



Cost-effectiveness of anterior surgical decompression surgery for cervical degenerative disk disease: a systematic review of economic evaluations

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Abstract

Purpose No clear consensus exists on which anterior surgical technique is most cost-effective for treating cervical degenerative disk disease (CDDD). One of the most common treatment options is anterior cervical discectomy with fusion (ACDF). Anterior cervical discectomy with arthroplasty (ACDA) was developed in an effort to reduce the incidence of clinical adjacent segment pathology and associated additional surgeries by preserving motion. This systematic review aims to evaluate the evidence regarding the cost-effectiveness of anterior surgical decompression techniques used to treat radiculopathy and/or myelopathy caused by CDDD.

Methods The search was conducted in PubMed, EMBASE, Web of Science, CINAHL, EconLit, NHS-EED and the Cochrane Library. Studies were included if healthcare costs and utility or effectivity measurements were mentioned.

Results A total of 23 studies were included out of the 1327 identified studies. In 9 of the 13 studies directly comparing ACDA and ACDF, ACDA was the most cost-effective technique, with an incremental cost effectiveness ratio ranging from \$2.900/QALY to \$98.475/QALY. There was great heterogeneity between the costs of due to different in- and exclusion criteria of costs and charges, cost perspective, baseline characteristics, and calculation methods. The methodological quality of the included studies was moderate.

Conclusion The majority of studies report ACDA to be a more cost-effective technique in comparison with ACDF. The lack of uniform literature impedes any solid conclusions to be drawn. There is a need for high-quality cost-effectiveness research and uniformity in the conduct, design and reporting of economic evaluations concerning the treatment of CDDD.

Trial registration PROSPERO Registration: CRD42020207553 (04.10.2020).

Keyword Cervical degenerative disk disease · Anterior decompressive surgery · Cost-effectiveness · Cost-utility · Economic evaluations

Abbreviations

ACD	Anterior cervical discectomy	ACDF	Anterior cervical discectomy and fusion
ACDA	Anterior cervical discectomy with arthroplasty	CASP	Clinical adjacent segment pathology
		CCEMG	Campbell and Cochrane Economics Methods Group
		CDDD	Cervical degenerative disc disease

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CEA	Cost-effectivity analysis
CHEC	Consensus health economic criteria
CPT	Current procedural terminology codes
CUA	Cost-utility analysis
DRG	Diagnosis related group codes
EPPI-Centre	Evidence for Policy and Practice Information and Coordinating Centre
EQ-5D-5L	EuroQol-five dimensions
ICER	Incremental cost effectiveness ratio
QALYs	Quality-adjusted life years
MNPa	Medicare national payment amounts
PROMs	Patient reported outcome measures
RCTs	Randomized controlled trials
SF—36/12/6	Short Form Health Survey
USD	United States Dollars
WTP	Willingness to pay

Introduction

No consensus exists on which anterior surgical technique is more cost-effective to treat cervical degenerative disk disease (CDDD) resulting in cervical degenerative radiculopathy and/or myelopathy.

The incidence of degenerative pathologies is significantly increasing as the population ages [1, 2]. Generalized spinal disk degeneration occurs in more than 90% of adults past the 5th decade of life [3]. This age group now represents 32.8% of the population in Europe and is projected to reach 40.6% by 2050 [2]. Complaints of radiculopathy and/or myelopathy differ in severity, but are often disabling. This leads to restrictions in daily life and loss of professional capability with absenteeism as a result, leading to an increase in societal costs. Healthcare costs are driven up further when patients require surgical treatment, in combination with associated hospitalization and rehabilitation.

One of the most common procedures for treating patients with radiculopathy and/or myelopathy as a consequence of single- or multilevel CDDD is anterior cervical discectomy with fusion (ACDF) or without (ACD) [4]. A recent study by Neifert et al. predicts a significant increase in ACDF-procedures in those aged 45–54 in the next 20 years which involves the working population [5–7]. Both techniques show good short-term clinical results [8]. However, patient-reported satisfaction gradually drops to 68–96% after 7–20 years [9, 10]. This is thought to be the consequence of the development of new complaints of radiculopathy and/or myelopathy at a segment adjacent to the site of previous surgery, also known as clinical adjacent segment pathology (CASP) [11]. The underlying mechanism is thought to be compensation for the loss of motion in the fused segment, resulting in overstraining of the adjacent segments in addition to progression of natural degeneration [12–14]. This

occurs at an estimated cumulative rate of 1.6 to 4.2% per year after fusion surgery. Patients with CASP often require additional surgery, which drives up health-care costs even further [11, 15, 16].

Anterior cervical discectomy with arthroplasty (ACDA) was developed in an effort to reduce the incidence of CASP by preserving motion in the operated segment(s). Previously conducted research has shown that no significant differences in clinical or radiological outcomes among these different techniques [12, 17, 18]. Multiple trials with long-term follow-up report significantly lower additional surgery rates for ACDA in comparison with ACDF, both for single- and multilevel surgeries [19–23]. Proper interpretation remains difficult however, as reported additional surgery rates vary strongly, from 0 to 11.6% for ACDA, and 0 to 18.2% for ACDF in 2–7 years follow-up [24–26].

