Safety and Efficacy of Skipping C7 Instrumentation in Posterior Cervicothoracic Fusion

Matthew K. Tobin, Cristian Gragnaniello, Felicia Wang Sun, Shivani D. Rangwala, Daniel M. Birk, Sergey Neckrysh

OBJECTIVE: **To analyze the safety and efficacy of skipping instrumentation at the C7 vertebra during posterior cervicothoracic fusions.**

METHODS: **This is a retrospective chart review of 53 patients who underwent multilevel posterior cervical fusion between 2010 and 2015. Of 53 patients, 7 patients were instrumented at C7, serving as the control group, whereas the remaining 46 patients were not. Evaluation of efficacy was based on intraoperative complications, operative time, estimated blood loss, significant long-term complications, and radiographic evidence of fusion.**

RESULTS: **Skipping the C7 level resulted in a significant reduction in estimated blood loss (321 ± 214 mL in the C7 bridge group vs. 531 ± 365 mL in the control group) and an insignificant, but decreased, reduction in operative time (155 ± 70 minutes in the C7 bridge group vs. 194 ± 66 minutes in the control group). Two intraoperative complications were noted in the C7 group, and 1 intraoperative complication was noted in the control group. In addition, patients skipped at C7 maintained sagittal balance with fusion rates similar to control patients at follow-up. No significant long-term complications were found in both groups.**

CONCLUSIONS: **Skipping C7 in a multilevel posterior cervicothoracic fusion demonstrates significantly reduced estimated blood loss and faster operative times compared with the control group. In addition, postoperative assessment yielded similar rates of fusion in both groups. Serious negative outcomes of skipping C7 were not found in this retrospective study. Our study results illustrate the clinical benefits of skipping instrumentation at C7 to minimize surgical risk in patients undergoing posterior cervical fusion across the cervicothoracic junction.**

INTRODUCTION

Surgical correction of cervical spine deformities is one of the most common procedures performed in the United States. Various approaches exist, including anterior cervical fusion and posterior cervical fusion (PCF), for the treatment of cervical spine pathologies. PCF is indicated for cervical myelopathy and radiculopathy due to degenerative spondylosis and ossification of the posterior longitudinal ligament.[1] Between 2002 and 2009, 1.3 million cervical spine procedures were performed in the United States, and PCF was the third most-common procedure performed, steadily increasing from 6.5% to 9.5% in the 8-year time period.[2] With the number of PCF procedures performed each year increasing, there is still limited literature on the procedural elements and complications of a posterior approach, namely across the cervicothoracic junction.

It has been reported that approximately 9% of all injuries involved the C7 segment. Injuries include vascular, neurologic, and structural.[1,3,4] The anatomy of the C7 vertebra is unique as it has features both of cervical and thoracic vertebrae. At least 4 different type of screws have been described, including lateral mass, pedicle, transfacet, and translaminar trajectories. Pedicle screw fixation at C7 offers the greatest pull-out strength and greatest resistance to axial loading and is therefore the trajectory of choice whenever this segment of the spine is indicated to be included in a posterior construct.

Key words
- Cervical spine
- Posterior spinal fusion
- Spinal instrumentation
- Spine surgery
- Surgical approach
- Surgical outcome
- Thoracic spine

Abbreviations and Acronyms
EBL: Estimated blood loss
PCF: Posterior cervical fusion
PSF: Posterior spinal fusion
VA: Vertebral artery

Department of Neurosurgery, University of Illinois at Chicago, Chicago, Illinois, USA

To whom correspondence should be addressed: Sergey Neckrysh, M.D. [E-mail: neckrysh@uic.edu]

Matthew K. Tobin, Cristian Gragnaniello, Felicia Wang Sun, and Shivani D. Rangwal contributed equally to this work.

