Original Article

Posterior occiput-cervical fixation for metastasis to upper cervical spine

ABSTRACT

Background: Metastasis to craniocervical area may result in instability manifesting as disabling pain, cranial nerve dysfunction, paralysis, or even death. Stabilization is required to prevent complications. Nonoperative treatment modalities are ineffective in providing stability and adequate pain relief. We present our experience of diagnosis, presentation, and surgical management for metastatic tumors to the upper cervical spine (UCS).

Methods: Single-center single-surgeon database of consecutively operated posterior occiput-cervical fusion for metastasis to UCS was reviewed from 2007 to 2016. Demographics, clinical, and surgical data were collected through chart review. Pain scores based on Visual Analog Scale (VAS) and other radiological data were noted. Kaplan–Meier curve was used for survival analysis. Clinical outcomes and complications were recorded.

Results: A total of 29 patients (17 females/12 males) had the mean age of 56.7 ± 13.5 (24–82). Predominant metastasis included from the breast in 9 (31.03%) cases, followed by renal in 5, melanoma in 4, and 3 each from lung and colon. Axis was involved in 24 cases (C2 body in 21, pedicle in 8 cases). Atlas was involved in 9 cases (lateral mass in 8 cases and arch in 3 cases) and occiput was involved in three cases. Average Spinal Instability Neoplastic Score was 10 ± 2.3 (7–14). Mild cord compression was seen in 7 cases. Fusion extended from occiput to C4 fusion (n = 23), C5 (n = 5), and C6 (n = 1). Average blood loss was 364.8 ± 252.1 ml and operative time was 235 ± 51.9 min. Average length of stay was 7 ± 2.8 days (3–15). VAS improved from 8.3 ± 1.5 to 1 ± 1.1 ($P < 0.001$). C2 angulation corrected from 2.1 ±5.3 (0 –17) to 0.5 ±1.2 (P = 0.045). Three patients each developed cardiopulmonary complications and deep infection. The average survival was 14.5 ± 15.1 (0.15–50) months.

Conclusion: C2 body is the most common site of metastasis. Occiput-cervical fusion for unstable upper cervical metastasis offers a good palliative treatment for pain relief and improved quality of life.

Keywords: Cancer, fusion, metastasis, occiput-cervical, survival

INTRODUCTION

Tumors metastasize to the spinal column in 33% of cases.[1] The craniocervical junction (CCJ) is rarely involved, in just 0.5% of these cases.[2] The CCJ and upper cervical spine (UCS) have complex and intricate anatomy involving numerous joints and ligaments that contribute to motion and stability. Metastasis causing disruption to this fine balance often results in instability, significant pain, cranial nerve palsies, and even death.[3-6]

Conservative methods including Halo and collars may fail to provide adequate stabilization and carry significant risk of associated complications including dysphagia, pressure sores, and poor compliance. Surgery at the terminal end of the vertebral column is challenged by the availability of

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adequate anchor points for surgical stabilization. In addition, lysis, osteoporosis, deformities, and general health of the patients add to the complexity.

Surgical approaches for tumor resection of the UCS carry another set of complexities and associated complications. Posterior approaches for occiput-cervical fixation (OCF) have been described in numerous small case reports and series,[1,5,7-9] with a few of them describing disease variations.[10-13]

We present our series of posterior-only operated OCF cases following metastasis to the UCS and CCJ and discuss the surgical details, complications, and outcomes. To our knowledge, this is the largest single surgeon consecutive series to date.

METHODS

The study was approved by the Institutional Review Board of The Ohio State University. The institutional database was reviewed retrospectively from January 2007 to December 2017. All cases with documented metastasis to the occiput, atlas, or axis vertebra, for which OCF surgery was done were considered. Cases with revision surgeries, previous cervical spine surgeries, and previous or second stage anterior cervical surgeries were excluded.

Indication for surgery included metastasis to the UCS (with or without CCJ) presenting with mechanical pain (neck pain worsening when upright or associated with range of motion) with or without clinical deformity or torticollis, neurodeficit, and instability (odontoid fracture displaced >5 mm or angulated >11°). All cases were discussed in the tumor board for consensus. Minimum period of expected survival was 3 months, as determined by the oncologist.

Data, including demographics, symptoms, neurological findings, and treatment details, were collected in a Microsoft Excel sheet. Pain scores (preoperative and at final follow-up) were collected using the Visual Analog Scale (VAS) from 0 to 10 and neurological function was collected using the Frankel Grade before and after surgery. Computed tomography scan images were assessed to identify the extent of metastatic disease and separately noted to identify which part of the vertebra was involved. Odontoid process angulation and displacement with respect to C2 body was measured.

