



Bridging the Cervicothoracic Junction During Multi-Level Posterior Cervical Decompression and Fusion: A Systematic Review and Meta-Analysis

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Abstract

Study Design: Systematic review and Meta-analysis.

Objective: This systematic review seeks to compare fusion, reoperation and complication rates, estimated blood loss (EBL), and surgical time between multi-level instrumented fusions with LIVs (lowest instrumented vertebra) in the cervical spine and those that extend into the thoracic spine.

Summary of Background Data: Several studies address the question of whether to extend a long-segment, posterior cervical fusions, performed for degenerative disease, into the upper thoracic spine. Recommendations for appropriate LIV continue to vary.

Methods: A comprehensive computerized literature search through multiple electronic databases without date limits up until April 3rd, 2020 using combinations of key search terms and sets of inclusion/exclusion criteria was performed.

Results: Our comprehensive literature search yielded 3852 studies. Of these, 8 articles consisting of 1162 patients were included in the meta-analysis. In 61.2% of the patients, the fusion did not cross the cervicothoracic junction (CTJ) (cervical LIV, CLV). In the remaining 38.8%, the fusion extended into the upper thoracic spine (thoracic LIV, TLV). Overall, mean patient age was 62.5 years (range: 58.8-66.1 years). Our direct analysis showed that odds of fusion were not statistically different between the CLV and TLV groups (OR: .648, 95% CI: .336-1.252, $P = .197$). Similarly, odds of reoperation (OR: 0.726, 95% CI: 0.493-1.068, $P = .104$) and complication rates were similar between the 2 groups (OR: 1.214, 95% CI: 0.0750-1.965, $P = .430$). Standardized mean difference (SMD) for the blood loss (SMD: .728, 95% CI: 0.554-.901, $P = .000$) and operative (SMD: 0.653, 95% CI: .479-.826, $P = .000$) differed significantly between the 2 groups. The indirect analysis showed similar fusion (Effect Size (ES)_{TLV}: .892, 95% CI: .840-.928 vs ES_{CLV}:0.894, 95% CI:0.849-.926); reoperation rate (ES_{TLV}:0.112, 95% CI: 0.075-.164 vs ES_{CLV}: .125, 95% CI: .071-.211) and complication rates (ES_{TLV}: .108, 95% CI: .074-.154 vs ES_{CLV}:0.081, 95% CI: .040-.156).

Conclusions: Our meta-analysis showed that fusion, complication, and reoperation rates did not differ significantly between patients in whom multi-level posterior fusions ended in the cervical spine vs those of which was extended into the thoracic spine. The

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mean blood loss, operative time and length of stay were significantly lower in patients with CLV at C6 or C7, compared to their counterparts. These data suggest that, absent focal, C7-T1 pathology, extension of long, posterior cervical fusions into the thoracic spine may not be necessary.

Keywords

posterior cervical fusion, cervicothoracic fusion, cervicothoracic junction, outcomes, multi-level posterior cervical fusion, meta-analysis, systematic review

Introduction

Spine surgeons have been taught that long, posterior cervical fusions ending at C7 risk subjacent failure at the cervicothoracic junction. In recent years, a number of studies have sought to compare the outcomes of surgeries ending in the lower cervical spine vs those extended into the upper thoracic spine. These studies have offered conflicting results and recommendations.

In biomechanical terms, the mobile, lordotic cervical spine, that allows the head to remain over the body and facilitates forward gaze, meets the stiffer thoracic kyphosis, designed to facilitate lung expansion.^{1,2} The abrupt change in alignment and mobility at the cervicothoracic junction (CTJ) is thought to predispose patients with long posterior cervical fusion to early subjacent failure. In response, many surgeons have recommended extension of these constructs into the upper thoracic spine.^{1,3}

The results of extant studies comparing the radiographic outcomes of different caudal end levels have been contradictory. Some studies show that revision rates are up to 17% higher when the construct ends at C7 as opposed to T1 or T2,¹ while others show no significant difference in revision rates.^{3,4} In fact, various studies have shown no statistically significant difference in fusion rates, complications rates and radiological parameters between constructs ending cervically vs those that cross the CTJ.^{2,4}

In our previous work, we suggested that clear benefits of extension into the thoracic spine were limited and that this approach was best limited to patients with poor bone quality, poor C7 fixation potential, or significant spondylosis, instability or deformity at C7-T1. We noted that thoracic extension was associated with a significant increase in surgical time and blood loss.^{5,6}

In this meta-analysis, our goal was to compare fusion, reoperation and complication rates along with estimated blood loss (EBL), surgical time and length of stay (LOS) between constructs with cervical LIV and those that extend into the thoracic spine.

Materials and Methods

Study Design

A systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) Statement for Reporting Systematic Reviews.⁷ The study was Institutional Review Board exempt.

Search Criteria

We conducted a comprehensive computerized literature search through multiple electronic databases without date limits up until April Week 3, 2020 using combinations of key search terms. Initial searches were designed to be all encompassing and capture as many articles as possible. Project lead and team members then narrowed the results using the inclusion/exclusion criteria below. MEDLINE searches employed both PubMed and Ovid engines; Web of Science was also queried for potential studies. PubMed included biomedical literature from MEDLINE and additional life science journals (1947-Present). The Ovid search included: Ovid MEDLINE(R) (1946-Present). Web of Science collections searched included: Science Citation Index Expanded (SCI-EXPANDED) (1900-present) and Emerging Sources Citation Index (ESCI) (2005-present). The search strategy used for PubMed, OVID Medline, and Web of Science are shown in Supplemental Digital Content (SDC).