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At this junction, the most important vascular structure susceptible to damage is the vertebral artery (VA). Reported complications of iatrogenic damage to the VA during a posterior approach include fistulas, pseudoaneurysms, massive bleeding, late-onset hemorrhage, thrombosis, embolism, cerebellar or brain stem infarction, and death.[1] Instrumentation poses the greatest risk to the VA due to limited visibility of equipment trajectory.[5] However, the artery is most likely to enter the foramen transversarium of C6 and is reported to enter at the level of C7 in only 1.5%–4.5% of cases.[6]

Other risks include breach of the pedicle wall with nerve root injury (laterally), spinal cord and dura mater injury (medially), as well as esophageal perforation in cases in which the screw is too long during instrumentation at this junction. Bhatia[1] describes cerebrospinal fluid leaks to be one of the most common complications in spinal surgery with a posterior approach, with incidence of 0.5%–13%.[1]

Structurally, the decreased pedicle area of C7 and proximity of the VA increase complications of instrumentation, potentially compromising strength of the overall construct. In addition, screws placed in C7 and T1 do not lie in the same anatomical plane, requiring aggressive bending of the rods, which can weaken the rod, or the use of side connectors, which can be cumbersome and require increased operative time to successfully use them. Further, iatrogenic postoperative instability can occur from removal of bony, muscular, or ligamentous structures in the cervical spine region. One of the more common postoperative complications following posterior fusion is axial neck pain. Preservation of the C7 spinous process and its associated nuchal attachments has shown to decrease rates of axial symptoms.[1]

For a given cervical spine procedure, the perioperative complication rates for posterior approaches are greater than anterior approaches.[7-10] Relative to anterior approaches, a posterior approach for a multilevel cervical fusion surgery has been linked to greater respiratory complications, postoperative infections, symptomatic hematomas, and an increased need for blood transfusions.[9] In addition, in patients with a primary diagnosis of cervical spondylosis with myelopathy, there is evidence for increased complications (relative to other diagnosis), with 26% of cases involving 3 or more complications.[10]

The increased complications in a posterior approach to cervical spinal surgery are well researched. As per our knowledge, the consequences of not instrumenting at C7 and bridging across the cervicothoracic junction (termed "C7 bridge" by authors) in a posterior approach are not documented. In this retrospective chart review, we will demonstrate that a C7 bridge in posterior spinal fusion (PSF) procedures across the cervicothoracic junction will avoid the vascular and neural risks associated with the C7 vertebral level and still offer the same postoperative fusion stability relative to procedures involving instrumentation at C7.

MATERIALS AND METHODS

Patient Population

Following institutional review board approval (UIC #2014-0137), a retrospective chart review was performed on a total of 53 patients who underwent PSF across the cervicothoracic junction between November 2010 and December 2015 at our institution. All 53 patients met inclusion criteria of age greater than 18 years old, a posterior approach for spinal fusion procedure, and multilevel instrumentation across the cervicothoracic junction. Of these 53 patients, 7 patients were instrumented at C7 and served as the control group. These patients had screws placed at C7 for several reasons, including inability to instrument T1 (2 patients), history of anterior cervical fusion at C7 (1 patient), C7 fracture (1 patient), inability to instrument at C6 (1 patient), C7–T1 facet fracture (1 patient), and cage placement (1 patient). The remaining 46 patients were not instrumented at C7 (described as "C7 bridge" group).

A thorough review of clinic notes, operative notes, nursing records, anesthesia records, radiographic imaging, and postoperative follow-up notes was completed for each patient. Data recorded for each patient include clinical diagnosis, age, surgical procedure performed, stage of surgery (standalone or as part of a 1, 2, or 3 stage procedure), levels instrumented, instrumentation at C7 vertebrae, intraoperative complications, total operative time, estimated blood loss (EBL), time to postoperative follow-up, and significant long-term complications. Significant long-term complications are defined as those found on postoperative follow-up and include symptoms of worsening pain (relative to preoperative symptoms), muscle weakness, wound infection, or new symptoms not present before surgery.