Presently, ACDA is often discouraged as the implant costs are higher than those for ACDF while the clinical outcomes are similar. However, preventing additional surgeries due to CASP and new complaints might be a reason for ACDA to be a more cost-effective technique in the long run.

There are high quality systematic reviews available concerning the clinical effectiveness of these different anterior decompression surgeries for CDDD [27, 28]. To date, only one systematic review, dating from 2014, and one narrative review have been conducted concerning the cost-effectiveness of these techniques. Conclusive evidence is therefore still lacking [29, 30]. This systematic review aims to evaluate the current evidence on cost-effectiveness of anterior cervical decompressive surgeries in patients with CDDD resulting in radiculopathy and/or myelopathy. The methodological quality of the included studies will be determined to be able to draw conclusions concerning the level of evidence.

Materials and methods

Review protocol

This systematic review was executed in accordance with the PRISMA statement [31, 32] and the five-step approach on preparing a systematic review of economic evaluations by Van Mastrigt et al. [33–35]. The study protocol has been published in the PROSPERO-database before commencing the study (registration number CRD42020207553).

Search strategy and eligibility criteria

Searches for clinical and economic studies were systematically carried out in PubMed, EMBASE (OVID), Web of Science (Clarivate Analytics), CINAHL (EBSCO), Econlit (EBSCO), NHS EED (CRD) and the Cochrane Library (CENTRAL) and Cochrane database of Systematic

Reviews. The search was conducted without using filters. The final search was conducted on September 16th, 2020 (Appendix File 1).

Studies were included if they met all of the following eligibility criteria: (1) CDDD resulting in radiculopathy and/or myelopathy, (2) anterior decompressive surgery (3) cost sources, health care and societal perspective costs, total costs (health care perspective costs plus societal perspective costs), costs per quality-adjusted life years (QALY) (4) utility measurement tool, gained quality-adjusted life years.

Study selection and data collection

Duplicates were removed, potential studies were screened on title and abstract, and full texts were assessed by two independent researchers (*VS*, *XOZ*) using all eligibility criteria. This assessment was done in “Rayyan” [36]. If necessary, consensus was reached between both authors through discussion.

Randomized controlled trials (RCTs), prospective comparative studies concerning cost-effectiveness and both full and partial economic evaluations were included. Cost-utility analyses (CUA) and cost-effectiveness analyses (CEA) were also included if they had a retrospective study design.

The following data were extracted from the included articles; study design, year of publication, country, baseline characteristics of patients, diagnosis, type of interventions, primary and secondary outcome measures as described above. The complete data collection sheet can be found in Appendix File 2. Cost-effectiveness of two interventions can be compared using the incremental cost-effectiveness ratio (ICER), where the difference in costs between two interventions will be divided by the difference in their effect [37].

Quality assessment

The methodological quality of the economic evaluations was assessed by two independent reviewers (*VS*, *OZ*) with the checklist of Consensus on Health Economic Criteria (CHEC) by Evers et al. [38]. The CHEC-list consists of 19 categories, including performed discounting and sensitivity analysis, where a single point can be assigned to each category with a maximum score of 19 points. A CHEC-list score between 15 and 17 points is rated as average methodological quality [38]. Risk of bias was assessed by two independent reviewers (*VS*, *SM*). RCTs were assessed with the Cochrane Risk of Bias tool in Review Manager 5.3 [39]. Non-randomized controlled trials were assessed with the Risk of Bias in Non-Randomized Studies of Interventions

(ROBINS-I) tool [40]. Full risk of bias assessment sheets and CHEC list scores are outlined in Appendix File 3 and Appendix File 4.

Analysis

All costs were converted to American Dollars to the reference year 2020 with the use of a web-based tool, developed by the Campbell and Cochrane Economics Methods Group (CCEMG) and the Evidence for Policy and Practice Information and Coordinating Centre (EPPI-Centre) (v.1.6) [41]. If the index year was not mentioned in the study, subsequently the last year of patient inclusion or the year of publication was used as index year. Heterogeneity was assessed with the Chi-squared test in Review Manager 5.3 [42]. Descriptive statistics were used and reported in a narrative summary according to the Cochrane handbook [39]. Sensitivity analyses of the different study designs were checked for consistency of results.

Results

Study selection

The systematic search in the databases yielded 1948 articles, 1327 of which remained after removal of duplicates. Of the 28 studies eligible for inclusion, 6 studies were based on data of overlapping patient cohorts. Of these, the most recent studies with the largest patient cohort and the longest follow-up time were included. One study was included through cross-referencing [43], resulting in a total of 23 studies [44–65]. A flowchart of the selection process is presented in Fig. 1.

