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ORIGINAL ARTICLE

Posterior unilateral exposure and stability reconstruction with pedicle and lamina screw fixation for the cervical dumbbell tumorectomy: a case report and biomechanical study

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Abstract

Purpose Cervical dumbbell tumor is usually removed via a posterior approach and may require the spinal fixation sometimes. However, the present surgical methods involved either more trauma or a higher risk of instability of the cervical spine. A new technique of unilateral exposure and stability reconstruction with pedicle and lamina screws fixation for posterior cervical dumbbell tumorectomy was described and compared with conventional techniques.

Methods Posterior unilateral exposure, hemi-laminectomy and facetectomy were performed in one patient with the cervical dumbbell tumor between C3 and C4. The stability was reconstructed by the unilateral pedicle and lamina screws fixation (UPLS), and a strip of shaped allograft bone was also implanted between the superior and inferior lateral mass. Biomechanical stability test of this new technique was investigated using seven fresh-frozen human cervical spine specimens (C4–C7) and compared with unilateral pedicle screw (UPS) and bilateral pedicle screw fixation (BPS) techniques. A continuous pure moment of ± 2.0 Nm was applied to the specimen in flexion, extension, lateral bending and axial rotation.

Results The cervical dumbbell tumor was removed completely, and bone fusion with continuous bone trabecula was maintained in the patient on the final follow-up examination at 18 months postoperatively. Biomechanical stability tests revealed that the range of motion of the UPLS fixation plus graft bone implant was the same as the BPS fixation in flexion (1.8°vs. 1.5°, $p = 0.58$) and extension (2.3°vs. 2.2°, $p = 0.73$), but significantly bigger in lateral bending (3.9° vs. 1.0°, $p < 0.001$) and axial rotation (6.8° vs. 3.8°, $p = 0.002$), which were significantly smaller than the UPS fixation in all directions (all $p < 0.001$).

Conclusions For the treatment of cervical dumbbell tumor, posterior unilateral exposure and stability reconstruction with pedicle and lamina screws fixation following hemi-laminectomy and facetectomy appear to be a more stable and lesser trauma technique.

Level of evidence Diagnostic: individual cross-sectional studies with consistently applied reference standard and blinding.

Keywords Dumbbell tumor · Cervical spine · Mechanical testing · Biomechanical stability

Introduction

Spinal dumbbell tumor, firstly described as an intra/extra-spinal tumor of neural origin, usually grows across the bony neural foramen and the dura of the nerve root sleeve [1, 2], with incidence of 13–17% in spinal cord tumors [3, 4]. The majority of dumbbell tumors are schwannomas, frequently located at the cervical spine [5, 6]. To eliminate the cervical dumbbell tumor requires complete resection of the lesion and the maximal reduction in neurological symptoms and minimal neurological deficits after the surgery [7].

However, spinal deformity occurs in up to 18% of adult patients after laminectomy; it would be higher when combined with facetectomy [8, 9]. Therefore, it was recommended that spinal fixation and fusion would be required when more than 50% of the facet joint was resected [10, 11]. In certain cases, such as malignant tumors, erosion or destruction of bone was already present. The loss of bone has the potential effect to the stability of spinal column,

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so fusion with instrumentation is sometimes required to prevent complications such as pain, deformity or loss of neurological function. Until now, after the cervical dumbbell tumor removed, there are two kinds of fixation methods for the stability reconstruction of the cervical spine: (1) The ipsilateral pedicle screws/lateral mass screws and rod/plate fixation, facing a higher risk of instability [4, 9, 12, 13]; (2) The bilateral pedicle screws/lateral mass screws and rods fixation, involving a larger soft tissue exposure and bony defect [14–16].

Therefore, for the cervical dumbbell tumorectomy after hemi-laminectomy and facetectomy, we introduce a new technique that consists of posterior unilateral exposure and stability reconstruction with pedicle and lamina screws fixation and graft bone implant to restore the spinal stability, which we hypothesize that it would not only have a well biomechanical stability but also a less trauma. A description of the method, a report of clinical experience in one case, and the results of comparative biomechanical testing of three different posterior cervical fixation methods are provided.

Materials and methods

Case

A 50-year-old woman complained neck pain and numbness in her left side for three years. Preoperatively, images of the contrast enhancement MRI showed a crumbly tumor at the C3, C4 level and a large mass extension into the vertebral body, intra- and extradural region. The coronal CT image showed the lesion involving the C3 and C4 vertebrae, neuro-foramina and the posterior facet joints on the left side (Fig. 1).