Magnetic resonance imaging (MRI) T2-weighted axial scans at the site of maximum tumor volume were assessed for thecal sac compression and graded as "No compression" if no epidural disease was present, "Mild" if epidural disease present without spinal cord compression, "Moderate" if spinal cord compression was seen but cerebrospinal fluid (CSF) could be seen, and "Severe" if spinal cord compression was seen with no CSF column.

Spinal Instability Neoplastic Score (SINS) was calculated using the clinical and radiological data. Operative details including surgical time, blood loss, tumor resection, intraoperative complications, and postoperative complications were noted. Hospital length of stay (LOS) from the time of surgery was noted. Overall survival was calculated using the Kaplan–Meier method. $P < 0.05$ was considered statistically significant.

RESULTS

Thirty-nine cases were assessed, of which seven were excluded based on the exclusion criteria [Figure 1]. Twenty-nine cases included 17 males and 12 females. The average age at the time of surgery was 56.7 ± 13.5 years.

Major primary histology of metastasis included breast in nine cases (31%), renal in five (17.2%), melanoma in four (13.8%), and lung in three cases [10.3%; Table 1].

The majority of the cases had single-level involvement ($n = 25$, 86.2%); two-level metastasis was seen in three cases and three-level in one case. The axis was involved most often, in 24 cases. C1 was diseased in eight cases and occipital condyle was involved in three cases. Additional subaxial metastasis included C3 in two cases. In the atlas, unilateral lateral mass was the most common site of metastasis, in 8 cases (27.6%), and the body was most commonly involved in the axis, in 21 cases (72.4%) as in Table 2 and Figure 2.

Pain was the presenting symptom in all cases. Average preoperative pain based on VAS score was 8.3 ± 1.5 (5–10). Most patients had severe pain between 8 and 10 ($n = 22$). No neurological deficit was seen in any case. MRI showed no epidural disease in most cases ($n = 22$), while mild

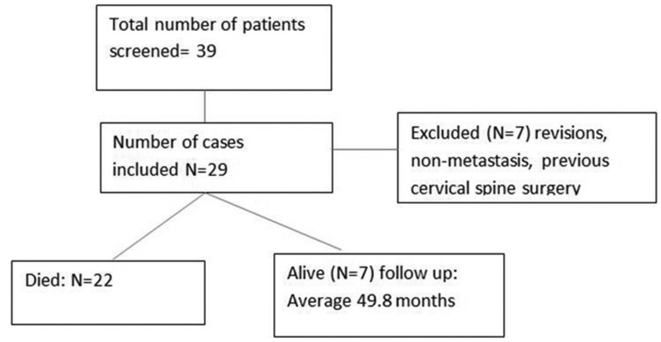

Figure 1: Flowchart showing the selection of cases

cord compression was seen in 7 cases. Among the patients with odontoid involvement, subluxation was seen in 12 cases (4.4 ± 4.05 [1.8 ± 3.4 mm]) and angulation was seen in 4 cases (5.16 ± 7.39 [2.1° ±5.3°]) [Table 3].

Table 1: Demographics and tumor details

Characteristics	*N* (%)
Age, mean±SD (range)	56.7±13.5 (24-82)
Gender, *n* (%)	
Female	17 (58.6)
Male	12 (41.4)
Tumor type, frequency (%)	
Bladder cancer	1 (3.45)
Breast cancer	9 (31.03)
Colon cancer	3 (10.34)
Lung cancer	3 (10.34)
Melanoma	4 (13.79)
Metastatic carcinoma	1 (3.45)
Multiple myeloma	1 (3.45)
Esophageal cancer	1 (3.45)
Plasmacytoma	1 (3.45)
Renal cancer	5 (17.24)

SD - Standard deviation

Table 2: Anatomical location of the metastasis

Location of metastasis	*N* (%)
Number of levels involved (%)	
Single	25 (86.2)
Two	3 (10.3)
Three	1 (3.5)
Cervical vertebrae involved (%)	
C1	5 (17.2)
C1/C2	3 (10.3)
C2	20 (69.0)
C2/C3	1 (3.5)
C1 involvement (%)	
Anterior arch (right)	1 (3.4)
Posterior arch (right)	2 (6.9)
Lateral mass	8 (27.6) unilateral; 1 (3.4) unilateral
C2 involvement (%)	
Odontoid	10 (34.5)
Body	21 (72.4)
Pedicle	8 (27.6)
Posterior elements	2 (6.9)
Occipital condyle involvement (%)	
No involvement	26 (89.7)
Unilateral	3 (10.3)