Study characteristics

Characteristics and results of the included studies are displayed in Table 1. Chi-squared was larger than 99%, indicating a very high heterogeneity between studies, and a meta-analysis was therefore not performed. Publication years ranged from 2005 [52] to 2019 [45]. Follow-up time ranged from 1 [48, 49, 58] to 10 years post-operative [55]. Probabilistic models simulated 5 years [45, 56] to life-long follow-up [51]. Twenty studies were performed in the United States of America, one in Canada [50], one in Korea [45] and one in Spain [53]. Three prospective economic evaluations [48, 58, 66] were included; all others were retrospective CEAs or CUAs. In a total of 5 studies, a Markov Analysis was performed [44, 45, 47, 51, 56].

Thirteen studies compared ACDA and ACDF directly [43–47, 56, 60–65, 67, 68] and four studies compared

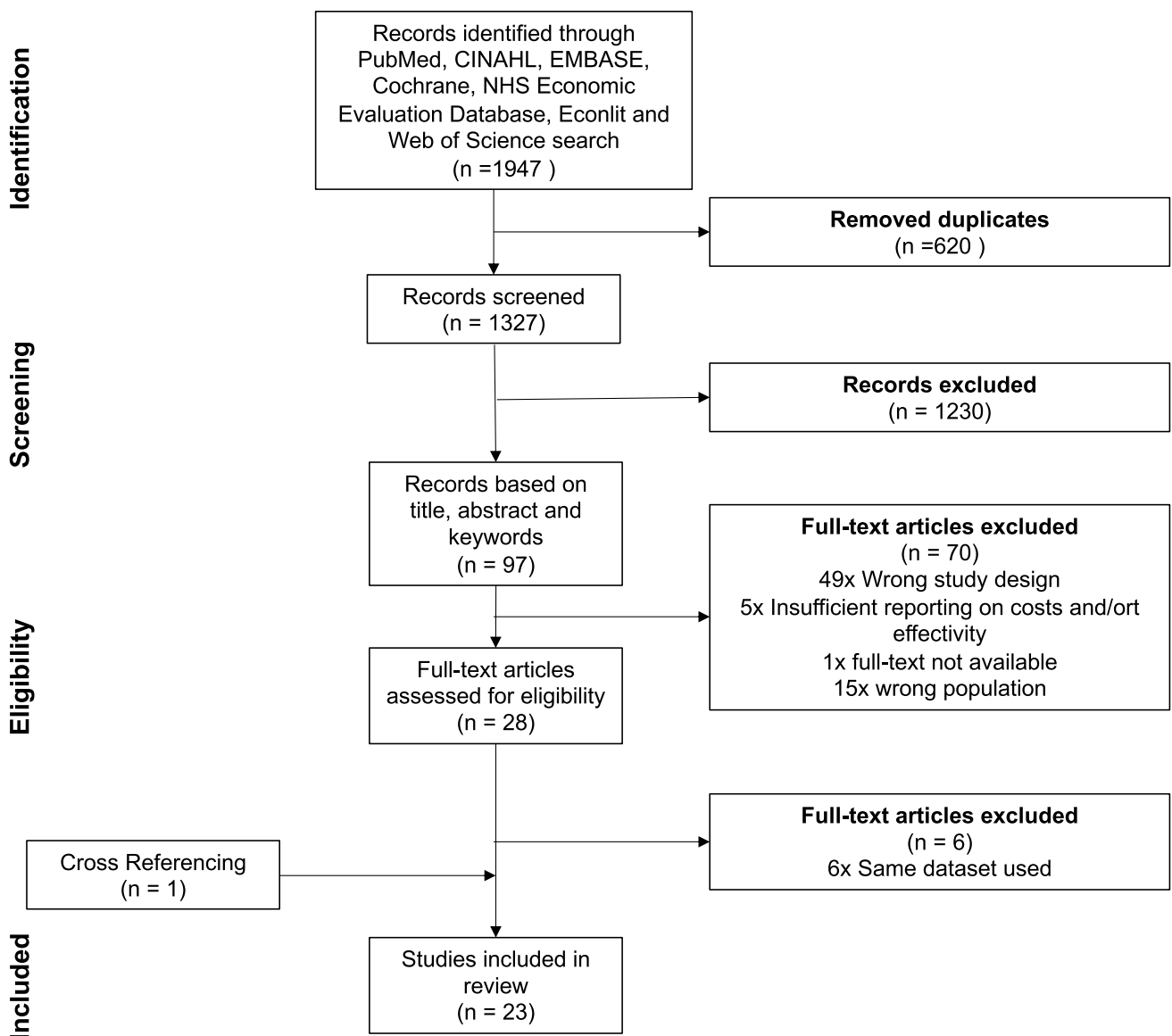


Fig. 1 The PRISMA flowchart of the inclusion process

ACDF with posterior decompressive techniques [48, 49, 58, 66]. The six remaining studies described costs without (surgical) cohort [51, 54, 57] or compared auto- and allograft techniques for ACDF, but costs are represented separately [Table 1] [52, 53, 55]. There was a large variety in the evaluated study populations, as some studies only included patients with radiculopathy [46, 47, 49, 51, 53] or myelopathy [48, 66], and other studies specifically evaluated single-level surgeries [46, 49, 54, 55, 59, 63, 69, 70] in contrast to those that only assessed multi-level surgeries [43, 48, 56, 61, 64].