Search Terms

Our search strategy focused on the combinations of key terms: “posterior cervical fusion,” “posterior cervical decompression,” “cervicothoracic fusion,” “discectomy,” “diskectomy,” “anterior cervical fusion,” “sagittal alignment,” “thoracolumbar alignment,” “cervical alignment,” “posterior instrumentation,” “vertebral segmentation,” “cervical vertebrae/diagnostic,” “imaging,” “cervical vertebrae surgery,” “spinal fusion,” “cervicothoracic deformity,” “ossification of the posterior longitudinal ligament,” “cervical spondylotic myelopathy,” “intervertebral disc degeneration,” “radiculopathy,” “horizontal gaze,” “vertebral segmentation,” “Roussouly,” “subaxial cervical spine,” “adjacent-segment pathology,” “sagittal balance,” “adjacent segment disease,” “adjacent segment degeneration,” “pseudarthrosis,” “spinal stenosis,” “spondylitis,” “spondylosis,” “C7,” “T1,” “cervicothoracic,” “cervicothoracic,” “cervical-thoracic,” and “multi-level cervical.”

Inclusion/Exclusion Criteria

Articles were screened using inclusion criteria: full-text studies published in peer-reviewed journals in English or translated into English and studies with patients undergoing multi-level posterior cervical fusions or combined anterior and posterior cervical fusion involving C7, with primary diagnosis of degenerative cervical spine disease.

Studies with the following criteria were excluded: 1) non-English; 2) patients undergoing single-level fusion, 3) indication for surgery was trauma, tumor, fracture or infection, 4) the primary procedure was arthroplasty, laminoplasty, corpectomy, or anterior cervical discectomy and fusion only, and 6) any case reports, reviews, editorials, and abstracts.

Data Extraction

Two research librarians (DE and HL) and 2 researchers (DS and AD) performed the electronic database search. Two authors (MG and JS) independently reviewed potentially these studies to be included in the systematic review. Disagreements on the inclusion of a study between the 2 authors were resolved by a third author (ET). In addition, we also performed manual searches of review bibliographies and reference lists of primary studies not captured by the electronic searches. To further avoid missing studies not referenced in our original

papers’ bibliographies or our literature searches, we sought additional recommendations from prominent researchers in the field. Additional full text references were then obtained and analyzed for inclusion. Figure 1 shows the PRISMA flowchart for search methodology.

Two authors independently extracted the following data from the studies: demographic such as sex and age; sample size, study design, minimum posterior levels, caudal levels, surgical approach (such as posterior or combined anterior and posterior approach), length of follow-up, and fusion assessment details. The primary outcomes of the study were: fusion, complication, and reoperation rates. Our secondary outcomes were: estimated blood loss, operative time, complication details, and patient reported outcomes.

Meta-Analysis

We conducted both direct and indirect meta-analysis. These analyses were performed for fusion rate, reoperation rate,

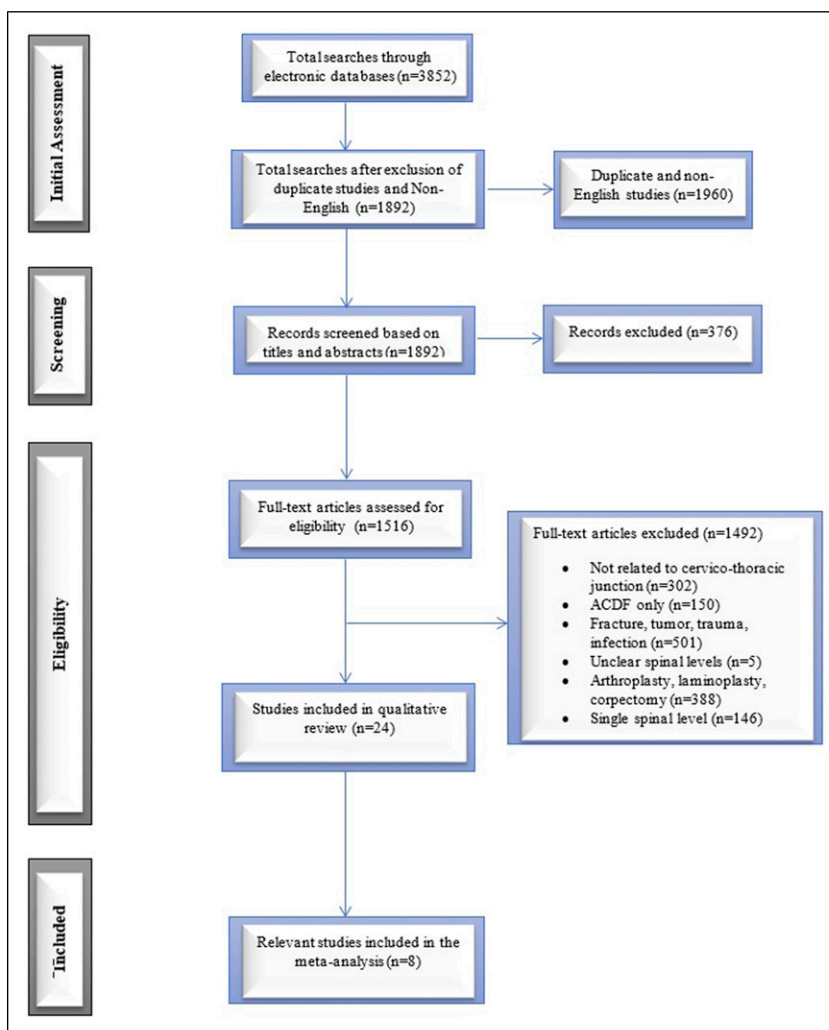


Figure 1. Flow chart of systematic review.