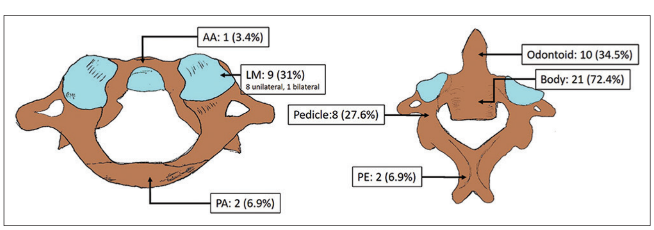

Figure 2: Anatomical distribution of metastasis to C1 and C2 (number of cases, percentage). AA: Anterior arch of C1, PA: Posterior arch of C1, LM: Lateral mass of C1, PE: Posterior elements of C2

The mean SINS was 10 ± 2.3 (7–14). Most patients (21, 72.4%) had an intermediate score (SINS: 7–12), while the remaining had unstable scores (SINS: >12). There was a significant with a weak-to-moderate correlation seen between SINS and preoperative VAS score [Table 4 and Figure 3; $r = 0.38$, $P = 0.042$].

All cases had posterior OCF using an occipital plate and lateral mass screws. Most patients had extension of fusion to C4 ($n = 23$), five had extension to C5 and one to C6. The mean operative time was 235.0 ± 51.9 (175–360) minand the blood loss was 364.8 ± 252.1 [75–1300 cc; Table 5]. Tumor resection was not done in any patient. In all cases, demineralized bone matrix (DBM) was used. No collar was utilized in the postoperative period for any of the patients.

The average LOS was 7 ± 2.8 (3–15) days. Most patients died at the time of last follow-up ($n = 22$, 75.9%). The overall survival time was 14.5 ± 15.1 (0.15–50) months [Figure 4]. Postoperative pain was significantly reduced from preoperative VAS of 8.3 ± 1.5 to 1.0 ± 1.1 ($P < 0.001$). The subluxation angle was also significantly reduced from 12.4° ± 6.2° to 2.8° ± 1.3° [$P = 0.019$; Tables 6 and 7].

Complications included two deaths in the immediate postoperative period and one patient each developing pneumonia and deep wound infection requiring debridement [Table 5].

Mean follow-up of the cases who were still alive was 49.8 ± 22.85 (18–84) months. In the follow-up, no recurrences were noted and no patient underwent a revision surgery.

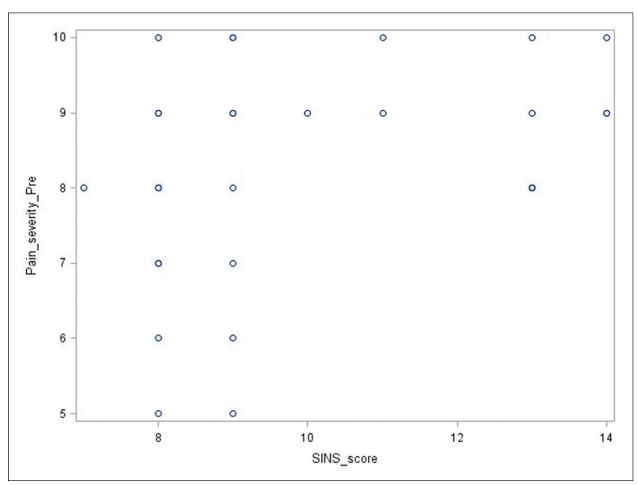

Figure 3: Spearman correlation between Spinal Instability Neoplastic Score and presurgery pain severity score

Table 3: Subluxation or angulation of C2

Case number	Subluxation (mm)	Angulation (°)
1	1	2
2	2	0
4	2	0
5	4	14
7	10	17
8	2	0
9	11	17
11	12	12
18	3	0
19	2	0
21	2	0
22	2	0
Average±SD	4.4±4.05	5.16±7.39

SD - Standard deviation

Table 4: Association between pain and Spinal Instability Neoplastic Score

Pain (VAS 0-10)	SINS score (0-14)		
	0-6 (stable)	7-12 (intermediate)	13-14 (unstable)
0-4 (mild)			
5-7 (moderate)		7	
8-10 (severe)		14	8