Cost-effectiveness was expressed in ICER in 14 of the included studies [44, 45, 51–53, 56, 59–65]. Fifteen studies determined QALYs based on derivatives of the

Short-Form (SF) questionnaires, of which 8 studies used the SF-6D [66], or converted the SF-12 [44, 46, 64] or SF-36 [52–54, 56, 59–61, 69, 70] to the SF-6D to determine a cumulative or yearly QALY gain. Three studies used EuroQol-five Dimensions (EQ-5D-5L) to determine QALYs [49, 57]. One study expressed clinical effectiveness in value of work productivity and net economic benefit [43]. All studies reported healthcare costs, seven of which also reported costs from a societal perspective [47, 49, 54, 57, 64, 71]. Costs were calculated based on costs, charges or a combination of both. Charges were based on Medicare National Payment amounts (MNPAs) by Current Procedural Terminology codes (CPT) and Diagnosis Related Group codes (DRG) in eighteen studies [44, 47–49, 51,

Table 1 Results of included studies

Author (year)	Country	Study design	Study time span (years)	Study population	Utility measurement tool	Cost resources		Charges	Yearly QALY gain/ Dollars)	Total costs (2020 US Dollars)	Yearly QALY gain Dollars)	Total costs (2020 US Dollars)	ICER (2020 US Dollars /QALY)	Sensitivity analysis
						Health care perspective	Societal perspective							
Ament et al. (2016)	USA	rCUA	5–8	CDR/CDM 2-level	SF-12	Procedure hospitalization adverse events	Loss of productivity	MNPa, CPT, DRG	0.68	125.66	0.71	89.498	– 182.637 (SP) 9.423 (HCP)	Yes
Bhadra et al. (2009)	UK	rCEA	5	CDR 1-level	SF-12	Procedure hospitalization outpatient visits	–	Department of health, UK, cost manual 2005	–	3,688 + 816 (+plate)	–	4.653	–	No
Ghori et al. (2016)	USA	rCEA (Markov)	–	CDR	Re-operations	Procedure hospitalization pharmaceuticals outpatient visits re-operations	Loss of productivity rehabilitation	MNPa, CPT, DRG	–	35.758	–	27.663	11.556	Yes
Hyongsang-Lee et al. (2019)	Korea	rCBA (Markov)	5	CDR/CMD	Re-operation, utility measurement (?)	Procedure hospitalization operations physician fees	–	–	0.74	3.586	0.83	4.192	2.9	No
Kim et al. (2018)	USA	rCEA (Markov)	7	CDR/CMD	SF-6D (SF-12)	Procedure hospitalization physician fees	–	MNPa, CPT, DRG	0.22	110.415	0.24	112.235	10.075	Yes
McAnany et al. (2018)	USA	rCEA	7	CDR/CMD 1-level	SF-6D (SF-36)	Procedure hospitalization physician fees	–	MNPa, CPT, DRG	0.55	171.497	0.65	205.431	51.936	Yes
McAnany et al. (2014)	USA	rCEA	5	CDR/CMD	SF-6D (SF-36)	Procedure hospitalization physician fees re-operation	–	MNPa, CPT, DRG	0.56	142.976	0.57	122.045	– 665.957	Yes
Menzin et al. (2010)	USA	rCEA	2	CDR/CMD	Value of work productivity	Implants Procedures hospitalization physician fees radiography	Postoperative wages loss of productivity	MNPa, CPT, DRG	–	14.761	–	14.226	NET = 8.653	No

Table 1 (continued)

