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Axial Spondylectomy and Circumferential Reconstruction via a Posterior Approach

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Abstract

Background—Spinal metastases of the second cervical vertebra are a subset of tumors that is particularly difficult to address surgically. Previously described techniques require highly morbid circumferential dissection posterior to the pharynx for resection and reconstruction.

Objective—To perform a biomechanical analysis of instrumented reconstruction configurations used after axial spondylectomy and demonstrate safe use of a novel construct in a patient case report.

Methods—Several different published and novel reconstruction configurations were inserted into 7 occipitocervical spines that underwent axial spondylectomy. A biomechanical analysis of the constructs' stiffness in flexion and extension, lateral bending, and rotation was performed. A patient then underwent a posterior-only approach for axial spondylectomy and circumferential reconstruction.

Results—Biomechanical analysis of different constructs demonstrated that anterior column reconstruction with bilateral cages spanning C1 lateral mass to C3 facet in combination with occipitocervical instrumentation was superior in flexion-extension and equivalent in lateral bending and rotation to currently used constructs. In the patient in which this construct was placed via a posterior-only approach for axial spondylectomy and instrumentation, the patient remained at neurological baseline and demonstrated no recurrence of local disease or failure of instrumentation to date.

Conclusion—When comparing C1 lateral mass to C3 facet bilateral cage plus occipitocervical instrumentation to existing anterior and posterior constructs, this novel reconstruction is biomechanically equivalent if not superior in performance. In a patient, the posterior-only approach for C2 spondylectomy with the novel reconstruction was safe, durable, and avoided the morbidity of the anterior approach.

Keywords

axis; biomechanics; C2; metastasis; occipitocervical fusion; spine; vertebrectomy

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1. They were on the design team for a corpectomy cage that was not used in the study.
2. They performed consulting work pertaining to spinal biologics.
3. Globus Medical Corporation provides partial funding for Dr. Kelly's fellowship position.

Introduction

Metastatic disease of the spine is an increasingly prevalent source of morbidity, affecting 5-10 % of all cancer patients.¹ Patchell et al demonstrated that decompression plus radiation is superior to radiation alone.² Additionally, operative management of metastatic spine lesions has been demonstrated to improve pain and neurological function.³

Lesions of the second cervical vertebra present challenges to the surgeon considering a spondylectomy and reconstruction at that level. Significant bony resection at this level may be indicated for primary spine tumors or metastatic disease. Performing a tumor resection in this region requires the surgeon to operate around the rostral cervical spinal cord, avoid pharyngeal injury, and preserve the vertebral arteries. Finally, after successful resection, the spine must be reconstructed. Despite these challenges, successful resection and stabilization have been previously reported in the literature.⁴⁻⁹ Biomechanical analysis by Scheer et al demonstrates that anterior column support combined with posterior craniocervical instrumentation is adequate and sufficient to reconstruct the defect created by C2 spondylectomy.¹⁰

A biomechanical analysis is presented of several constructs that provide occipitocervical fixation and anterior column support. Finally, we present a case report of a novel posterior-only circumferential reconstruction following bilateral transpedicular C2 spondylectomy.

Materials and Methods

Specimen Preparation

Seven fresh human cadaver occipitocervical spines (occiput-C5) were used in this investigation. The specimens were obtained from MedCure© (Portland, OR) tissue bank. The specimens were harvested from one female and six male cadavers (mean age at death, 59 ± 6 years). Dual-energy radiograph absorptiometry (QDRA-010; Hologic Discovery, Waltham, MA, USA) was used to quantify the bone mineral density of the specimens (mean bone mineral density, 0.95 ± 0.26 g/cm²). The spines were radiographed in the anteroposterior and lateral planes to ensure the absence of fractures, deformities and any metastatic disease. The spines were carefully denuded of paravertebral musculature while preserving the spinal ligaments, joints and disc spaces. Each spine was potted proximally at occiput and distally at C5 in a 3:1 mixture of Bondo auto body filler (Bondo MarHyde Corp, Atlanta, GA) and fiberglass resin (Home-Solution All Purpose Bondo MarHyde Corp). Plexiglas markers, each having three infrared light-emitting diodes, were secured rigidly to the anterior aspect of each vertebral body via bone screws to track motion with the Optotrak Certus [NDI, Inc. Waterloo, Canada] motion analysis system. The location of the markers (denoting a rigid body) was aligned sagittally along the curvature of the spine. The Optotrak Certus software superimposes the coordinate systems of two adjacent vertebral bodies in order to inferentially determine the relative Eulerian rotations in each of the three planes. The markers were placed at C1 and C3.