SINS - Spinal Instability Neoplastic Score, VAS - Visual Analog Scale

Table 5: Operative details

Features	*N*±SD (% or range)
Distal level of posterior fusion (%)	
C4	23 (79.3)
C5	5 (17.2)
C6	1 (3.5)
Operative complications	
None (%)	29 (100)
Blood loss (ml)	364.8±252.1 (75-1300)
Operative time (min)	235.0±51.9 (175-360)
Days of hospital stay	7.0±2.8 (3-15)
Postoperative complication (%)	
Wound infection	1 (3.6)
Acute respiratory failure - death	2 (7.2)
Pneumonia	1 (3.6)

Table 6: Pre- and post-operative pain

Postoperative pain (VAS 0-10)	Preoperative pain (0-10)		
	0-4	5-7	8-10
0-4 (mild)		22	7
5-7 (moderate)			
8-10 (severe)			

VAS - Visual Analog Scale

Table 7: Paired *t*-test between pain severity score and subluxation angle

	Presurgery	Postsurgery	*P*
Pain severity score	8.3±1.5 (5-10)	1.0±1.1 (0-3)	<0.0001
Subluxation angle	12.4±6.2 (2-17)	2.8±1.3 (1-4)	0.019

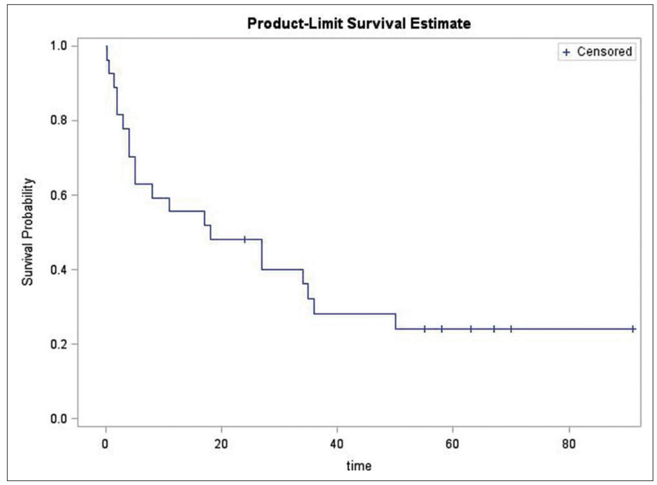

Figure 4: Survival curve after surgery using the Kaplan–Meier method

DISCUSSION

The CCJ and the UCS allow for a complex transition from the skull base onto the subaxial spine. The CCJ joint articulation and ligamentous structures allow for the intricate balance between mobility and stability.[14,15] Invasion of the structures with metastasis disrupts this fine balance and may result in catastrophic biomechanical and functional impairment. Around one-third of cancer patients have spinal metastasis, of which the CCJ is rarely involved.[2,16]

Management of these metastases is mainly determined by the presentation, radiology characteristics, disease status, histology, and survival analysis. All our cases were extensively discussed in the tumor board for consensus regarding the best possible course of action.

Pain is the most common and often presenting symptom in metastasis to the UCS. In contrast, pain following metastasis to the subaxial spine is often a late manifestation, following a fracture or compression.[3] All the patients in our series had moderate-to-severe mechanical pain. Pain was also reported to be the primary complaint in other series.[3,17,18]

The axis was the most common site of metastatic involvement (24/29), where the body of the C2 was involved most often. This pattern was also seen in the series by Bilsky *et al*.[3] and Algra *et al*., in their radiological study of metastasis, found the vertebral body, especially the posterior portion, is first to be involved in metastasis.[19] Pedicles are usually involved once the body is metastasized.[19] Metastasis through the basivertebral venous plexus has been suggested to be the feeder that lodges the tumor emboli in the posterior portions of the vertebral body.[20] The large C2 body with a rich vascular supply favors seeding of metastatic emboli.[21]

Pathological destruction from metastasis excludes the use of any classification system to categorically define instability following metastasis. Since most fractures follow bone lysis, the fracture patterns are not well defined enough to follow surgical guidelines of Hangman, Odontoid, or Jefferson fracture classifications.[22-25] Authors have used trauma classifications to extrapolate fractures from metastasis.[3,17,26-28] Criteria commonly employed include relative position of the odontoid as displacement >5 mm or an angulation of >11°.[3,17] In our series, we only had four cases that exceeded this instability limit. Bilsky *et al*. had 38.4% cases that were unstable.[3] Luksanapruksa *et al*. reported 93.3% of their cases had pathological fracture or instability, although the instability criterion used was not mentioned.[17] Considering these proportions, instability criteria cannot be used in isolation to determine surgical intervention.