Surgery was done by 2 surgeons with relevant experience of 5–10 yrs. After general anesthesia and intubation, the patient was placed in the prone position with the head maintained in the neutral position with three-pin head holder. A longitudinal midline incision was made and a subperiosteal dissection was done at the involving side. In order to expose the distal part of the tumor, muscles were dissected from the superior to the inferior vertebrae and laterally to the lateral part of the facet joint. For the exposure of the intervertebral foramen tumor, the traction of muscle was performed as lateral as possible to fully expose the distal part of the tumor. The left hemi-laminectomy and unilateral facetectomy of

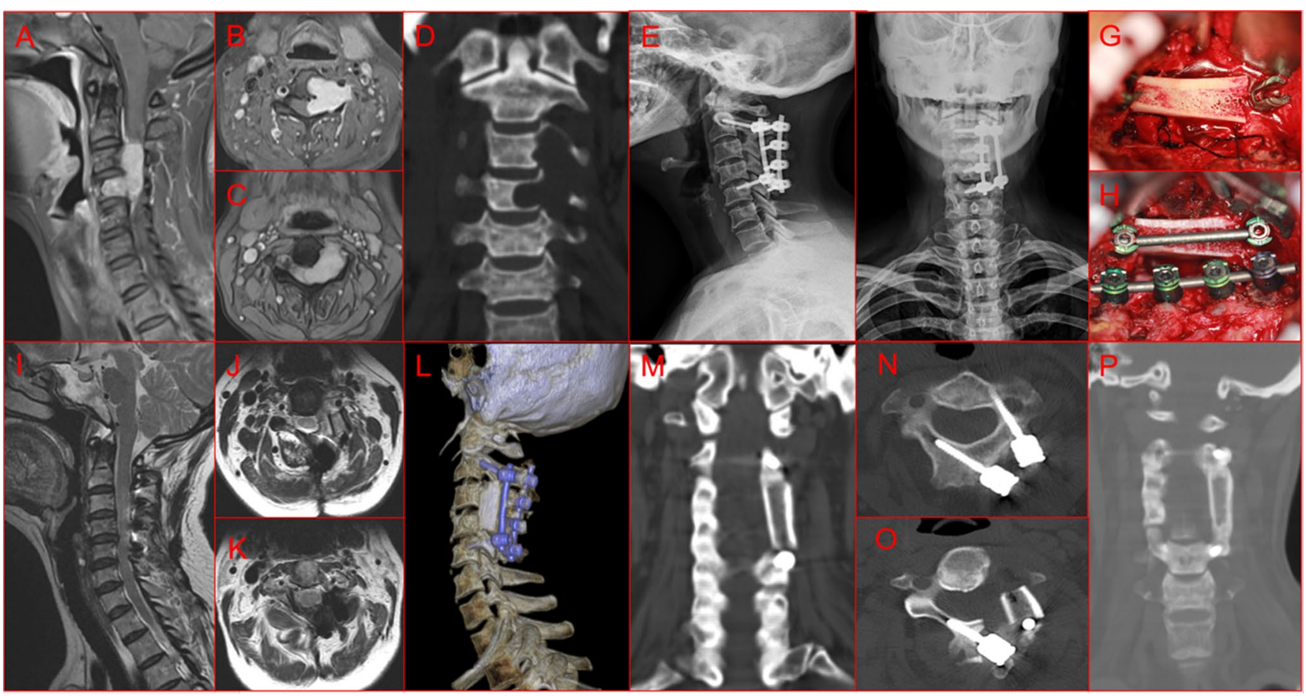

Fig. 1 A 50-year-old woman. **a–d** A crumbly tumor at the C3, 4 level involving the C3 and C4 vertebrae, neuroforamina and the posterior facet joints on the left side. **e, f** The stability was reconstructed by the fixation of the C2 and C5 pedicle screw plus C2–C5 laminar screws connected with the titanium rod. **g, h** Intraoperative photograph revealed a strip allogenic bone was implanted between lateral masses of C2 and C5. **i, j, k** MRI after surgery showed complete removal of the tumor and fluid collection. At one month postoperatively, the CT images showed the correct positioning of the fixation device, **l–o** and graft bone fusing was observed at 18-month follow-up **p**

C3 and C4 were performed. The intradural tumor component was first removed by standard microsurgical techniques. Blunt dissection along the tumor capsule longitudinally and laterally was performed to expose the margin of the intra spinal portion. Removal of the foraminal and extraforaminal tumor components were performed by resecting within the capsule and from inside to outside along the vertebral foramen. Removal within the capsule can avoid vertebral artery injury and venous plexus bleeding. The capsule should be separated to the normal nerve root when it was not determined whether there was residual tumor in the distal part. With the tenacity and large range of mobility of the distal nerve root, it could be pulled enough to expose and resect the residual tumor completely.