Flexibility Testing

The occiput of each spine was fixed to the load frame of a custom built six-degree-of-freedom spine simulator, and a pure moment was applied to the construct through servomotors.¹¹⁻¹³ The specimen was maintained moist throughout the test by spraying it with 0.9% saline. All tests were carried out at room temperature of 25° Celsius. Each of the test constructs were subjected to three load-unload cycles in each of the physiologic planes generating flexion, extension, right-left lateral bending and right-left axial rotation load displacement curves. This was achieved by programming the motors to apply continuous moments in each physiologic plane. A typical load-unload cycle in the sagittal plane

comprised of Neutral-Full Flexion + Full Extension -Neutral (3 times). Data from the third cycle was considered for analysis. The design of the load frame enables unconstrained motion of the spine in response to an applied load. There was no compressive preload applied on the specimen.¹⁴ A load control protocol was used to apply a maximum moment of ± 1.5 Nm at a rate of $1^\circ/\text{sec}$.^{11,15,16}

The three dimensional intervertebral rotation was obtained from the Optotrak Certus data files in the form of Euler angles (degrees) about the X, Y and Z axes: $+R_x / -R_x$, $+R_y / -R_y$ and $+R_z / -R_z$ denoting flexion-extension, right-left axial rotation and right-left lateral bending range of motion (ROM), respectively. The Euler sequence used was xzy.

Study Design

Each of the seven spines was initially tested in the intact state. Following intact testing, all specimens were posteriorly instrumented from occiput-C5 using occipital plate and lateral mass screw fixation from C1-C5 (excluding C2) and a 3.5 mm titanium rod (ELLIPSE® Occipito-Cervico-Thoracic-Stabilization System, Globus Medical, Inc. Audubon, PA). An anterior corpectomy was performed at C2. The following constructs then underwent testing (Figure 1): In construct “1C” an expandable cage (XPand Corpectomy Spacer System, Globus Medical, Inc.) was used to reconstruct the body of C2 (Figure 1A). Next, a C2 spondylectomy was completed with preservation of the dens. Anterior reconstruction was performed with two struts of PMMA connecting the anterior body of C3 to the C1 facets (construct “PMMA”, Figure 1B). Posterior instrumentation was then adjusted to translate the skull such that the C1 and C3 facets were in the same plane (visual confirmation). In construct “2C” two expandable cages were inserted connecting the C3 facets to C1 facets (Figure 1C). We then removed the C1 anterior ring and odontoid process and inserted a single expandable cage spanning from C3-Clivus (construct “1C_{cliv}”, Figure 1D). Lastly, posterior instrumentation alone without anterior reconstruction (construct “PI”, Figure 1E) was considered as a worst-case scenario. The constructs were tested in the order mentioned. The 2C construct was tested before PMMA to remain conservative against the possibility of bias, as the cages were manufactured by the study sponsor. The radiographic images for the different constructs are provided in Figure 2. In the operative setting, constructs A, B, D, and E are achieved using combined anterior-posterior approaches, whereas construct C can be prepared using a posterior-only approach.

All constructs were subjected to the same load control protocol for flexibility testing as described earlier. Range of motion data at C1-C3 were obtained for all constructs in flexion-extension, lateral bending, and axial rotation. To avoid inhomogeneity of variance and allow for parametric statistical analysis, log transforms were applied to the raw data. Due to the small number of comparisons, alpha-value slippage concerns were ignored. Comparison of data was performed using t-tests assuming equal variance with a significance level of 0.05.

Results

The range of motion (ROM) values are presented for all constructs and loading modes in Figure 3, along with statistical comparisons. All the instrumented constructs significantly ($p < 0.05$) reduced ROM compared to the intact spine in all loading modes (data not shown).