SINS is widely used as a guide regarding the management of metastatic disease. Although the scoring system is very effective in decision-making, with good reliability, most patients fall in the intermediate range, where the treatment is not clearly defined.[29] Most of the cases in our series were in the intermediate range (21/29), where further management is based on surgeon judgment. The authors feel that, from a mechanical standpoint, in most cases, it is the clinical and radiological features that determine the surgical option where mechanical pain is the most important and often the only driver determining surgery. Authors have used mechanical instability as "impending" if associated with pain in upright position and neck movements.[17] We feel that such pain association is a strong sign of overt instability and not "impending," and needs intervention.

Overall disease status and survival estimate are equally important for decision-making. A 3-month period has been used by numerous authors to allow the patient to adequately recover from surgery. We used this period of estimated survival for our cases.

As with any unstable cervical spine situation, a cervical brace is often the first line of management for such lesions. A cervical collar does help to reduce pain; however, the pain relief is often not adequate, and the patients end up relying heavily on pharmacological pain management options. In the absence of overt instability or neurological deficit, it is reasonable to try a well-fitting brace and assess pain control.

Prolonged periods of cervical bracing may be cumbersome and associated with complications, including pressure sores. In their study, Bilsky *et al*. reported that patients used collar for a period of at least 6 weeks, after which it was weaned off.[3] In their analysis, Delcourt *et al*. found that cervical collars can have a complication rate ranging from 0% to 44.4%.[30] Sudden deaths from respiratory arrests have also been reported.[5] Conclusive data showing the effectiveness of nonsurgical treatment for metastasis to UCS is lacking. Using the trauma data involving C2 fractures in the geriatric population, Chapman *et al*., in their retrospective review of 322 cases using multivariate analysis, found nonoperative treatment had significantly higher 30-day mortality and operative intervention did not negatively impact survival.[31] Although it does not perfectly reflect the subset of cancer patients who are much more prone to complications following surgery, it does give an impression that conservative options are not risk-free. Considering the associated issues, if a collar is used, its use needs to be closely monitored for any complications.

The other, much more rigid option is the use of a Crown-Halo vest. Halo vests have a higher complication rate as compared to collars, especially in the elderly population. Age (>60 years) has been found to be significantly associated with higher complication in use of Halo vests.[32,33] The incidence of complications associated with Halo vests varies in the literature, between 11% and 92% (most of them between 30% and 50%).[34] Pin-related complications are most frequent. Other complications include respiratory, pneumonia, coughing, etc., Dysphagia may be seen in as high as 66% cases in the study by Bradley *et al*.[35]

Radiotherapy is often used for tumor control and also for pain palliation for metastasis if alignment is acceptable.[36] In the study by Bilsky *et al*., five cases form the initial nonoperative group (radiation with collar) eventually required surgery. Three of those failed radiation treatments developed mechanical instability and two chose for an elective fixation.[3]

The UCS provides a capacious area to the spinal cord. Epidural disease or subluxations are typically not severe enough to cause cord compression.[37,38] We had no patient with neurological deficit. Posterior decompression may be necessary in the presence of significant epidural disease with spinal cord compromise or following spinal canal compromise from marked irreducible bony subluxation.

The goal of surgical treatment in spinal metastasis is not radical resection but palliative pain relief and prevention of neurological deficit.[18]

Primary decompression or resection of tumors is most often necessary for primary malignancies rather than for metastasis.[4,36] Surgical approaches to the CCJ and the UCS include transoral, lateral extrapharyngeal, and mandibular osteotomy.[36,37,39,40] Complications in these approaches have been reported to be as high as 32% and include severe dysphagia, palatal dysfunction, lower cranial neuropathies, need for tracheostomy/gastrostomy, failure of the anterior construct, and infection.[10,28,41-43] Recently, most authors have favored only a posterior approach for stabilization without tumor resection for providing stability, pain relief, and neurological preservation.[3,5,17,36,44,45]

The main reason posterior instrumentation is sufficient perhaps lies in the biomechanics of load transfer to the UCS. Axial load from the occiput is transmitted through the occipital condyles on to the lateral mass of the C1. This transfers down through the C1–C2 joints. The load is primarily distributed by the posterior column (64%) and only 36% by the anterior column, which is in contrast to the lumbar spine.[46] As a result, posterior reconstruction is much more important and usually adequate to regain stability since the anterior structures are not primarily weight bearing.