complication rate, estimated blood loss, and operative time. For the discrete variables, the direct meta-analysis outcomes were reported using odds ratios (ORs) with 95% confidence intervals (CIs). The outcomes for continuous variables were expressed as standardized mean difference with 95% CIs. The outcomes for the indirect analysis were expressed as pooled proportions of events. All meta-analysis was conducted using random-effects model to account for high variability between the studies.⁸ Level of significance was set at $\alpha = .05$. All the meta-analyses were performed using Comprehensive Meta-Analysis version 3.3.070 (Biostat Inc., NJ, USA).

Quality and Publication Bias Assessment

The quality assessment was performed using Newcastle–Ottawa Quality Assessment Scale⁹ and GRADE (Grading for Recommendations, Assessment, Development and Evaluations) criteria¹⁰. Publication bias were represented as funnel plots. Besides examining for obvious asymmetry,¹¹ Begg and Mazumdar rank correlation,¹² and Egger's regression intercept¹³ tests were used to investigate the significance of the publication bias for discrete and continuous variables, respectively.

Number Needed to Harm Assessment

In an effort to understand the benefit/harm of crossing vs not crossing the CJT, we assessed the number of patients, on average, with a cervical LIV in order for 1 patient to require reoperation for subjacent degeneration over the course of 2 years follow-up. NNH was calculated as the reciprocal of absolute risk increase (i.e., the negative impact of a treatment in a given patient population).

Results

Our comprehensive literature search yielded 3852 studies. Of these, we excluded those (1960 studies) identified as duplicate or non-English language articles. After screening the titles and abstracts, a total of 1516 full-text articles were assessed for eligibility. Based on inclusion/exclusion criteria, we further excluded 1492 articles. A total of 24 studies were included in full-text analysis. Eight articles were included in the meta-analysis.^{6,4,14,2,5,15,1,3} All 8 included studies compared the surgical outcomes for patients undergoing multi-level posterior cervical fusion (PCF) crossing the CTJ with those ending in the lower cervical spine. Figure 1 shows the PRISMA search strategy.

Table 1 shows the demographic and characteristics of the studies included in the meta-analysis. There was a total of 1162 patient across 8 studies. For our analysis, we divided the patients into 2 groups: TLV (caudal level instrumentation at T1 to T4), and CLV (caudal level instrumentation up to C6 or C7; C6 = 18.7% & C7 = 81.3% of cases). 61.2% were part of the CLV group, with the remaining 38.8% in the TLV group. Overall, mean age of patients was 62.5 years (range:58.8-

66.1 years). In both groups, the majority of patients were female. All the surgeries were either multi-level posterior or combination or anterior-posterior cervical fusions. Long posterior fusions required a minimum of 3 levels, but included levels ranged from C2 to T4.

Direct Meta-Analysis

- 1) *Fusion rate*- Direct (CLV vs TLV) fusion rate was compared among 6 different studies with the total sample size of 1026 patients. The overall fusion rate was 87.4% (n = 897). Four of the 6 studies assessed the fusion radiographically. The remaining 2 studies did not report this information. Our analysis showed that odds of fusion were not statistically different between crossing vs not crossing the CTJ groups (OR: .648, 95% CI: .336-1.252, $P = .197$). The detailed results are shown in the forest plot in Figure 2.
- 2) *Reoperation rate*- 6 studies (n = 1054) were compared directly to assess the reoperation rates between CLV and TLV groups. The overall reoperation rate was 13.6% (n = 143). As seen from the forest plot (Figure 3), the odds of reoperation did not differ significantly between the 2 groups (OR:0.726, 95% CI: 0.493-1.068, $P = .104$).
- 3) *Complication rate*-We compared 6 studies (n = 911) directly to measure the complication rates between CLV and TLV groups. The overall complication rate was 9.5% (n = 87). The odds of complication were similar between the 2 groups (OR:1.214, 95% CI: 0.0.750-1.965, $P = .430$). The detailed analysis is shown in the forest in Figure 4.
- 4) *Mean estimated blood loss*- 3 studies (n = 570) were directly compared with respect to the mean estimated blood loss between CLV and TLV groups. Our analysis showed that the standardized mean difference (SMD) was significant between the 2 groups (SMD: .728, 95% CI:0.554-.901, $P = .000$). As seen from the forest plot (Figure 5), crossing the CTJ during the PCF resulted in significantly greater blood loss compared to the CLV group.
- 5) *Mean operative time*- Direct comparison (CLV vs TLV) of mean operative time was performed among 3 studies (n = 570). As seen from the forest plot (Figure 6), the SMD differed significantly between the 2 groups (SMD: 0.653, 95% CI: .479-.826, $P = .000$). This shows that crossing the CTJ resulted in significantly longer mean operative time than not crossing the CTJ.
- 6) *Mean length of stay*- 2 studies (n = 441) were directly compared with respect to the mean length of stay for the CLV and TLV groups. SMD was significant between the 2 groups (SMD: .404, 95% CI:0.210-.599, $P = .000$). The data suggests that PCF with a TLV resulted in longer LOS compared to the CLV group (Figure 7).