Author (Year)	Country	Study design	Study time span (years)	Study population	Utility measurement tool	Cost resources		Charges	Yearly QALY gain/ACDF	Total costs (2020 US Dollars)	Yearly QALY gain ACDA	Total costs (2020 US Dollars)	ICER (2020 US Dollars /QALY)	Sensitivity analysis
						Health care perspective	Societal perspective							
Merill et al. (2018)	USA	rCUA	7	CDR/CMD 2-level	SF-6D (SF-36)	Direct costs	–	MNPa, CPT, DRG	0.69	175,192	0.72	195,415	98,475	Yes
Overley et al. (2018)	USA	rCEA (Markov)	5	CDR/CMD 2-level	SF-6D (SF-36)	Procedure hospitalization	–	MNPa, CPT, DRG	0.65	129,112	0.69	144,267	68,957	Yes
Qureshi et al. (2013)	USA	rCEA	20	CDR/CMD 1-level	SF-36	Hospitalization physician fees	–	ICD-9,NIS, MNPa, CPT, SRG	0.10	20,075	0.17	14,304	– 3,857	Yes
Radcliff et al. (2016)	USA	rCEA	7	CDR/CMD 1-level	SF-36	Physician fees health plans	–	MNPa, CPT	0.64	46,998	0.62	32,851	20,679	Yes
Warren et al. (2013)	USA	rCUA	2	CDR/CDM 1-level	SF-36	Procedure hospitalization physician fees	–	MNPa, CPT, DRG	0.47	22,329	0.32	20,784	10,302	Yes
Alvin et al. (2016)	USA	rCEA	1	CDR 1-level	EQ-5D-5L	Procedure hospitalization pharmaceuticals outpatient visits	Loss of productivity re-habilitation missed income	MNPa, CPT, DRG	0.13	17,335	Posterior	21,186	ICER (ACDF-posterior) 59,748	No
Whitmore et al. (2012) <i>Adjusted cost-to-charge ratio</i>	USA	pCEA	1	CDM multi-level	SF-36, EQ-5D-5L	Procedure hospitalization diagnostics	–	MNPa, CPT, DRG, ICD-9	0.61	25,732	0.63	33,343	– 41,208	No
Ghogwala et al. (2011)	USA	pCUA	1	CDM multi-level	SF-36, EQ-5D-5L	Hospital charge data	–	MNPa, CPT, DRG, ICD-9	0.16	23,233	0.13	35,571	411,267	No
Witw et al. (2016)	Canada	pCEA	2	CDM	SF-6D	Procedure hospitalization physician fees re-operations	–	On individual level from the micro-cost values provided by the hospital finance department	–	24,279	–	13,818	10,396	Yes

Table 1 (continued)

Author (Year)	Country	Study design	Study time span (years)	Study population	Utility measurement tool	Cost resources	Charges	Yearly QALY gain/ACDF	Total costs (2020 US Dollars)	Yearly QALY gain/ACDA	Total costs (2020 US Dollars)	ICER (2020 US Dollars/QALY)	Sensitivity analysis
						Health care perspective Societal perspective							
Angevine et al. (2005)	USA	rCEA	5	CDR/CDM	SF-36	Procedure hospitalization physician	MNPa, CPT, DRG	0.87	16,496	0.90	1,659	47,828	Yes
Fernandez-Farren et al. (2012)	Spain	rCEA	5	CDR	SF-6D (SF-36)	Rehabilitation additional treatments	Instituto de Cirugía Ortopédica y Traumatología de Barcelona	1.40	16,795	1.8	11,262	-4,033	No
Virk et al. (2014)	USA	rCEA	10	CDR/CDM 1-level	Beaver Dam health outcome studies, quality of wellbeing	Hospitalization physician fees graft fees	MNPa, CPT	0.63	17.44	0.63 0.63 (PEEK)	16,987 23,308 (PEEK)	-	Yes
Carreon et al. (2013)	USA	rCEA	5	CDR/CDM 1-level	SF-6D (SF-36)	Procedure hospitalization physician fees	2012 Medicare Fee schedule	0.18	18,752	-	No comparative (surgical) group	-	Yes
Chotai et al. (2017)* <i>Range is displayed (younger vs older population)</i>	USA	rCEA	2	CDR/CDM <4-levels	EQ-5D-5L	Hospitalization procedure physician fees pharmaceuticals	Absenteeism costs of caregivers	0.14–0.28	23,276–25,076	-	-	-	No
Rihn et al. (2019)	USA	rCEA (Markov)	Lifetime (until 99 y.o.)	CDR	Spinal cord injury questionnaire (Dijkers 2005)	Physician fees outpatient visits	MNPa	-	17,610 (1-level) 18,086 (2-level)	-	-	-	Yes

NET Net Economic Benefit, QALY Quality Adjusted Life Years, rCEA retrospective Cost-Effectiveness Analysis, pCEA prospective Cost-Effectiveness Analysis, rCUA retrospective Cost-Utility Analysis, pCUA prospective Cost-Utility Analysis, CBA Cost-Benefit Analysis, CDR Cervical Degenerative Radiculopathy, CDM Cervical Degenerative Myelopathy, SF-6D Short Form-six Dimensions, SF-12 Short Form-2 Dimensions, SF-36 Short Form-36 Dimensions, SF-6D (SF-36) SF-36 converted to SD-6D, SF-6D (SF-12) SF-12 converted to SD-6D, EQ-5D-5L EuroQol—five Dimensions, SP Societal Perspective, HCP Health Care Perspective, MNPa Medicare National Payment amounts, MIS Nationwide Inpatient Sample, CPT codes Current Procedural Terminology codes, DRG codes Diagnosis Related Group codes

For comparison, all costs were converted to American Dollars with reference year 2020

52, 54–65] for hospitalization, procedure and physicians. Reported costs varied from physician and procedural costs only, to all resource costs associated with an intervention, including costs for caregiver time or absenteeism.