Complications in our series included two patients who died in the immediate postoperative period from respiratory failure and one other case developed deep wound infection. Other complications that have been reported include loosening of hardware, bacteremia, meningitis, thrombosis, pneumonia, and urinary tract infection.[18,47-49] We routinely involve plastic surgery services for wound closure considering future radiation therapy will benefit from quick and adequate wound coverage.

We used occipital plates and lateral mass screws as the implant of choice. From a biomechanical standpoint, these offer a high fatigue failure.[50] The occipital screws have a high pull out strength when inserted bicortical through the occiput tables. Similarly, lateral mass screws are safe to insert and offer multiple points of distal anchor to prevent failure in torsion. In most cases, the construct needs to be extended distally into the mid cervical spine. This is determined by the extent of lytic destruction, especially of C2 pedicles which offer good screw purchase. Other factors include overall spine alignment and quality of screw purchase. We have a low threshold of extending to the mid cervical spine, considering more anchor points prevent failure in torsion and also higher fatigue failure since fusion is not expected. We avoid ending the construct above a degenerated level to avoid eventual distal junctional failure.

Fusion was not studied in this series. No implant-related complication was seen needing revision. We feel that most implant constructs usually outlive the survival period even if implant fatigue was too set in to be significant. Attempt at fusion and the choice of fusion material is a surgeon's preference. Graft material is matter of debate in cancer surgeries.[51] Fusion mass often suffers from overall poor healing potential, an effect of radiation and chemotherapy. We used only DBM in all cases reported here. Bilsky *et al*. used autologous iliac crest bone graft in patients where the expected survival was longer than 6 months.[3] Other authors have used autograft along with allograft and DBM for fusion with no details of any specific prerequisites.[17,18] In general, autologous bone graft should be avoided in cancer surgeries unless the graft material has been treated.[51] Coumans *et al*. used liquid nitrogen to treat the autologous bone graft before using.[52] None of the above studies utilizing autograft mention details regarding if pretreatment was done to kill the cancer cells. In their meta-analysis, Elder *et al*. suggested that the attempt to achieve fusion should be based on the survival estimate.[51] Oda *et al*. reported 12 months, while Coumans *et al*. reported 6 months, as the minimum life expectancy to attempt fusion.[52,53] Our average survival was 14.5 months. Few other series have reported survival between 6 months and 16 months.[3,17,18] The average fusion time reported by Luksanapruksa *et al*. was 562.56, days which is beyond the survival of 14.5 months in our series.[17] In our series, we used only DBM and observed no failure. It is a matter of further research, if some material (synthetic/allogenic) may be a used to allow speedy and cost-effective fusion; however, the benefits of this fusion mass may not be appreciated clinically.

Although our study had some limitation including single-center, single-arm, retrospective study analyzing only one type of implant, we feel our series adds to the existing literature and discusses the outcome of a technique related to a very unique group of patients with UCS metastasis.