Table 1. Demographic and Study Details.

Article	Mean age(Yrs.)	Females (%)	Sample size	Minimum posterior levels	Minimum radiographic follow ups (months)	Patients with minimum radiographic follow ups (%)	Overall revision rate (%)	Overall Fusion rate (%)	Fusion assessment	Conclusions (Cervical vs Thoracic LIV)
Truumees et al 2020(USA) Retrospective	63.5	41.3	264	3	24	84	10.6	88.3	Radiography at 2 years	Cervical LIV
Lee et al 2019(Korea) Retrospective	63.1	41.3	46	3	24	93.5	0	93.5	Radiography at last follow-up	Cervical LIV
Huang et al 2019(USA) Retrospective	63	48	129	NA	NA	NA	10.1	97.7	Radiography at follow-up	Not definitive
Kenamer et al 2019(USA) Retrospective	66.1	33.9	221	3	12	79.7	10.8	94	NA	Not definitive
Truumees et al 2018(USA) Retrospective	59.5	48	177	3	24	95	7.3	83.6	Radiography at 2 years	Cervical LIV
Osterhoff et al 2017(Europe) Retrospective	64	39	74	3	6	70	29.7	NA	NA	Not definitive
Schroeder et al 2016(USA) Retrospective	61.9	47	189	3	12	31.5	27.8	73.5	Radiography at 1 year	Thoracic LIV
Bechara et al 2012(USA) Retrospective	58.8	56	62	4	NA	NA	0	100	Radiography at last follow-up	Not definitive

Abbreviations: LIV, Lowest Instrumented Vertebra.

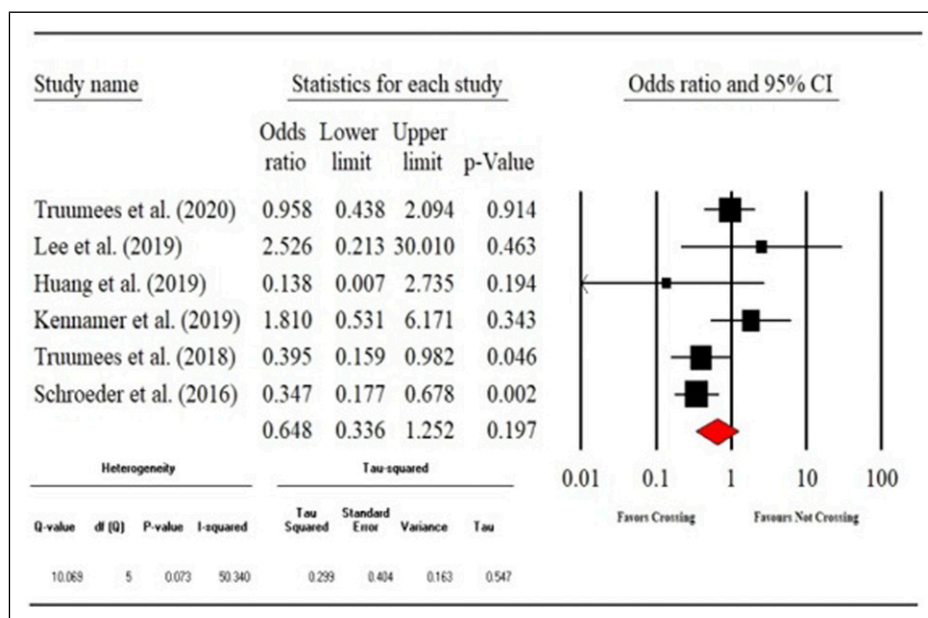


Figure 2. Fusion rate.

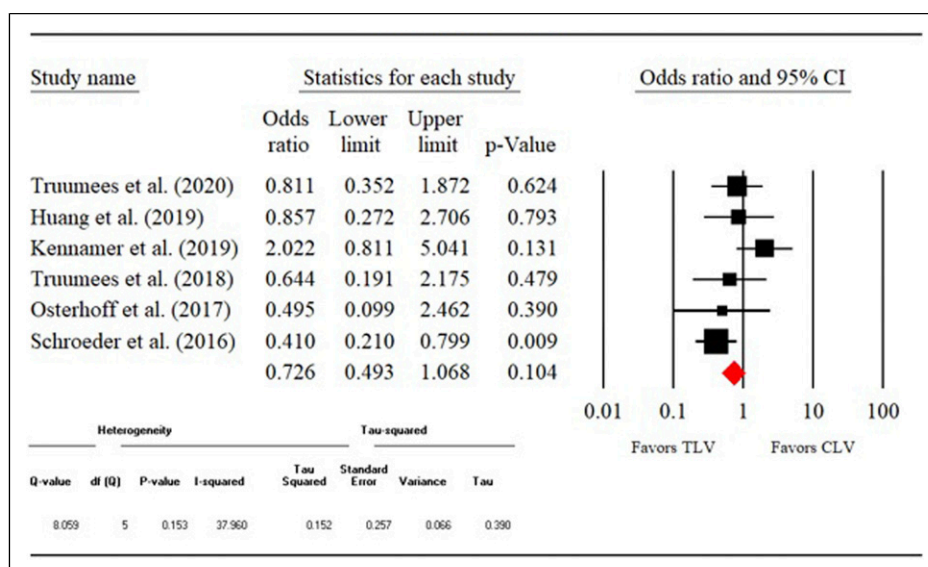


Figure 3. Reoperation rate.