The defect of dura was carefully sutured by biological artificial dura. According to the space between the C2 and C5 lateral mass, a strip allograft bone shaped into a cuboid (with the length, width, and height of 3.2, 1.0, and 0.6 cm) was implanted in the clearance of the intervertebral foramen and the lateral mass as the stability reconstruction of the unilateral lateral mass and facet column. Furthermore, unilateral pedicle screws (C2 and C5) combined with laminar screws (C2–C5) and rod were implanted (Mountaineer, Johnson and Johnson, USA) (Fig. 1). Finally, the incision was closed in layers and a drainage tube was placed. And the tumor tissue specimens were examined by the pathologist.

Biomechanical study

Seven fresh-frozen human cadaveric cervical spine specimens from C4 to T1 were tested in this study. The donors were all male with age ranged from 35 to 70 yrs (Average age of 44.3 years). Lateral and anterior/posterior radiographs of the spine specimens were taken to rule out obvious neoplastic, traumatic, congenital conditions, earlier surgery or facet arthropathy. Bone mineral density (BMD) of the lumbar region of these specimens was measured by using the dual-energy x-ray absorptiometry. The average BMD was 1.031 g/cm2, indicating none of osteoporotic specimen was included in the present study. All specimens were placed in double layer plastic bags and stored at − 20 °C conservation cabinet. Each specimen was thawed to room temperature before test and dissected the musculature, but the ligaments, disks and joint capsules were preserved. The upper third part of C4 and T1 vertebrae were potted in dental stone mounts such that the C5/6 disk was horizontal.

For the pedicle screw placement, we first used landmarks to locate the entry points of the pedicle and then used a high-speed drill to open the entry cortex. The standard process for pedicle insertion was then performed. The optimal screw length close to the anterior cortex of the vertebral body was determined in the preoperative planning of the screw trajectories. The screws were 26–32 mm long.

As regard to the lamina screw placement, the screw entry point was located at the initiation of the lamina from the spinous process at the midpoint of its dorsal arch. A high-speed drill was used to open the entry of cortical window. Using a thin pedicle finder, the contralateral lamina was carefully drilled along its length, with the pedicle finder aimed at the lateral mass. Procedures were performed under oblique cervical fluoroscopy (axial view of the lamina) to confirm that the pedicle finder did not violate the inner cortex of the lamina. Typically, the tip of the screw should not pass the medial margin of the lateral mass, and its orientation should be parallel to the slope of the lamina under anterior–posterior fluoroscopy. The length of screws was within the range of 18–22 mm.

For the experimental protocol, screws were inserted into each vertebra from C4 to C7, followed by attachment of the rod for the pedicle screws and plate for the lamina screws. All instrumentations (Foshan Stable Surgical Implant, Guangdong, China) were made of titanium alloy Ti-6Al-4 V.

A custom-designed and fabricated spine testing machine was used to apply a pure moment of ± 2.0 Nm to the top vertebra, while the specimen was allowed to move in an unconstrained fashion [17, 18]. The loading arm applied a continuous pure moment through 2 U-joints and 1 linear bearing at a rate of 1°/sec in all 3 primary directions of loading: flexion–extension, right and left axial rotation, and right and left lateral bending. The load was applied for 3 complete loading cycles. The first 2 cycles were for preconditioning, and the third cycle results were used for analysis. During flexibility testing, the position of each vertebra was recorded by monitoring infrared light-emitting diodes rigidly attached to each vertebra. A probe with 4 infrared light-emitting diodes on the base of the spine machine defined a general anatomic specimen coordinate system. An opto-electronic camera system (Optotrak Certus; Northern Digital Inc., Waterloo, Ontario, Canada) was used to measure the three-dimensional coordinates of the markers at a sampling frequency of 20 Hz. The range of motion (ROM) and neutral zone (NZ) between the C4 and C7 in flexion–extension, left–right lateral bending and left–right axial rotation were calculated, respectively. Each specimen was tested in a total of six configurations and the sequence 3–6 were randomized:

1. Intact
2. Injured specimens
3. Unilateral pedicle screws fixation (UPS)
4. Bilateral pedicle screws fixation (BPS)
5. Unilateral pedicle and lamina screws fixation (UPLS)
6. Unilateral pedicle and lamina screws fixation combined with graft bone implant (UPLS + G)