Study results

In 9 of the 13 studies directly comparing ACDA and ACDF, ACDA was the most cost-effective technique [43–45, 47, 56, 59, 61, 65, 69]. The ICER of ACDA over ACDF ranged from \$2.900/QALY [45] to \$98.475/QALY [61], three of which passed \$50.000/QALY, which is commonly regarded as the willingness to pay threshold (WTP). All studies showed comparable QALY-gain with minimal differences. Figure 2 displays the total costs and total QALY gain for ACDA and ACDF. Figure 3 illustrates an ICER plane of 10 of the 13 studies comparing ACDF directly to ACDA, the other three are not depicted as there was no QALY-gain reported [46, 47].

The QALY-gain or cumulative QALYs were mentioned in seventeen studies [44, 45, 48, 49, 52, 54–65]. The yearly QALY-gain ranged from 0.10 [63] to 0.87 [52] for ACDF and from 0.17 [63] to 0.83 [45] for ACDA. Costs for subgroups such as radiculopathy and myelopathy or single- and multilevel surgery could not be compared due to the heterogeneity in reporting costs. Cost ranges are mentioned instead of means due to the large heterogeneity in calculation and reporting of costs between studies. Healthcare costs from the healthcare perspective ranged from \$3.586 [45] to \$175.192 [61] for ACDF and from \$4.192 [45] to \$205.431 [59] for ACDA. When including societal costs, costs ranged from \$35.758 [47] to \$125.660 [64] for ACDF and from \$14.226 [43] to \$89.498 [64] for ACDA.

Quality of identified studies

The methodological quality of each economic evaluation was critically assessed according to the CHEC-criteria, which can be found in Appendix File 3. CHEC scores ranged from 8 to 18, with a mean score of 14.2. This indicates an overall moderate methodological quality.

The risk of bias assessment can be found in Appendix File 4. Based on the criteria for randomized studies overall risk of bias was high. According to the ROBINS-I tool, the overall quality of non-randomized studies was moderate.

Discussion

The objective of this systematic review was to evaluate the current evidence on cost-effectiveness of anterior cervical decompressive surgeries in patients with CDDD resulting in radiculopathy and/or myelopathy. The most important

conclusion to be drawn from this review is the lack of literature on the subject and, more importantly, the large heterogeneity between studies in determining both costs and effectiveness. Solid conclusions can thus not be drawn regarding the most cost-effective technique to treat CDDD. Figure 2 reflects the large variety in results of the included study. These methodological challenges draw attention to the need for high quality cost-effectiveness research, and uniformity in methodology and reporting.

Radcliff et al. described similar heterogeneity in a recent publication about economics of cervical disk replacement [72]. There was large heterogeneity in health care and societal perspective costs due to differences in calculation methods of costs and/or charges, included costs, different in- and exclusion criteria and baseline characteristics. It is noteworthy to mention that the lowest costs are reported in studies conducted outside of the United States of America (United Kingdom, Spain and Korea). This is not surprising considering the prominent difference in healthcare systems.

The Panel on Cost-Effectiveness in Health and Medicine in the United States recommends performing cost-effectiveness studies from the societal perspective [73]. Nevertheless, only 6 out of 23 studies included in this review have reported on societal perspective costs. The variety in the calculation of costs and charges was reliant on the inclusion of costs such as hospitalization, physician fees, procedural costs, pharmaceuticals, rehabilitation, caregivers and work absenteeism. Furthermore, it should be noted that some studies evaluated patients with radiculopathy or myelopathy alone, and other studies included all CDDD patients. There was also an important difference in the inclusion of single-level or multi-level surgeries. Another important factor is the large variation in study follow-up time. This may have a significant impact on cost-effectiveness as both the costs and clinical effectivity might be influenced by the occurrence of CASP and possible additional surgery rates [11, 16].

The clinical effectivity of the surgical interventions was determined based on different utility measurement tools. Most studies used derivatives of the SF-questionnaires and converted these to SF-6D, however these converted questionnaires cannot equally be compared to their originals [74]. The reported effectiveness of the evaluated interventions was comparable in all studies and the difference in QALY-gain can be interpreted as not clinically significant. This is in line with previous literature that shows no clinical difference between ACDA and ACDF [17, 18].