Indirect Meta-Analysis

1) *Fusion rate*- 7 studies reported the fusion rate (n = 1088). There were 422 patients (38.8%) in TLV group and 666 patients (61.2%) in the CLV group. The rates of successful fusion were 90.0% and 86.9%, respectively. As seen from the forest plot SDC (Supplemental Appendix A4), fusion rates between the 2 groups were comparable (Effect Size (ES)_{TLV}: .892, 95% CI: .840-.928 vs ES_{CLV}:0.894, 95% CI:0.849-.926).

2) *Reoperation rate*- The rate of fusion was reported in 8 studies (n = 1162). Patients sample size of the TLV and CLV groups was 438 (37.7%) and 724 (62.3%), respectively. A total of 48 patients (10.96%) in TLV group underwent a reoperation. The reoperation rate in the CLV group was 13.12% (95 of 724). The 2 groups had similar overall reoperation rate (ES_{TLV}:0.112, 95% CI: 0.075-.164 vs ES_{CLV}: .125, 95% CI: .071-.211). The details of the analysis are shown in the forest plot SDC (Supplemental Appendix A5).

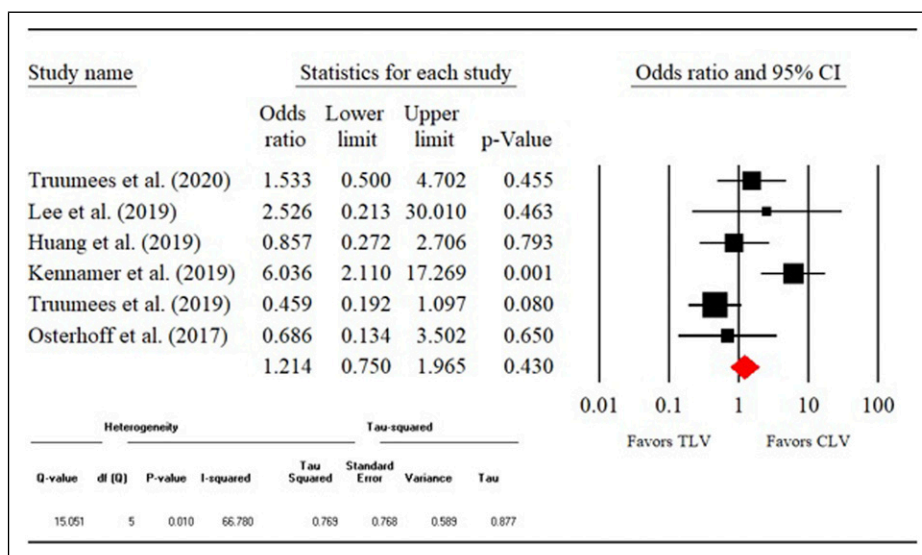


Figure 4. Complication rate.

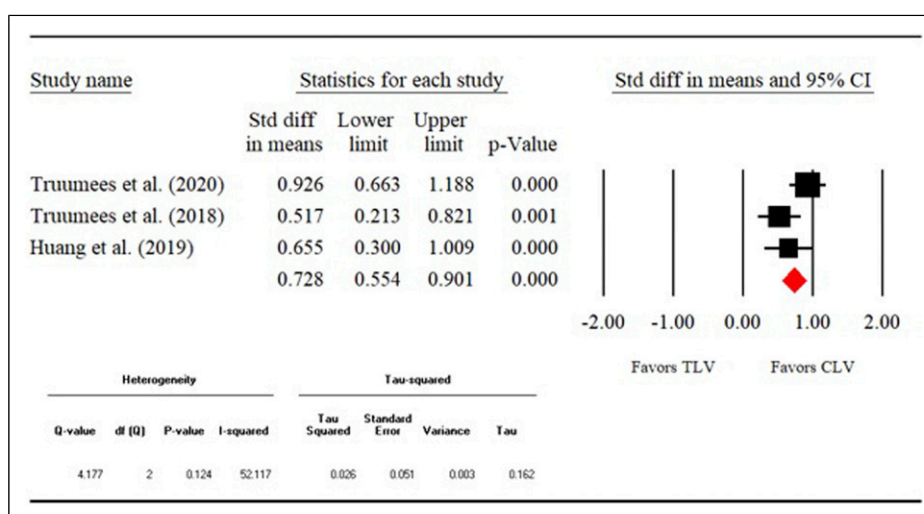


Figure 5. Mean estimated blood loss.

Table 2 summarizes the indications for secondary interventions from the various studies. For the TLV group; there were 13 cases of infection, 13 were not listed, 9 nonunion, and 5 cases of adjacent segment disease (ASD). In the CLV group, there were 42 cases of ASD, 17 not listed, 12 nonunion, and 9 cases of infection.

- 3) *Complication rate*- 7 studies consisting of 973 patients were evaluated for reported complication rates. The complication rates for the TLV vs CLV groups were 9.9% and 8.5%, respectively. SDC (Supplemental Appendix A6) forest plot shows the detailed analysis. As seen, complication rates between the 2 groups were similar ($ES_{TLV}: .108, 95\% CI: .074-.154$ vs $ES_{CLV}: 0.081, 95\% CI: .040-.156$).