CONCLUSION

Symptomatic metastasis to the UCS can be effectively managed with posterior OCF without tumor resection or anterior reconstruction. The procedure allows for improved clinical outcomes, including pain relief and prevention of neurological decline.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Phillips E, Levine AM. Metastatic lesions of the upper cervical spine. Spine (Phila Pa 1976) 1989;14:1071-7.
2. Sherk HH. Lesions of the atlas and axis. Clin Orthop Relat Res 1975;109:33-41.
3. Bilsky MH, Shannon FJ, Sheppard S, Prabhu V, Boland PJ. Diagnosis and management of a metastatic tumor in the atlantoaxial spine. Spine (Phila Pa 1976) 2002;27:1062-9.
4. George B, Archilli M, Cornelius JF. Bone tumors at the cranio-cervical junction. Surgical management and results from a series of 41 cases. Acta Neurochir (Wien) 2006;148:741-9.
5. Nakamura M, Toyama Y, Suzuki N, Fujimura Y. Metastases to the upper cervical spine. J Spinal Disord 1996;9:195-201.
6. Rao S, Badani K, Schildhauer T, Borges M. Metastatic malignancy of the cervical spine. A nonoperative history. Spine (Phila Pa 1976) 1992;17:S407-12.
7. Hertlein H, Mittlmeier T, Schürmann M, Lob G. Posterior stabilization of C2 metastases by combination of atlantoaxial screw fixation and hook plate. Eur Spine J 1994;3:52-5.
8. Sjöström L, Olerud S, Karlström G, Hamberg M, Jonsson H. Anterior stabilization of pathologic dens fractures. Acta Orthop Scand 1990;61:391-3.
9. Sundaresan N, Galicich JH, Lane JM, Greenberg HS. Treatment of odontoid fractures in cancer patients. J Neurosurg 1981;54:187-92.
10. Dunn EJ, Anas PP. The management of tumors of the upper cervical spine. Orthop Clin North Am 1978;9:1065-80.
11. Harrington KD. Anterior cord decompression and spinal stabilization for patients with metastatic lesions of the spine. J Neurosurg 1984;61:107-17.
12. Piper JG, Menezes AH. Management strategies for tumors of the axis vertebra. J Neurosurg 1996;84:543-51.
13. Rea GL, Mullin BB, Mervis LJ, Miller CL. Occipitocervical fixation in nontraumatic upper cervical spine instability. Surg Neurol 1993;40:255-61.
14. Bonadio WA. Cervical spine trauma in children: Part I. General concepts, normal anatomy, radiographic evaluation. Am J Emerg Med 1993;11:158-65.
15. Goel VK, Clark CR, Gallaes K, Liu YK. Moment-rotation relationships of the ligamentous occipito-atlanto-axial complex. J Biomech 1988;21:673-80.
16. Fornasier VL, Horne JG. Metastases to the vertebral column. Cancer 1975;36:590-4.
17. Luksanapruksa P, Buchowski JM, Wright NM, Valone FH 3rd, Peters C, Bumpass DB, *et al.* Outcomes and effectiveness of posterior occipitocervical fusion for suboccipital spinal metastases. J Neurosurg Spine 2017;26:554-9.
18. Fourney DR, York JE, Cohen ZR, Suki D, Rhines LD, Gokaslan ZL. Management of atlantoaxial metastases with posterior occipitocervical stabilization. J Neurosurg 2003;98:165-70.
19. Algra PR, Heimans JJ, Valk J, Nauta JJ, Lachniet M, Van Kooten B. Do metastases in vertebrae begin in the body or the pedicles? Imaging study in 45 patients. AJR Am J Roentgenol 1992;158:1275-9.
20. Coman DR, DeLong RP. The role of the vertebral venous system in the metastasis of cancer to the spinal column; experiments with tumor-cell suspensions in rats and rabbits. Cancer 1951;4:610-8.
21. Cirpan S, Sayhan S, Yonguc GN, Eyuboglu C, Güvençer M, Naderi S. Surgical anatomy of neurovascular structures related to ventral C1-2 complex: An anatomical study. Surg Radiol Anat 2018;40:581-6.
22. Landells CD, Van Peteghem PK. Fractures of the atlas: Classification, treatment and morbidity. Spine (Phila Pa 1976) 1988;13:450-2.
23. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis 1974. J Bone Joint Surg Am 2004;86:2081.
24. Grauer JN, Shafi B, Hilibrand AS, Harrop JS, Kwon BK, Beiner JM, *et al.* Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J 2005;5:123-9.
25. Verheggen R, Jansen J. Hangman's fracture: Arguments in favor of surgical therapy for type II and III according to Edwards and Levine. Surg Neurol 1998;49:253-61.
26. Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. J Bone Joint Surg Am 1974;56:1663-74.
27. Clark CR, White AA 3rd. Fractures of the dens. A multicenter study. J Bone Joint Surg Am 1985;67:1340-8.
28. Dunn ME, Seljeskog EL. Experience in the management of odontoid process injuries: An analysis of 128 cases. Neurosurgery 1986;18:306-10.
29. Fourney DR, Frangou EM, Ryken TC, Dipaola CP, Shaffrey CI, Berven SH, *et al.* Spinal instability neoplastic score: An analysis of reliability and validity from the spine oncology study group. J Clin Oncol 2011;29:3072-7.
30. Delcourt T, Bégué T, Saintyves G, Mebtouche N, Cottin P. Management of upper cervical spine fractures in elderly patients: Current trends and outcomes. Injury 2015;46 Suppl 1:S24-7.
31. Chapman J, Smith JS, Kopjar B, Vaccaro AR, Arnold P, Shaffrey CI, *et al.* The AOSpine North America geriatric odontoid fracture mortality study: A retrospective review of mortality outcomes for operative versus nonoperative treatment of 322 patients with long-term follow-up. Spine (Phila Pa 1976) 2013;38:1098-104.
32. Bransford RJ, Stevens DW, Uyeji S, Bellabarba C, Chapman JR. Halo vest treatment of cervical spine injuries: A success and survivorship analysis. Spine (Phila Pa 1976) 2009;34:1561-6.
33. Boakye M, Arrigo RT, Kalanithi PS, Chen YR. Impact of age, injury severity score, and medical comorbidities on early complications after fusion and halo-vest immobilization for C2 fractures in older adults: A propensity score matched retrospective cohort study. Spine (Phila Pa 1976) 2012;37:854-9.
34. Lee D, Adeoye AL, Dahdaleh NS. Indications and complications of crown halo vest placement: A review. J Clin Neurosci 2017;40:27-33.
35. Bradley JF 3rd, Jones MA, Farmer EA, Fann SA, Bynoe R. Swallowing dysfunction in trauma patients with cervical spine fractures treated with halo-vest fixation. J Trauma 2011;70:46-8.
36. Moulding HD, Bilsky MH. Metastases to the craniovertebral junction. Neurosurgery 2010;66:113-8.
37. Atanasiu JP, Badatcheff F, Pidhorz L. Metastatic lesions of the cervical spine. A retrospective analysis of 20 cases. Spine (Phila Pa 1976) 1993;18:1279-84.
38. Colak A, Kutlay M, Kibici K, Demircan MN, Akin ON. Two-staged operation on C2 neoplastic lesions: Anterior excision and posterior stabilization. Neurosurg Rev 2004;27:189-93.
39. Jones KM, Schwartz RB, Mantello MT, Ahn SS, Khorasani R, Mukherji S, *et al.* Fast spin-echo MR in the detection of vertebral metastases: Comparison of three sequences. AJNR Am J Neuroradiol 1994;15:401-7.
40. Hastings DE, Macnab I, Lawson V. Neoplasms of the atlas and axis. Can J Surg 1968;11:290-6.
41. Jones DC, Hayter JP, Vaughan ED, Findlay GF. Oropharyngeal morbidity following transoral approaches to the upper cervical spine. Int J Oral Maxillofac Surg 1998;27:295-8.
42. Jónsson B, Jónsson H Jr., Karlström G, Sjöström L. Surgery of cervical spine metastases: A retrospective study. Eur Spine J 1994;3:76-83.
43. Rhines LD, Fourney DR, Siadati A, Suk I, Gokaslan ZL. En bloc resection of multilevel cervical chordoma with C-2 involvement. Case report and description of operative technique. J Neurosurg Spine 2005;2:199-205.
44. Fehlings MG, David KS, Vialle L, Vialle E, Setzer M, Vrionis FD.