The iliac bone graft was harvested and shaped to the required size, and then, inserted into the space of C4 and C7 lateral mass at the involving side. The destabilized specimen following the C5 and C6 right hemi-laminectomy and ipsilateral totally C5/6 facetectomy served as simulation of the bony defect after cervical dumbbell tumorectomy. A posterior review of the cervical spine specimens with instrumentation in the flexibility test are showed in Fig. 2. Motion tests were also randomized under the same injury condition in order to minimize any deterioration of the specimens. All six tests were completed on the same day. Anteroposterior and lateral radiographs of each specimen were taken in each testing configuration (Fig. 3).

Approval for this study was granted by our institutional review board, and the patient agreed to publication of the case report.

Statistical analysis

All collected data were further processed with SPSS software (SPSS Inc, Chicago, IL) and expressed in mean ± standard deviation. Differences in ROM and NZ among different conditions were analyzed using repeated measures analysis of variance at a 95% level of significance. The post hoc test was Student–Newman–Keuls analysis.

Results

Case

Postoperatively, the pathological report after operation indicated a schwannoma. The postoperative MRI and CT scan indicated that the tumor was completely resected and the cervical spine was sufficiently reconstructed. At 18 months postoperatively, her symptoms disappeared and bone fusion was also observed with no instrumentation failure (Fig. 1).

Biomechanical study

No screw loosening or fixation failure was observed during test. The C4-C7 ROMs of the intact were 23.1° ± 4.9° in flexion, 13.6° ± 5.4° in extension, 29.4° ± 4.5° in lateral bending and 23.0° ± 5.7° in axial rotation. The ROMs significantly increased in all directions following the injury (Table 1).

The ROMs of the UPS fixation were 11.3° ± 1.8° in flexion, 9.5° ± 3.7° in extension, 11.9° ± 3.3° in lateral bending, and 11.6° ± 2.3° in axial rotation, which were significantly larger than UPLS, UPLS + G or BPS fixation conditions in all directions (all $p < 0.001$) (Table 1). The ROMs of the UPLS + G fixation were the same as the BPS fixation in flexion (1.8° vs. 1.5°, $p = 0.58$) and extension (2.3° vs. 2.2°, $p = 0.73$), but significantly bigger in