The theory that ACDA may be the superior surgical intervention for symptomatic CDDD has been the topic of discussion for multiple years. ACDA was developed in an effort to maintain motion and thereby prevent overstraining of the adjacent segments and consequent CASP. In spite of higher implant costs, ACDA might be a more cost-effective technique on the long term as CASP

and additional surgeries with associated costs could be avoided. Due to the variances in reported data on costs and clinical effectivity, stated cost-effectiveness cannot equally be compared. However, there seems to be a trend of higher cost-effectiveness in ACDA in comparison with ACDF. The WTP is dependent on the burden of disease and varies strongly per country. In this study, WTP was only mentioned in US-orientated studies, of which 12 upheld a WTP of \$50.000/QALY and 2 upheld a WTP \$100.000/QALY. Three out of the 9 studies in favor of ACDA reported an ICER that passed the threshold of a WTP of \$50.000/QALY, 2 out of the 3 studies in favor of ACDF passed this threshold. It can be stated that both techniques are expensive, which gives rise to the question of which technique is most cost-effective.

Besides determining the most cost-effective technique, it is important to improve cost-effectiveness, either by reducing costs or by improving clinical effectivity. Patient profiling may play a significant role. More research is needed to investigate which baseline characteristics predict better patient-reported outcome measures (PROMs) post-operatively, which could influence surgical decision-making. Moreover, it is strongly recommended that future cost-effectiveness analyses should be prospective and conducted uniformly. It would be profitable to have guidelines for the conduct of economic evaluations in

spine surgery to create uniformity in methodology and reporting, as has recently been published for osteoporosis research [75].

In contrast to the limited number of narrative reviews concerning economics of cervical spine surgery, we provide a detailed and systematic overview of relevant literature. The strength of this systematic review is its methodological quality, as it was executed in accordance with the proposed PRISMA statement [31, 32] and the five-step approach on preparing a systematic review of economic evaluations by Van Mastrigt et al. [33–35]. The main limitation that may have biased the result of this study was the inclusion of only full text and published studies but not conference proceedings, PhD dissertations or gray literature. Three studies were manufacturer-sponsored or had a possible financial benefit [53, 64, 69] and two studies did not provide information on funding [46, 55]. Another limitation is that we did not differentiate between the costs of different manufacturers for disk prostheses. We expect limited influence on our results, in contrast to an increase in heterogeneity of our data.

Results from this systematic review were mostly extracted from data from North-America and thus may not be relevant for other continents. Data from other continents, or even countries, is essential as costs between countries vary.

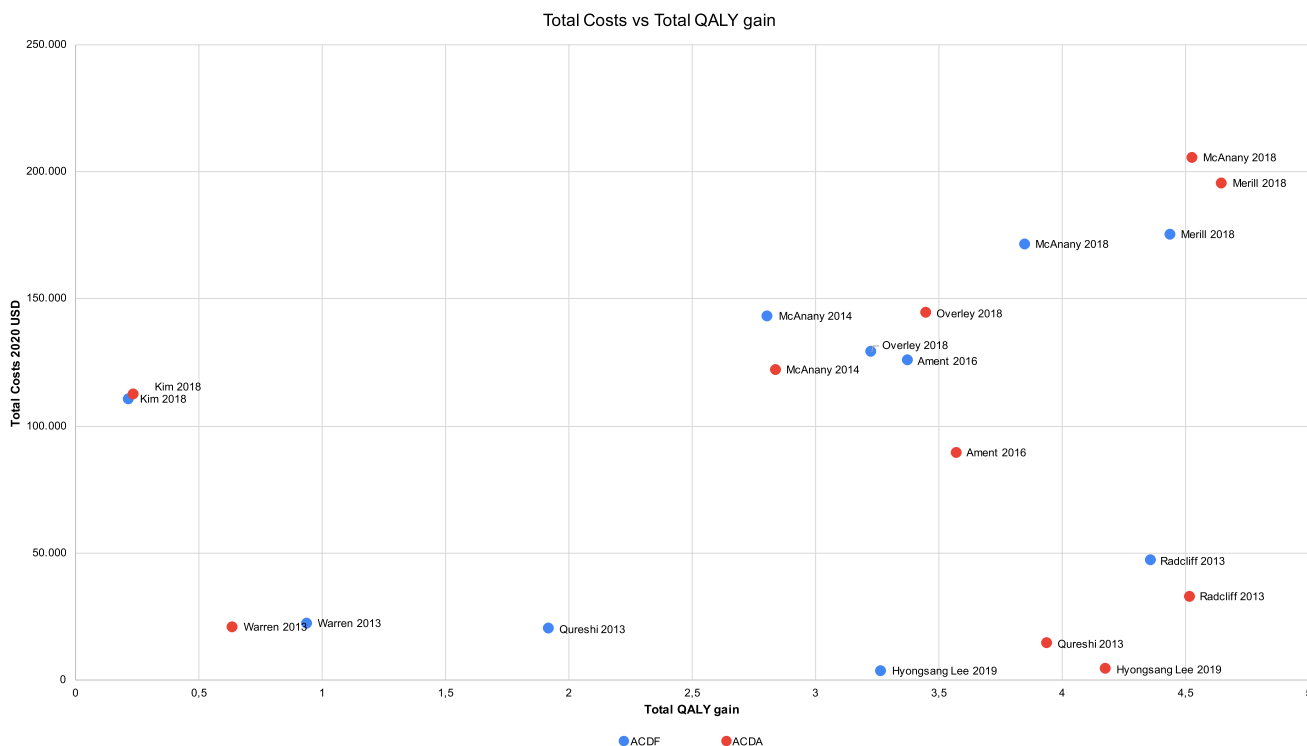


Fig. 2 A scatterplot displaying the total costs and total QALY gain for ACDA (red) and ACDF (blue) separately, as reported by the individual studies