Decision making in the surgical treatment of cervical spine metastases. Spine (Phila Pa 1976) 2009;34:S108-17.

45. Fung KY, Law SW. Management of malignant atlanto-axial tumours. J Orthop Surg (Hong Kong) 2005;13:232-9.
46. Pal GP, Sherk HH. The vertical stability of the cervical spine. Spine (Phila Pa 1976) 1988;13:447-9.
47. Kirchner R, Himpe B, Schweder B, Jürgens C, Gille JJ, Faschingbauer M. The clinical outcome after occipitocervical fusion due to metastases of the upper cervical spine: A consecutive case series and a systematic review of the literature. Z Orthop Unfall 2014;152:358-65.
48. Zimmermann M, Wolff R, Raabe A, Stolke D, Seifert V. Palliative occipito-cervical stabilization in patients with malignant tumors of the occipito-cervical junction and the upper cervical spine. Acta Neurochir (Wien) 2002;144:783-90.
49. Vieweg U, Meyer B, Schramm J. Tumour surgery of the upper cervical spine – A retrospective study of 13 cases. Acta Neurochir (Wien) 2001;143:217-25.
50. Zipnick RI, Merola AA, Gorup J, Kunkle K, Shin T, Caruso SA, *et al.* Occipital morphology. An anatomic guide to internal fixation. Spine (Phila Pa 1976) 1996;21:1719-24.
51. Elder BD, Ishida W, Goodwin CR, Bydon A, Gokaslan ZL, Sciubba DM, *et al.* Bone graft options for spinal fusion following resection of spinal column tumors: Systematic review and meta-analysis. Neurosurg Focus 2017;42:E16.
52. Coumans JV, Marchek CP, Henderson FC. Use of the telescopic plate spacer in treatment of cervical and cervicothoracic spine tumors. Neurosurgery 2002;51:417-24.
53. Oda I, Abumi K, Ito M, Kotani Y, Oya T, Hasegawa K, *et al.* Palliative spinal reconstruction using cervical pedicle screws for metastatic lesions of the spine: A retrospective analysis of 32 cases. Spine (Phila Pa 1976) 2006;31:1439-44.