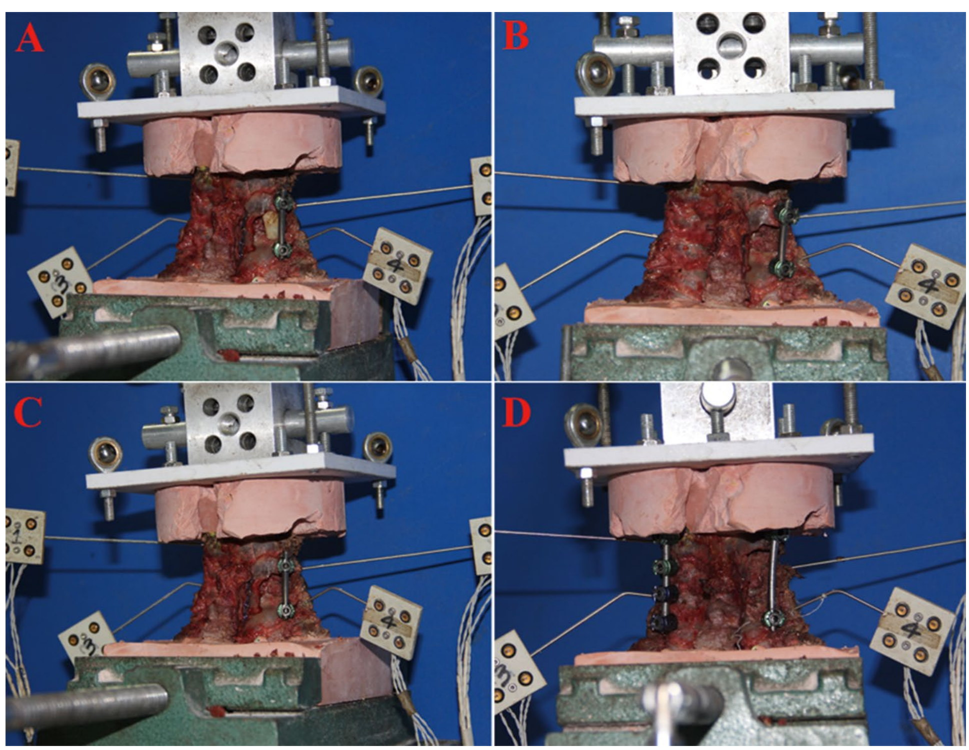

Fig. 2 A posterior review of a cervical spine specimen with instrumentation in the flexibility test: unilateral pedicle and lamina screws fixation + graft bone implant **a**, unilateral pedicle screws fixation **b**, unilateral pedicle and lamina screws fixation **c**, bilateral pedicle screws fixation **d**. The upper third part of C4 and T1 was embedded in dental stone and set in the spine test machine. NDI Marker carrier was rigidly attached to each vertebra. Segmental motion was measured using an opto-electric camera system (Certus; Northern Digital, Waterloo, Ontario)

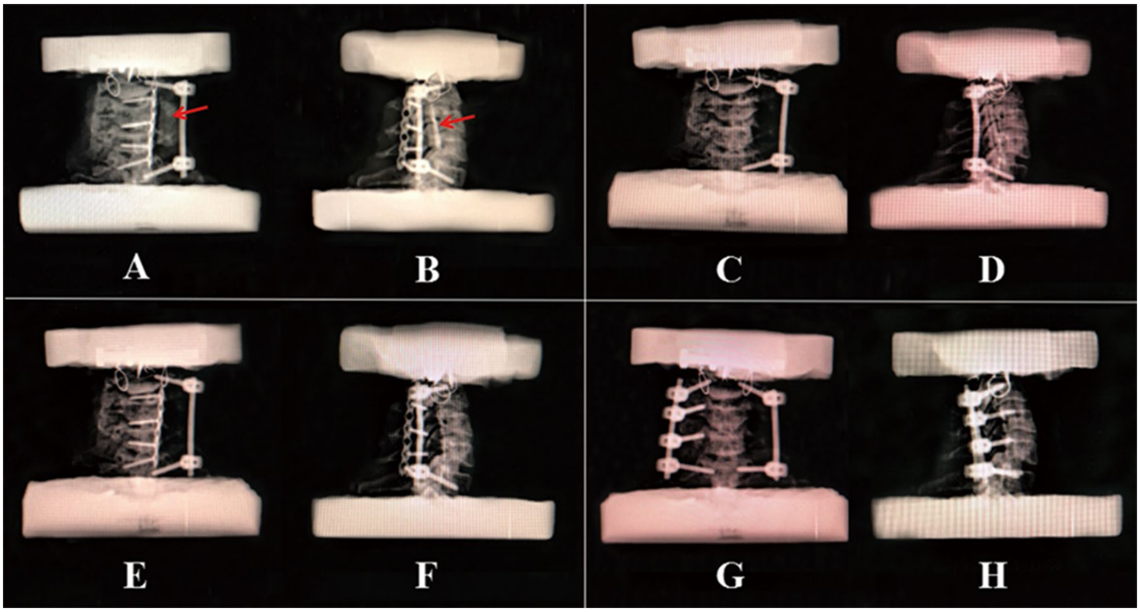

Fig. 3 Anterior–posterior and lateral radiographs of the tested specimen with instrumentation: unilateral pedicle and lamina screws fixation + graft bone implant, **a, b** unilateral pedicle screws fixation, **c, d**, unilateral pedicle and lamina screws fixation **e, f**, bilateral pedicle screws fixation **g, h**

Table 1 ROMs between the C4 and C7

	Intact	Injured	UPS	UPLS + G	UPLS	BPS
Flexion	23.1(4.9)^{abcd}	30.5(2.6) ^{abcd}	11.3(1.8)^{abcd}	1.8(0.8)^{a}	1.9(0.6)^{a}	1.5(0.6)^{a}
Extension	13.6(5.4)^{abcd}	21.6(4.5) ^{abcd}	9.5(3.7)^{abcd}	2.3(0.8)^{a}	2.5(0.7)^{a}	2.2(1.1)^{a}
Lateral bending	29.4(4.5)^{abcd}	37.5(6.8) ^{abcd}	11.9(3.3)^{abcd}	3.9(1.3)^{ad}	4.6(1.3)^{ad}	1.0(0.6)^{abc}
Axial rotation	23.0(5.7)^{abcd}	38.6(6.2) ^{abcd}	11.6(2.3)^{abcd}	6.8(1.8)^{ad}	7.5(1.5)^{abd}	3.8(0.4)^{abc}