Surgical Procedures

All patients were operated on by the same team of physicians at our institution with the operative technique described to follow. Posterior cervicothoracic fusion was performed either a standalone approach (Stage 0) or as part of a multistage surgical plan (Stages 1–3). Intraoperative motor-evoked potentials were monitored through the procedure with baseline values recorded following patient positioning. Motor-evoked potentials were determined by transcranial electrical stimulation with evoked potentials being measured downstream at 4 bilateral muscle groups. A longitudinal posterior incision was made at midline, extending along all spinal levels to be instrumented. Careful dissection exposed the posterior spine elements and anatomical landmarks, including the cervical lateral masses and thoracic pedicle screw starting points. Lateral mass screws were placed in the cervical spine using the An method and pedicle screws were placed in thoracic pedicles after the pedicles were cannulated with a Lenke pedicle finder. Intraoperative anteroposterior and lateral radiographs were obtained to confirm proper hardware positioning. In C7 bridge procedures, screws were placed bilaterally at C6 and T1, with rods secured across the junction. In cases of decompression, laminectomy was performed using a high-speed drill and rongeurs. In multistage cases, PSF was done in conjunction with anterior instrumentation. Rods were contoured to achieve optimum cervical lordosis and thoracic kyphosis before they were secured in the screw tulips. Bony arthrodesis was performed through decortication and placement of bone graft. Further, it is important to note that to ensure construct stability in those patients where C7 was skipped, a minimum of 2 levels above and below C7 were instrumented.

Radiographic Follow-Up

Postoperative lateral computed tomography imaging was analyzed to assess postoperative fusion stability. Preoperative and

postoperative values of sagittal vertical axis, T1 slope, and cervical Cobb angle were obtained. Successful fusion was determined by lack of hardware malfunction, lack of instrument loosening or displacement, spinal stability, and lack of vertebral fractures. One patient in the control group (14.3%) did not have satisfactory preoperative imaging for radiographic evaluation, and 2 patients (28.6%) did not have postoperative imaging. Of the C7 bridge group, 2 patients (4.3%) did not have preoperative imaging available for radiographic measurements and 3 patients (6.5%) did not have postoperative imaging.

Statistical Analysis

Fisher's exact tests were used to analyze all categorical data using SAS software (SAS Institute, Inc., Cary, North Carolina, USA). Parametric data were analyzed using an unpaired *t* test or 2-way analysis of variance with Holm–Sidak multiple comparison testing using GraphPad Prism (Version 6.05; GraphPad Software Inc., La Jolla, California, USA). For operative time and EBL, outlier values were excluded if they were 1.5 × interquartile range below the first quartile value or above the third quartile value. Data are presented as the mean ± standard deviation, and a probability value of less than 0.05 was considered statistically significant.

RESULTS

Patient Population

A total of 53 patients were identified, 7 in the control group and 46 in the C7 bridge group (Tables 1 and 2). The control group had a mean age of 62 years, ranging from age 53 to 72 years. The control group consisted of 2 male (29.6%) and 5 female patients (71.4%). The C7 bridge group had mean age of 61 years, ranging from 42 to 86 years. Sex groups were similarly distributed, with 22 male (47.8%) and 24 female patients (52.2%) in C7 bridge group. The most common principle diagnosis in the C7 bridge group included myelopathy (34.8%), vertebral fractures (17.4%), and pseudoarthrosis (15.2%). Similarly, in the control group the most common preoperative diagnosis was cervical myelopathy (28.6%) and vertebral fractures (28.6%).

Table 1. Patient Demographics

Baseline Characteristics	Control ($N = 7$)	C7 Bridge ($N = 46$)	*P* Value
Female sex	5 (71.4)	24 (52.2)	0.436
Mean age, years (range)	62 (53–72)	61 (42–86)	0.727
Primary diagnosis			0.533
Cervical myelopathy	2 (28.6)	16 (34.8)	
Vertebral fracture	2 (28.6)	8 (17.4)	
Pseudoarthrosis	0	7 (15.2)	
Kyphotic deformity	0	4 (8.7)	
Cord compression	0	3 (6.5)	
Radiculopathy	0	1 (2.2)	
Osteomyelitis	1 (14.3)	1 (2.2)	
Other*	2 (28.6)	6 (13.0)	

Numbers in parentheses are percentages.
*Other diagnoses include traumatic spondylolisthesis, ankylosing spondylitis, revision of previous surgery, epidural lesion, vertebral body mass, and spinal stenosis.