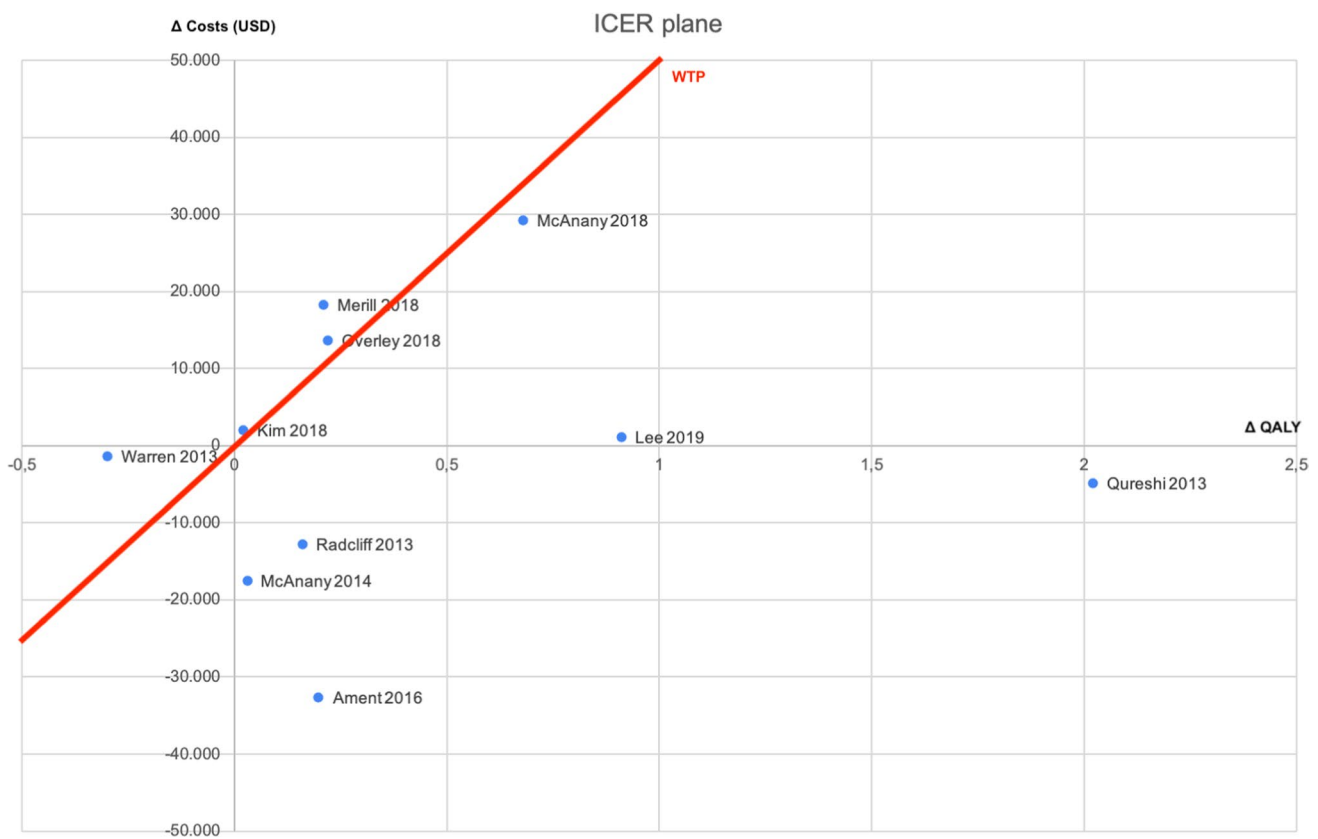


Fig. 3 The ICER plane of studies comparing ACDA to ACDF. The Y-axis represents the difference in costs (in 2020 USD), the X-axis represents the difference in QALY-gain. The red line represents the willingness-to-pay (WTP) threshold of \$50,000/QALY

Conclusion

This review evaluated cost-effectiveness of anterior surgical decompression techniques for radiculopathy and/or myelopathy due to CDDD. The most important result is the lack of uniform literature concerning the subject, which impedes any solid conclusions to be drawn. The results of this review show that both techniques are expensive. It seems that ACDA might be more cost-effective than ACDF as the majority of studies individually report ACDA to be the more cost-effective technique. In conclusion, there is a need for high-quality cost-effectiveness research and uniformity in reporting data to allow solid conclusions to be drawn.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s00586-022-07137-7>.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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