcome and safety of the procedure, there are multiple factors that contribute to the choice of procedure. Many aspects such as duration of the procedure or hospital stay, costs of intervertebral spacers, and radiographic outcome have been discussed in the literature. Furthermore, subjective factors, such as experience and comfort with a certain technique, also often contribute to the choice of procedure[60-62]. This meta-analysis demonstrated that on the grounds of clinical outcome and safety, there is no superior surgical intervention for pure cervical radiculopathy. Therefore, future research should elaborate on the other factors in order to elucidate the preferred surgical treatment. To begin with, more studies should focus on the cost-effectiveness of the procedures. Two RCTs[63,64] comparing economic outcomes of ACDF and PCF are already being conducted, but for other comparisons such as CDR versus ACDF, there are no RCTs that focus on patients with pure cervical radiculopathy, to our knowledge.

Conclusions

This meta-analysis demonstrated consistent results regarding clinical outcomes among all of the studied interventions for pure cervical radiculopathy. Complication and reoperation rates were also similar, with the exception of higher complication rates in patients in whom ABG was used. Based on clinical outcome and safety, there is no superior surgical intervention for pure cervical radiculopathy.

Appendix

(eA) Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/G81). ∎

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