Operative Results

The efficacy of not instrumenting at C7 was determined by surgical data between control and C7 bridge groups (Table 3). The majority of control patients (71.4%) underwent PCF as a standalone procedure, with 1 patient (14.3%) having it done as stage 1 and 1 patient (14.3%) having it done as stage 3 of a multistage plan. In the C7 bridge group, 18 patients (39.1%) underwent PCF as a standalone procedure with 3 (6.5%), 24 (52.2%), and 1 (2.2%) patient undergoing PCF as a stage 1, stage 2, or stage 3 procedure, respectively. Other stages commonly involved anterior cervical discectomy and fusion. The difference in EBL was statistically significant between the 2 groups. Overall mean EBL was significantly reduced for patients not instrumented at C7 relative to control group (321 ± 214 mL vs. 531 ± 365 mL, respectively; $P = 0.037$), with no differences seen when comparing different staged approaches. Although not significant, operative time had a trending decrease in the C7 bridge group compared with the control group (155 ± 70 minutes vs. 194 ± 66 minutes, respectively; $P = 0.17$). In the control group, mean levels fused were 8 ± 2.6 (range 3–16), including successful instrumentation at C7 vertebrae for all patients. In the bridge group, mean levels fused were 6.7 ± 1.6 (range 4–17) with no instrumentation done at C7 vertebrae for all patients. In the control group, 2 patients (28.6%) demonstrated long-term radiographic fusion whereas 25 (54.3%) of C7 bridge patients had long-term radiographic fusion ($P = 0.250$). The most common reason for lack of radiographic fusion was postoperative imaging done relatively early in the postoperative period when radiographic fusion may not yet be apparent.

Complications, Intraoperative and Postoperative

The safety of not instrumenting at C7 was determined by intraoperative and long-term complications (Table 3). There were 3 intraoperative complications identified, 1 in the control group and 2 in the C7 bridge group, which prolonged the surgical duration. One patient in the control group had intraoperative complications secondary to morbid obesity (body mass index >44), which prolonged surgery by 1 hour. One patient who was not instrumented at C7 had 2 incidental durotomies that were successfully repaired intraoperatively. One patient who was not instrumented at C7 had signs of possible left VA bleed during instrumentation at C2, which was successfully controlled without adverse effects to the patient.

Evaluation of same-day postoperative imaging in both groups showed secure hardware placement, lack of fractures, and secure spinal stability. No deaths were recorded in the follow-up period. In the postoperative follow-up period, there were 4 complications identified: 1 in the control group and 3 in the C7 bridge group. In the control group, 1 patient presented with new-onset muscle spasms and new-onset cervical neck pain radiating to right shoulder; this patient was directed to the emergency department for imaging and pain treatment and no further intervention was

Table 2. Surgeries Performed

Subject	Levels Fused	C7 Bridge (Y/N)
1	C3—T4	N
2	C5—T4	N
3	C3—T2	N
4	C3—T5	N
5	C6—T1	N
6	C5—T6	N
7	Occiput—T8	N
8	C1—T3	Y
9	C3—T4	Y
10	C5—T10	Y
11	C3—T4	Y
12	C5—T10	Y
13	C5—T2	Y
14	C4—T1	Y
15	C2—T2	Y
16	C2—T4	Y
17	C3—T4	Y
18	C4—T3	Y
19	C3—T3	Y
20	C3—T3	Y
21	C3—T2	Y
22	C3—T2	Y
23	C3—T2	Y
24	C3—T2	Y
25	C3—T2	Y
26	C2—T2	Y
27	C3—T4	Y
28	C5—T10	Y
29	C3—T2	Y
30	C3—T2	Y
31	C3—T3	Y
32	C3—T2	Y
33	C3—T1	Y
34	C3—T2	Y
35	C2—T3	Y
36	C2—T2	Y
37	C3—T2	Y
38	C2—T3	Y
39	C2—T3	Y
40	C1—T4	Y
41	C3—T2	Y
42	C3—T2	Y
43	C2—T2	Y
44	C3—T2	Y
45	C3—T2	Y
46	C5—T3	Y
47	C3—T2	Y
48	C3—T3	Y
49	C2—T2	Y
50	C3—T3	Y
51	C2—T5	Y
52	C2—T11	Y
53	C3—T4	Y