Data are presented as Mean (*SD*). a, statistical difference from Intact, or Injured, or UPS state ($P < 0.05$); b, statistical difference from UPLS + G state ($P < 0.05$); c, statistical difference from UPLS state ($P < 0.05$); d, statistical difference from BPS state ($P < 0.05$). ROM, range of motion; UPS, unilateral pedicle screws fixation; BPS, bilateral pedicle screws fixation; UPLS, unilateral pedicle and lamina screws fixation; UPLS + G, unilateral pedicle and lamina screws fixation combined with graft bone implant

lateral bending (3.9° vs. 1.0°, $p < 0.001$), and axial rotation (6.8° vs. 3.8°, $p = 0.002$). However, except the axial rotation (7.5° vs. 6.8°, $p = 0.044$), there were no significantly differences in extension (1.9° vs. 1.8°, $p = 0.452$), flexion (2.5° vs. 2.3°, $p = 0.270$), and lateral bending (4.6° vs. 3.9°, $p = 0.069$) between the UPLS and UPLS + G fixation status (Fig. 4).

NZs of the intact C4–C7 segment were 5.6°, 5.5°, 2.5° in flexion–extension, lateral bending and axial rotation, which were significantly increase in injured state (Table 2). NZs were reduced to 0.3° in flexion–extension, 0.1° in lateral bending and 0.3° in axial rotation after the BPS fixation, which were less than those following the UPLS or UPLS + G fixation (all $p < 0.05$). However, there were no significant differences in NZs of the three directions between the UPLS and UPLS + G fixation status (all $p > 0.05$) (Fig. 5).

Discussion

The "dumbbell tumor" means tumor that connect two or more separate regions, such as intradural, epidural and paravertebral regions. The dumbbell tumor was not uncommon as the incidences of 17% in spinal cord tumors, which accounted for 44% appear on the cervical spine [4]. The surgical approach of cervical dumbbell tumor that are both intra- and extra-foraminal is difficult and controversial [8], which includes the anterior approach [19], the anterolateral approach, [20, 21] the posterior approach, [22] and the combined anterior–posterior approaches [7]. The posterior approach is the most widely used, and generally surgeons are familiar with it [7]. Furthermore, one-stage posterior approach with hemi-laminectomy or laminectomy and facetectomy was feasible and effective

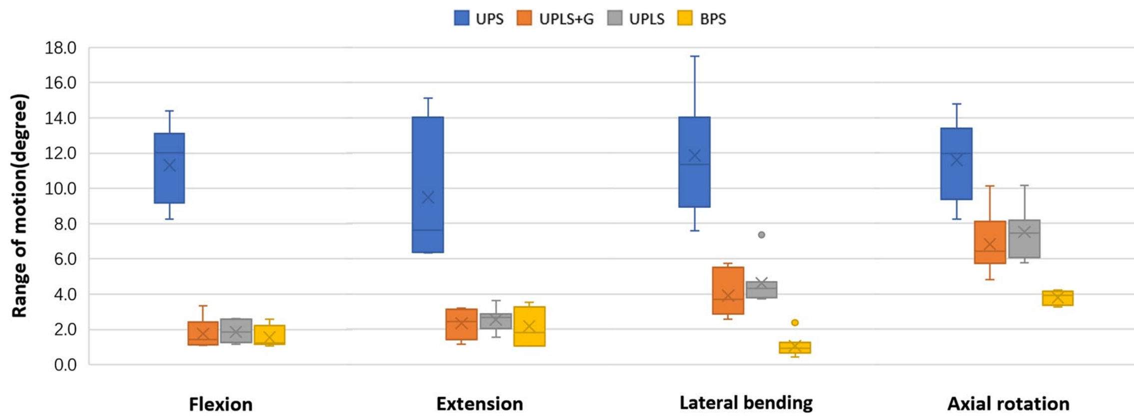

Fig. 4 A grouped boxplot showing range of motion (ROM) of C4–C7 segment in flexion, extension, lateral bending and axial rotation. The error bars represent one standard deviation. UPS, unilateral pedicle screws fixation; BPS, bilateral pedicle screws fixation; UPLS, unilateral pedicle and lamina screws fixation; UPLS + G, unilateral pedicle and lamina screws fixation combined with graft bone implant