Strength of Evidence

GRADE assessment was used to assess the strength of evidence as shown in Table 3. The confidence in the estimates (relative effect with 95% CI) for fusion, reoperation, complication rates, estimated blood loss and operative time were moderate.

Quality of Studies

Table 4 shows the Newcastle Ottawa Quality Assessment of the included studies. Overall, the quality of the studies was high, scores ranging from 4 to 6. Each study was awarded a star for representative of cohort, ascertainment of

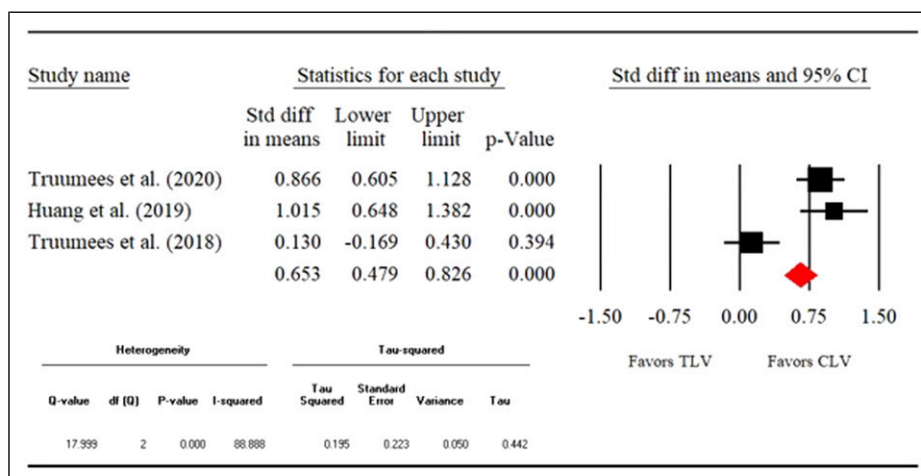


Figure 6. Mean operative time.

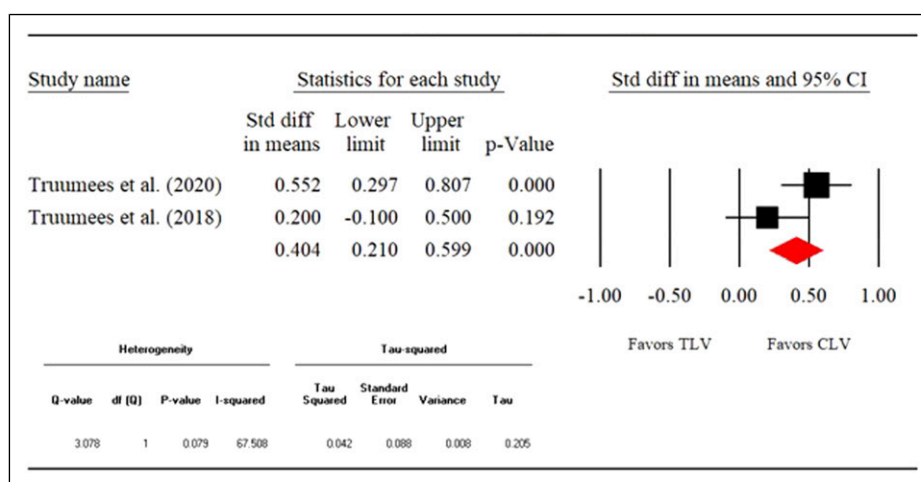


Figure 7. Mean length of hospital stay.

exposure, outcome of interest, assessment of outcome, adequacy of duration of follow-up, and adequacy of follow-up of cohort.

Publication Bias

The publication bias was assessed using the funnel plots. SDC (Supplemental Appendix A7-A10) show these details. As seen, there were no obvious asymmetry. This was further tested using egg and Mazumdar rank correlation and Egger’s regression intercept. Based on these analysis, we found that the publication bias was insignificant for all funnel plots ($P > .05$).

NNH Assessment

Based on the NNH calculation, we found that on average 18 and 21 patients would need to be treated with posterior cervical fusion ending at C7 in order for 1 patient to have

subjacent degeneration or reoperation over the course of 2 years follow-up, respectively.

Discussion

Posterior cervical decompression and fusion surgery is commonly performed for patients with multi-level cervical spondylotic myelopathy. There is a lack of consensus when choosing a LIV in long (more than 4 segment) fusions. Concerns about early subjacent failure have led to the suggestion that these fusions be carried into the upper thoracic spine. Our group has previously performed 2 multicenter studies comparing outcomes of patients in which the fusion crossed the CTJ vs those in whom it did not.^{5,6} These studies reported similar clinical and radiographic outcomes among the 2 groups. The studies also showed lower EBL, OR, and LOS in patients in which the fusion did not cross the CTJ. Based on our research, we have concluded that it is reasonable to choose C6 or C7 as a caudal fusion level if good anchorage is

Table 2. Reasons for Secondary Intervention for Various Studies.