Flexion-extension

The intact spine had a stiffness of 0.14 ± 0.04 N-m/ $^\circ$ in flexion-extension. All anterior reconstruction groups demonstrated increased stability when compared to both stand alone posterior occipitocervical instrumentation (PI), and the intact condition ($p < 0.05$). The ranking in stiffness from lowest to highest was PMMA (1.58 ± 0.99 N-m/ $^\circ$), 1C (1.83 ± 1.7 N-

m/°), 1C_{cliv} (2.29±0.93 N-m/°), and 2C (3.67±2.1 N-m/°). Statistically, the novel dual cage construct connecting the C3 facets to the C1 facets was stiffer than the PMMA construct. When compared to the PI construct (0.46±0.18 N-m/°), even the least stable anterior instrumentation (PMMA) increased the stiffness by 240%.

Lateral Bending

The intact spine had a stiffness of 0.20±0.06 N-m/° in lateral bending. Posterior instrumentation alone was particularly effective in lateral bending and had a stiffness of 4.34±2.37 N-m/°. The ranking in stiffness from lowest to highest was PMMA (5.23±5.47 N-m/°), 1C_{cliv} (5.65±2.78 N-m/°), 1C (8.07±5.72 N-m/°), and 2C (8.85±7.18 N-m/°). However, there were no statistical differences between any of the constructs. All of the constructs were statistically stiffer than the intact condition.

Axial Rotation

The intact spine had a stiffness of 0.02±0.003 N-m/° in axial rotation. In axial rotation, only the PMMA construct demonstrated a statistical increase in stability when compared to PI. The ranking in stiffness from lowest to highest was 1C_{cliv} (0.75±0.289 N-m/°), 1C (1.08±0.59 N-m/°), 2C (1.21±0.377 N-m/°), and PMMA (1.36±0.348 N-m/°). Conversely, PMMA, which demonstrated the worst stability in flexion-extension and lateral bending, demonstrated high stability in axial rotation. Both the PMMA and 2C constructs had improved stability with respect to 1C_{cliv} (p<0.05).

CASE REPORT

History

We report the management of a 27 year old man with metastatic Ewing Sarcoma. This patient was first diagnosed with left pelvic Ewing Sarcoma at age 23. His presenting symptom was sciatica due to tumor mass effect on the sciatic nerve. He underwent neoadjuvant chemotherapy followed by internal hemipelvectomy and reconstruction. He then underwent chemotherapy and radiation approximately three months after surgery. He was disease-free for approximately four years with regular follow-up including chest, abdomen and pelvis CT as well as tumor marker serology.

Four and a half years after initial diagnosis, this patient suffered a ground level fall after which he reported severe suboccipital neck pain. He presented to another hospital, where imaging revealed a pathologic fracture of the axis with significant tumor involvement (Figure 4). His cervical spine was stabilized with a halo orthosis and he was referred to our institution for further management. He was offered intralesional resection with reconstruction in order to stabilize his craniocervical junction and provide local control of his lesion.

Surgery

Two weeks after his injury, he was brought to the operating room. He underwent fiber optic endotracheal intubation and neuromonitoring. The halo was removed and a hard cervical collar was placed. The patient was rolled prone and his head secured with a Mayfield head holder. The occiput and the posterior cervical spine were exposed through a standard midline approach. C1 and C2 and partial C3 laminectomies were performed. The C2 and C3 nerve roots were ligated and divided. C1 lateral mass and C4 lateral mass screws were placed and a temporary fixation rod would be used on alternating sides to stabilize the spine during axis resection. The codominant vertebral arteries were identified in the sulcus arteriosus of the atlas, and mobilized bilaterally. Their location at the C1 foramen transversarium was identified for distal vascular control if needed. The pneumatic drill,

curettes and pituitary rongeurs were used to perform a transpedicular resection of the tumor, C2 pedicles and body of the axis (Figure 5). The patient was then translated posteriorly to facilitate linear alignment of the C1 lateral masses and the trimmed C3 superior articular processes. Expandable titanium cages were then adjusted to size, packed with morselized allograft and then used to span the C1 lateral masses and the trimmed C3 superior articular processes (Figure 6). Patency of the vertebral arteries was verified with intraoperative ultrasound after posterior translation of the cranium and cage placement. C3 to C5 lateral mass screws were then placed, as was an occipital plate and screw system. Rods were then placed and the C1 and C3 lateral mass screws were gently compressed to ensure adequate cage contact and loading. The C3-5 lateral masses, remaining C1 arch, and occiput were decorticated and the surfaces packed with allograft. Post-operative imaging is shown in Figure 7.