Table 2 NZs between the C4-C7

	Intact	Injured	UPS	UPLS + G	UPLS	BPS
Flexion–extension	5.6(4.7)^{abcd}	8.6(5.7)^{abcd}	4.2(2.0)^{abcd}	0.4(0.2)^{ad}	0.4(0.2)^{ad}	0.3(0.1)^{abc}
Lateral bending	5.5(2.8)^{abcd}	8.8(3.9)^{abcd}	2.4(1.2)^{abcd}	0.4(0.1)^{ad}	0.5(0.2)^{ad}	0.1(0.1)^{abc}
Axial rotation	2.5(0.9)^{abcd}	4.8(2.4)^{abcd}	1.2(0.6)^{abcd}	0.5(0.3)^{ad}	0.6(0.2)^{ad}	0.3(0.1)^{abc}

Data are presented as Mean (*SD*). a, statistical difference from Intact, or Injured, or UPS state ($P < 0.05$); b, statistical difference from UPLS + G state ($P < 0.05$); c, statistical difference from UPLS state ($P < 0.05$); d, statistical difference from BPS state ($P < 0.05$). NZ, neutral zone; UPS, unilateral pedicle screws fixation; BPS, bilateral pedicle screws fixation; UPLS, unilateral pedicle and lamina screws fixation; UPLS + G, unilateral pedicle and lamina screws fixation combined with graft bone implant

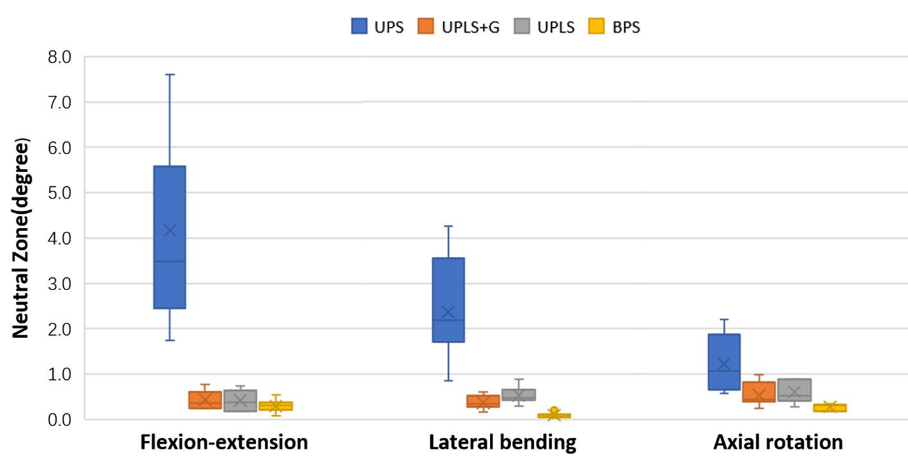

Fig. 5 A grouped boxplot showing neutral zone (NZ) of C4–C7 segment in flexion–extension, lateral bending and axial rotation. The error bars represent one standard deviation. UPS, unilateral pedicle screws fixation; BPS, bilateral pedicle screws fixation; UPLS, unilateral pedicle and lamina screws fixation; UPLS + G, unilateral pedicle and lamina screws fixation combined with graft bone implant

to totally and safely remove the cervical dumbbell tumor in most cases.

It still remains controversial whether the internal fixation and fusion should be performed after unilateral facetectomy. The loss of bone from the cervical spine has the potential to weaken the stability of the spinal column, and fusion with instrumentation sometimes is required to prevent complications such as pain, deformity or loss of neurological function [8–11]. The criteria for fusion in most cases series were previous deformity (i.e., kyphosis in the cervical spine), laminectomy of 3 or more levels, laminectomy encompassing a spinal junction, "young adults," facetectomy ≥ 50% (unilateral or bilateral), persistence of deformity after 1 year of the surgery and, C2 laminectomy [23]. According to the above views, internal fixation and fusion were performed for this case in the present study.

Until now, for the stability reconstruction of the cervical dumbbell tumorectomy after the hemi-/laminectomy and facetectomy, there were two kinds of fixation methods: unilateral and bilateral fixation technique. First, spinal internal fixation was performed with ipsilateral pedicle screws/lateral mass screws and rod/plate, which preserve the contralateral bone and soft tissue but face a higher risk of instability [4, 9, 12, 13]. Second, bilateral pedicle screws/lateral mass screws and rods were adopted for stability reconstruction, which had a better spinal stability but a larger soft tissue exposure and bony defect [14–16]. Therefore, we proposed the new fixation method as the unilateral fixation (pedicle screws) + middle line fixation (laminar screws), which would not only have less trauma but also a good biomechanical stability.