Y, yes; N, no.

done. In the C7 bridge group, one patient noted mild right deltoid weakness at 2 weeks postoperatively. Another patient reported new bilateral hand and jaw pain postoperatively, which improved without additional intervention. Another patient in the C7 group presented with a superficial infection of the inferior aspect of the incision, which recovered with outpatient antibiotic treatment. Other than the aforementioned postoperative complications, all other patients experienced an uneventful postoperative course.

DISCUSSION

Surgical intervention for correction of spinal deformities is growing in popularity in the United States. Advancements in hardware quality and intraoperative resources helped pioneer spinal surgery in an aging patient population. With regards to cervical spine surgery, there is extensive research comparing costs, outcomes, and complications between an anterior versus posterior approach. A posterior approach (relative to anterior) yields greater rates of perioperative complications (including respiratory complications, wound infections, symptomatic hematomas, C5 nerve palsy, and the need for blood transfusions) and greater mortality.[1,7-10] For each procedure, there is moderate variation in technique due to differences in surgical skill and patient population. As per our knowledge, there is limited literature on surgical technique of PSF across the cervicothoracic junction. Specifically, our study aims to illustrate the safety and efficacy of skipping instrumentation at the C7 vertebrae in a multilevel PSF surgery across the cervicothoracic junction. We hypothesize that skipping C7 will yield similar results compared with instrumentation at C7, without compromising construct stability and postoperative fusion.

In our study, the efficacy of avoiding instrumentation at C7 and rather bridging across the cervicothoracic junction was determined based on operative data, perioperative complications, and

Table 3. Operative Characteristics

Surgical Characteristics	Control ($N = 7$)	C7 Bridge ($N = 46$)	*P* Value
Stage of surgical plan*			*0.032*
Standalone	5 (71.4)	18 (39.1)	
Stage 1	1 (14.3)	3 (6.5)	
Stage 2	0	24 (52.2)	
Stage 3	1 (14.3)	1 (2.2)	
Duration of surgery, minutes†	194 ± 66	155 ± 70	0.170
Standalone/stage 1	190 ± 73	164 ± 57	0.845
Stage 2/3	218 ± 0	144 ± 80	0.845
Blood loss, mL‡	531 ± 365	321 ± 214	*0.037*
Standalone/stage 1	478 ± 369	324 ± 218	0.493
Stage 2/3	850 ± 0	320 ± 214	0.195
Levels fused (range)	8.7 (3–16)	7.9 (4–17)	0.626
Intraoperative complications	1 (14.3)	2 (4.3)	0.346
Long-term complications	1 (14.3)	3 (6.4)	0.436
Patients with long-term radiographic fusion	2 (28.6)	25 (54.3)	0.250

Numbers in parentheses are percentages unless otherwise noted.
Statistically significant *P* values indicated in italics.
*Posterior spinal fusion was performed as a standalone procedure or as part of a multistage (Stage 1, 2, or 3) surgical plan.
†One patient was excluded as an outlier from the C7 bridge group and only 46 patients were analyzed.
‡Six patients were excluded as outliers C7 bridge group and only 41 patients were analyzed.

radiographic evidence of successful fusion. Several studies have identified predictive factors for complications in cervical spine surgery. Tetreault et al.[11] found in comparing groups based on EBL that the group with greater than 500 mL EBL was correlated with greater operative times. In addition, they found longer operative time and 2-stage procedures contribute to more perioperative complications in patients undergoing surgery for treatment of cervical spondylotic myelopathy.[11] In our study, 2 patients (28.6%) underwent a multistage surgical plan in the control group, compared with 29 patients (61.7%) in the C7 bridge group. We found differences in EBL to be statistically significant between control and C7 bridge groups; however, the difference in operative time was not significantly different between groups.