Follow-up

The patient remained neurologically intact after surgery. The patient started high dose chemotherapy and autologous stem cell rescue 3 weeks after surgery. He was given 5 months for the aggressive chemotherapy regimen and ensuing recovery. He then underwent 56 Gray of intensity modulated radiation therapy delivered via a linear accelerator over the course of 8 weeks. 24 months after surgery the patient is at his neurological baseline and imaging demonstrated no evidence of tumor recurrence or instrumentation failure.

DISCUSSION

We compared the biomechanical properties of several axial spondylectomy constructs including those proposed by Sheer et al ¹⁰ and a novel construct through which loads from the C1 lateral masses are transmitted to the C3 facets using dual expandable cages. These findings concur with the current principles of spinal oncology that indicate the need for anterior and posterior reconstructions after spondylectomy.^{17,18} Furthermore, we demonstrate in combination with occipitocervical instrumentation, the C1 lateral mass to C3 facet double cages provide enhanced stability in flexion-extension and axial rotation compared to the PMMA and clival to C3 constructs, respectively. Admittedly, the clinical relevance of this superior biomechanical performance remains to be proven, but biomechanical data supports its consideration for particular clinical indications. The novel method for C1-3 anterior stabilization is at a minimal equivalent to current constructs and has, for the patient and surgeon, distinct advantages, namely avoidance of retropharyngeal instrumentation, which can lead to post-radiation pharyngeal erosion, as well as anterior approach morbidity.

Technically, the placement of the cages spanning the C1 lateral masses to the C3 facets is now feasible largely due to advancements in expandable cage technology. Distractible cages have been successfully used in oncologic spinal instrumentation for many years¹⁹. A recent case series demonstrated effective use of cage reconstruction in the subaxial and cervicothoracic spine.²⁰ The advantages include easier insertion and in situ expansion to maximize end plate contact. For C2 reconstruction, the smaller pre-distraction size and lack of sharp edges (resulting from sizing traditional Harm's cages) also facilitates placement of the cage while minimizing potential injury of the vertebral arteries. Additionally, use of expandable cages avoids the drawbacks of methylmethacrylate, which have been well documented, and include thermal injury, displacement, neurological injury and embolization.²¹⁻²⁸ A case series of axial vertebroplasties described the technique as a "challenging procedure" with higher risk than vertebroplasty in the thoracolumbar spine.²⁹ Finally, the use of the C1 lateral mass as the point of rostral contact for the expandable cage was advantageous in that this portion of the atlas is load-bearing under physiological conditions.

Complete spondylectomy can be achieved via a combined anterior and posterior or a posterior-only approach. A circumferential approach facilitates anterior cage placement but has disadvantages. The most obvious is the requirement of two separate incisions with the corresponding increase in operative time and morbidity. Anterior approaches, particularly pharyngeal incisions, have the risk of incision complications and dysphasia. Expected dysphagia and upper airway problems may lead to the need for gastrostomy, tracheostomy or both.⁶ Furthermore, the anterior instrumentation is in close proximity to the pharynx. This is particularly concerning because retropharyngeal instrumentation carries the risk of hardware exposure in patients who receive radiation and/or are malnourished due to systemic disease and/or dysphagia. Previously described posterior approaches limit dysphasia, but still place reconstructive material posterior to the pharyngeal wall. A recent review demonstrates that posterior fusion may be associated with transient dysphagia, but anterior approaches to the cervical spine are more often associated with this problem.³⁰ One series prophylactically kept patients endotracheally intubated and mechanically ventilated for at least 12 hours after a submandibular axial vertebrectomy in order to prevent complications related to the retropharyngeal dissection.⁸

A potential pitfall of our approach is the fact that the establishment of the bilateral transpedicular corridor requires bilateral sacrifice of the C2 and C3 nerve roots. Axial spondylectomy can be done with combined anterior and posterior incisions with preservation of all neurovascular structures, as advocated by some.^{6,31} However, preservation of the rostral cervical nerve roots is not necessary, with many surgeons advocating their routine sacrifice in atlantoaxial fusion. Indeed, a recent large case series demonstrates that C2 neurectomy is benign and facilitates exposure as well.³²