Article	Thoracic LIV (TLV)		Cervical LIV (CLV)	
	# Patients	Reasons	# Patients	Reasons
Truumees et al 2020	2	Infection	1	Cerebrospinal fluid leak and granulation
	2	Nonunion	2	Tissue
	2	Instability	2	Hematoma
	1	Post laminectomy syndrome	2	Infection
	2	Subjacent stenosis	9	Nonunion
	—	—	2	Subjacent disease
—	—	—	Spondylolisthesis	
Lee et al 20019	0	NA	0	NA
Huang et al 2019	5	Wound dehiscence and/or associated	1	Hematoma
	1	Infection	3	Adjacent level disease
	—	Persistent neurologic deficit	3	Hardware malfunction (loosing of C7 lateral mass screw)
Kenamer et al 2019	3	Adjacent level disease	10	Adjacent level disease
	5	Nonunion/hardware failure	5	Nonunion/hardware failure
	4	Infection	2	Spinal deformity
	—	—	2	Infection
Truumees et al 2018	NA	NA	NA	NA
Osterhoff et al 2017	1	Symptomatic lower adjacent segment disease or caudal implant failure	18	Symptomatic lower adjacent segment disease or caudal implant failure
	1	Cerebrospinal fluid leak	2	Surgical site infection
Schroeder et al 2016	1	Acute wound infection	2	Adjacent level disease
	1	Early hardware failure	3	Acute wound infection
	1	Late infection	5	Nonunion
	1	Nonunion	17	Not listed
	13	Not listed	3	Other
	1	Other	—	—
Bechara et al 2012	1	Trauma/fracture	—	—
	0	NA	0	NA

Abbreviations: LIV, Lowest Instrumented Vertebra; CLV, cervical LIV; TLV, thoracic LIV.

achieved at the caudal level and in the absence of C7-T1 pathology.

In this meta-analysis, we analyzed our own patients’ data along with the data from several other studies. In line with our findings, some studies show drawbacks to crossing the CTJ. Huang et al concluded “crossing the CTJ was associated with increased surgical time, estimated blood loss, and the rates of wound dehiscence.”¹⁴ Some of the differences in this study of 129 patients were dramatic. Mean EBL was over 350 mL greater in the TLV group. Lee et al found similar clinical and radiographic outcomes in TLV patients and those in which C7 was the caudal fusion end level.⁴ Based on these findings, they determined that “multi-level PCF stopping at C7 does not negatively affect C7-T1 segment failure.” They concluded “it is unnecessary to extend the long PCF levels caudally across the healthy CTJ for fear of development of adjacent segment disease at the C7-T1 segment.”

Other studies, however, recommend crossing the CTJ. In a review of 74 patients with at least 6 months of follow-up, Osterhoff and colleagues found a higher rate of re-operation in a group of patients in which constructs terminated at C7

compared to their TLV group.¹⁵ They concluded that, even in the absence of C7-T1 pathology, “one may consider bridging the cervicothoracic junction and to end the instrumentation at T1 or T2.” Schroeder et al also recommend extending multi-level cervical fusions to T1. They noted the odds of revision were 2.29 times greater when surgery stopped at C7 compared to operations that crossed the CTJ.¹

All of the studies mentioned, including our recent study of 264 patients, are significantly underpowered. A previous meta-analysis in 2019 from Goyal and others attempted to answer this question. They included 6, 2 1-arm and 4 comparative studies consisting of 530 patients.¹⁶ We performed a power analysis and concluded that a sample size of over 700 patients would be required to detect a 2% difference in revision rates among our 2 groups at a power of .80. To enable stronger recommendations for surgical strategy in this context, we conducted this meta-analysis.

In this meta-analysis, we looked at several different outcomes in 1162 patients from 8 studies. Fusion rates between the 2 groups were comparable, and the mean fusion rate was 87.4%. The odds of fusion were not statistically different in crossing vs not crossing the CTJ. The incidence of reoperation

Table 3. GRADE Assessment.

GRADE Assessment of Strength of Evidence										
Outcome	Number of studies	Number of patients	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Relative effect (95% CI)	Confidence in effect estimates (GRADE)	
Fusion rate (CLV)	7	666	Not serious	Serious	Not serious	Not serious	Insignificant	.901(.795-.955)	Moderate	
Fusion rate (TLV)	7	422	Not serious	Serious	Not serious	Not serious	Insignificant	.892(.842-.928)	Moderate	
Reoperation rate(CLV)	8	724	Not serious	Serious	Not serious	Not serious	Insignificant	.125(.071-.211)	Moderate	
Reoperation rate(TLV)	8	438	Not serious	Serious	Not serious	Not serious	Insignificant	.112(.075-.164)	Moderate	
Complication rate(CLV)	7	639	Not serious	Serious	Not serious	Not serious	Insignificant	.081(.040-.156)	Moderate	
Complication rate(TLV)	7	334	Not serious	Serious	Not serious	Not serious	Insignificant	.108(.074-.154)	Moderate	
Estimated blood loss*(CLV)	3	337	Not serious	Serious	Not serious	Not serious	Insignificant	223.6(118.3-328.8)	Moderate	
Estimated blood loss*(TLV)	3	233	Not serious	Serious	Not serious	Not serious	Insignificant	491.9(397.5-586.4)	Moderate	
Operative time*(CLV)	3	337	Not serious	Serious	Not serious	Not serious	Insignificant	196.9(150.7-243.3)	Moderate	
Operative time*(TLV)	3	233	Not serious	Serious	Not serious	Not serious	Insignificant	250.8(211.5-290.1)	Moderate	
Length of stay*(CLV)	2	272	Not serious	Serious	Not serious	Not serious	Insignificant	4.97(4.54-5.39)	Moderate	
Length of stay*(TLV)	2	169	Not serious	Serious	Not serious	Not serious	Insignificant	6.73(4.38-9.08)	Moderate	

*Relative effect for continuous variables represented as mean (95% CI).