Deen et al.[12] conducted a prospective study of 100 patients who received rod–screw fixation across the cervicothoracic junction, with instrumentation at C7 in all patients and an average of 4.5 levels fused. No injury to the VA was reported; however, the incidence of postoperative complications was provided. Perioperative (within less than 1 month of operation) complications included radiculopathy (4%), wound healing problems (4%), screw malposition (2%) and early loss of alignment (1%), and complications identified within 1–6 months postoperatively included pseudoarthrosis (2%) and hardware malfunction (2%).[12] Our reports of perioperative complications, 14% (N = 1) in control and 4% (N = 2) C7 bridge group, may be skewed due to small sample size.[12] We also found no reports of hardware malfunction or construct stability across both groups. Our study sheds light on the comparable efficacy of instrumenting at C7 and skipping instrumentation at C7 in PSF across the

Table 4. Radiographic Data

Measurement	Control	C7 Bridge	*P* Value
SVA, mm			
Preoperative	33.2 (6)	24.9 (44)	0.3684
Postoperative	18.9 (5)	36.3 (43)	*<0.0001*
Correction	−19.0 (5)	10.8 (41)	*0.0196*
T1 slope, degrees			
Preoperative	31.3 (6)	29.4 (44)	0.5646
Postoperative	31.7 (5)	35.5 (43)	0.1887
Correction	2.2 (5)	5.8 (41)	0.3201
Cobb angle, °			
Preoperative	0.2 (6)	−6.8 (44)	0.6042
Postoperative	2.7 (5)	−12.3 (43)	0.2550
Correction	−4.8 (5)	−5.3 (41)	0.9542

Numbers in parentheses are number of patients included in analysis.
Statistically significant *P* values indicated in italics.
SVA, sagittal vertical axis.

cervicothoracic junction with regards to operative data and perioperative complications.

Understanding cervical spine biomechanics is critical to appropriately treating cervical spine pathology. Instrumentation in spinal surgery serves a variety of purposes. It can offer further means of correction to cervical kyphosis or increased stability to the spine following laminectomy for decompression.

It has been observed that most failures of posterior constructs happen at the level of C7 if this is the lowest instrumented level and that this could be avoided by either placing bilateral pedicle screws in C6 or T1 as this will have a buttress effect on the C7 screws.[13] Placing C7 pedicle screws in a construct that crosses the cervicothoracic junction will add biomechanical stability to the construct. However, doing so poses some issues including having a more difficult time contouring a single tapered rod and the need to place additional hardware if domino connectors or 2 different rods are chosen (one in line with the lateral masses and one in line with the pedicle trajectories) is chosen.

From a biomechanical standpoint, either solution is strong and effective, as it has been seen that a single dual diameter rod that tapers from 5.5 to 3.5 mm and 2 different rods joined by domino connectors have similar stiffness, yield, and ultimate force, in a cadaver model.[14]

The concern for skipping instrumentation at a given level is the potential for reduced overall stability of construct and successful correction of preoperative spine deformity with surgical fusion. This has been commonly done but, to our knowledge, there are no reports looking at potential failures of these construct, either from a hardware failure, non-union, or loss of correction standpoint.

There is no optimum correction recommendation for cervical kyphosis, but it is well supported to at least return the spine to a neutral position.[15] In our small and limited series, we noted that skipping C7 in overall instrumentation, patients still achieved postoperative stability and maintained C7 sagittal balance (**Table 4**).

Despite the size of the study and all the limitations and potential concerns for external validity of the study, clinical, surgical, and radiographic records were thoroughly reviewed for each patient included in our study. The senior author (S.N.) always led the surgical team performing each procedure, minimizing variation in technique for the C7 skip approach to PSF surgery.

Further investigations are warranted and should include a prospective analysis with a larger sample size and data from at least 3 postoperative visits (3 months, 6 months, and 12 months). This study design can better match C7 bridge and control groups and closely follow postoperative course and construct stability in both groups.

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