Other potential difficulties include the challenge of completely resecting the dens. Without the use of lateral ports and an endoscope, it is doubtful that total dens resection can be completed. Additionally, increased manipulation of the vertebral arteries is necessary and potentially increases the risk of damage leading to devastating neurological compromise. We recommend preoperative CT angiogram to discern which vertebral artery is dominant for intraoperative decision-making if injury were to occur. Single non-dominant arterial injury is well tolerated by most patients. As with other types of C2 instrumentation, dissection or manipulation of contralateral intact vertebral artery should be avoided if vertebral artery injury occurs. And finally, not to be understated, the placement of the cage is difficult due to the more posterior location of the C3 facet and its slope. Creative use of lordotic endcaps and drilling of the C3 facet is required for a good fit.

CONCLUSION

Axial spondylectomy is a challenging operation due to limited access, surrounding anatomical structures, and the need for robust reconstruction. Expandable cages spanning from the lateral masses of C1 to the superior articular processes of C3 combined with multisegment posterior occipitocervical fixation provide solid reconstruction of C2 spondylectomy that can be accomplished through a single surgical approach. Though technically difficult, this technique produces a construct that is at least biomechanically equivalent to all tested configurations of circumferential reconstruction and avoids many of the shortcomings of those alternative constructs. Further clinical experience will be needed to validate the utility of this technique.

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Figure 1.

Photographs of cadaveric occipitocervical constructs tested. (A) C2 corpectomy with cage spanning from anterior arch of C1 to the body of C3, posterior view and anterior view, (B) Complete spondylectomy of C2 with Steinman pins and methylmethacrylate spanning from C1 lateral masses to the body of C3, (C) Complete spondylectomy of C2 with cages spanning from the C1 lateral masses to the C3 facets (D) Complete spondylectomy of C2 and resection of anterior arch of C1 with cage spanning from the clivus to C3 body, (E) Posterior occipitocervical fixation without any other reconstruction after C2 spondylectomy and C1 anterior arch resection.

Figure 2.

Corresponding radiographs of the constructs created for biomechanical testing. (A) C2 corpectomy with cage spanning from anterior arch of C1 to the body of C3, posterior view and anterior view, (B) Complete spondylectomy of C2 with Steinman pins and methylmethacrylate spanning from C1 lateral masses to the body of C3, (C) Complete spondylectomy of C2 with cages spanning from the C1 lateral masses to the C3 facets (D) Complete spondylectomy of C2 and resection of anterior arch of C1 with cage spanning from the clivus to C3 body, (E) Posterior occipitocervical fixation without any other reconstruction after C2 spondylectomy and C1 anterior arch resection.

Figure 3.

Results of cadaveric testing. The stiffness of each construct in (A) flexion-extension, (B) lateral bending and (C) axial rotation is depicted in the graphs. Significant differences ($p < 0.05$) are noted (“*”). Though superior in some aspects, the overall performance of the C1 lateral mass to C3 facet construct was generally equivalent to previously used constructs for C2 reconstruction.

Figure 4.

Preoperative sagittal images demonstrated the tumor involvement and pathological fracture of the C2 vertebra. T2 weighted (A) T1 weighted post contrast (B) and computed tomography images (C).

Figure 5.

Technique for posterior decompression of C2. An intraoperative lateral cervical spine radiograph is shown (A) Temporary fixation is achieved with a unilateral C1-3 screw and rod construct. The vertebral arteries have been mobilized. An axial corpectomy via the transpedicular corridor is performed using the pneumatic drill. An artist's depiction of the same (B).

Figure 6.

Artist's rendition of the expandable cages spanning the C1 lateral masses to C3 facets. (A) Lateral image of left cage placement between left C1 lateral mass and left C3 superior facet. (B) Posterior view of bilateral cage construct. Note the C3 superior facet needs to be trimmed to facilitate flush surface contact of the endplates of the cage to the surfaces of C1 and C3. The C1 and C3 screws and temporary rods were excluded in this illustration to clearly demonstrate the cage construct.

Figure 7.

Postoperative images demonstrating Occiput to C5 fusion with cages spanning the C1 lateral masses to C3 facets. Sagittal (A) and coronal (B) computed tomography reconstructions with patent vertebrobasilar flow on coronal views. Lateral cervical (C) anteroposterior (D) and spine radiographs taken two years post-operatively.