Abbreviations: LIV, lowest instrumented vertebra; CLV, cervical LIV; TLV, thoracic LIV.

Table 4. Quality Assessment.

Newcastle-Ottawa Quality Assessment of Included Studies						
Research Question: Long posterior cervical fusion- crossing vs not crossing the cervicothoracic junction						
Studies	Selection			Outcome		
	Representative of cohort	Ascertainment of exposure	Outcome of interest	Assessment of outcome	Adequacy of duration of follow-up	Adequacy of follow-up of cohort
Truumees et al 2020	*	*	¥	*	*	*
Lee et al 2019	*	*	*	§	*	*
Huang et al 2019	*	*	*ξ	*	Υ	ψ
Kenamer et al 2019	*	*	*	*	*	*
Truumees et al 2018	*	*	*	*	*	*
Osterhoff et al 2017	*	*	*	*	*	#
Schroeder et al 2016	*	*	*	*	*	^
Bechara et al 2012	*	*	*	*	*	€

¥: Fusion and complication rates were obtained outside the published data (Other outcome data such as reoperation rate, blood loss, and operative time were reported in the published data)

§: Fusion assessed by an independent reviewer in a blind manner

ξ: Fusion and reoperation rates were not available in the published data (Complication rate, blood loss, and operative time data were available in the published data)

Υ: Radiographic follow-up details were not provided in the published study

ψ: Patients follow-up rate was not provided in the paper

#: 70% of patients completed minimum radiographic follow-up

^: Only 31.5% of patients completed minimum radiographic follow-up

€: Patients follow-up rate was not provided in the paper

*: Meets the criteria

was similar in both groups, and the odds of a postoperative complication were similar between the 2 groups.

The aggregate data suggests similar re-operation rates, but, perhaps, a lower subjacent degeneration rate in the TLV group. To study this further, we calculated a NNH. We found that about 20 patients would have to undergo posterior cervical fusion with a CLV in order for 1 patient to have require additional surgery for subjacent degeneration over the course of 2-year follow-up. This number would likely be substantially increased if, at the time of index surgery, those with significant degeneration, deformity, instability at C7-T1, or poor anchorage at C7 were offered surgery with a TLV. The small C7 lateral mass is often unsuitable as caudal end-level fixation.¹⁷ In most cases, a C7 pedicle screw would be recommended, but this option may be ill-advised in patients of small, sclerotic or highly osteoporotic C7 pedicles. This setting, the larger T1 (and/or T2) pedicles offer safer, mechanically stronger end level fixation. In this setting, no separate C7 anchor is required.¹⁷

Utilizing a CLV for long posterior cervical fusions decreases morbidity, as measured by lower EBL and shorter operative times. CLV are also associated with shorter hospital LOS which has both health and cost advantages.

While we were unable to do a direct cost analysis, it would be reasonable to extrapolate decreased costs with CLV surgery given both the reduced length of stay and reduced implant utilization.

Limitations and Strengths

The major limitations of this study include its retrospective nature and heterogenous patient populations. Across the 8 studies, individual surgeons may have different indications for the various surgical techniques, including concomitant anterior surgery and LIV. There may also be differences in the 2 groups in terms of their baseline co-morbidities and spinal pathologies. Once critical variable was the percentage of patients who had anterior cervical fusions and the number of levels over which those fusions were carried. Most of those anterior fusions did not include the C6-7 and very few included the C7-T1 level. Truumees et al (2018 & 2020) studies showed that overall 17.2 % and 12.4% of the patients in TLV and CLV groups had both anterior/posterior fusions, respectively. These may have contributed to increased morbidity, as measured by higher EBL, longer operative times and hospital LOS in the TLV group. Another limitation of the analysis is variability in the fusion assessments of these studies which were measured at different time points. This limits some generalizability from the long-term follow-ups.

While the meta-analysis enabled us to include the largest number of patients reported, inconsistent reporting still resulted in some variables with lower patient numbers. Some of

the studies did not report at all on certain variables such as length of stay and follow-ups. This resulted in an analysis of only 441 patients for length of stay.

Patient reported outcomes are not included in this study, which is another limitation. Inconsistent reporting across the 8 studies prevented our ability to analyze this measure. In the 2 studies in which PROMS were reported, no differences were seen between CLV and TLV constructs. There is also insufficient data in these studies to report on pre-operative and post-operative measures of alignment, such as the C2-C7 sagittal vertical axis. A growing body of literature suggests these parameters may influence post-operative outcomes. The available data utilized different measures of local and global spinal balance. Within those studies, no significant differences in alignment were noted with CLV and TLV constructs. Future research in this arena should include more vigorous reporting of patient reported outcome measures and sagittal balance measures.

Some of the strengths of our study include: 1) systematic review and meta-analysis using PRISMA guidelines; 2) greater sample size as compared to previous published study; 3) robust quality assessment using Newcastle–Ottawa Scale and GRADE guidelines; and 4) NNH assessment of our data.

Conclusions

Based on our current study, we have concluded that it is reasonable to choose C6 or C7 as the LIV if good anchorage can be achieved and in the absence of C7-T1 pathology. Utilizing a CLV for long posterior cervical fusions decreases morbidity, as measured by lower EBL and shorter operative times. CLV are also associated with shorter hospital LOS which has both health and cost advantages.

Declaration of Conflicting Interests

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Supplemental Material

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