The hemi-laminectomy combined with the facetectomy had advantage for excising the dumbbell tumor. Because most tumors were located unilaterally in the spinal canal or paravertebral space, the tumors could be excised easily from the large posterolateral space provided by the hemi-laminectomy and facetectomy. Furthermore, the erosion or destruction of bone had already present as shown in our case. The unilateral posterior approach preserved the posterior and contralateral soft and bony tissue, which means that less muscle tissue dissection and bone structure breaking not only reduce the surgical time and bleeding, but also minimize the trauma to patient.

In addition, the hemi-laminectomy and facetectomy can minimize the damage to spinal stability by preserving the spinous process, supra- and intraspinous ligaments and contralateral facet joint, which can reduce the risk of postoperative complications such as axial pain. With this approach, the unilateral fixation (pedicle screws) + middle line fixation (laminar screws) also showed a good biomechanical stability, as the ROM was the same as the BPS fixation in flexion (1.8° vs. 1.5°) and extension (2.3° vs. 2.2°). In this study, we also used a strip allogeneic bone placed between the lateral mass and facet to rebuild the stability of the unilateral facet joint column. Interestingly, the graft bone significantly decreased the ROM of the axial rotation compared with the state without it, which may result by the increased interface friction between the graft bone and the upper and lower articular surfaces that treated with a drill. Obviously, graft bone fusion was observed in our case at the final follow-up. Therefore, the reconstruction of the facet joint with the graft bone not only benefit to the stability of cervical spine instantly but also valuable in the long term.

Shi et al. [24] performed a biomechanical test of the hybrid unilateral pedicle screw combined with a contralateral translaminar screw fixation for C4-5 segment. Their results showed that the ROM of the hybrid fixation method had a smaller value than our study in axial rotation (2.2° vs. 7.5°), but bigger values in flexion–extension (13.7° vs.4.4°) and lateral bending (7.5° vs. 4.6°). Those differences may result by the different injury model and segments. Furthermore, they found that the hybrid fixation had the same values of the ROM compared with the bilateral pedicle screw fixation in flexion–extension and the axial rotation, but lager value in the lateral bending, which was similar to our study. This method would reduce the risk of vascular, nerve and spinal cord injury, especially for the screw placement. For the unilateral pedicle screw implantation after the hemi-laminectomy and facetectomy, the trajectory of the pedicle can be easily feeling by the probe or even be seen in some extent, which would be very useful to the find the entry point of screw and handle the direction correctly and quickly. On the other hand, for the trans-laminar screw insertion, it can be placed through the basilar part of the spinous process at the involving side to the lamina, or even the notch of the outside of the contra-lateral lamina, as it was generally used to prevent vertebral artery injury when asymmetry or unilateral occlusion is present for the incidence of vertebral artery injury occlusion [25, 26].

Expose and remove the cervical dumbbell tumor sufficiently and completely is the premise condition for the hemi-laminectomy, facetectomy and cervical fixation. The total-laminectomy would be done for some situations as a larger tumor or it is adhered with the epidural. Also, the operative view of the hemi-laminectomy is relatively small may make it more difficult to stop bleeding, detach the tumor and suture the dura. However, using with intraoperative microscope will greatly improve the safety of this operation. Furthermore, for the biomechanical study, due to the source limitation of the human cadaver specimens, only the male specimens were used. This is a limitation in terms of screw stability, as the bone quality is often somewhat poorer in older female donors. Clinically, we only reported one case, and there was no comparative group such as no fixation or bilateral fixation. Nevertheless, we will continue to pursue the prospective case cohort study with longer follow-up time. We believe that the design will improve as cases accumulate.

In conclusion, for the surgical treatment of dumbbell tumor in the subaxial cervical spine, posterior unilateral exposure and stability reconstruction with pedicle and lamina screws fixation and graft bone placement to restore the spinal stability following hemi-laminectomy with facetectomy appears to be a feasible and an effective technique.

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Compliance with ethical standards

Conflict of interest The authors have no personal, financial or institutional interest and ethical/legal conflicts involved in this article.

References

1. Heuer GJ (1929) The so-called hour-glass tumor of the spine. Arch Surg 18:935–981. https://doi.org/10.1001/archsurg.1929.01140130023001
2. O'Toole JE, McCormick PC (2003) Midline ventral intradural schwannoma of the cervical spinal cord resected via anterior corpectomy with reconstruction: technical case report and review of the literature. Neurosurgery 52:1482–1485. https://doi.org/10.1227/01.neu.0000065182
3. Gu BS, Park JH, Roh SW, Jeon SR, Jang JW, Hyun SJ, Rhim SC (2015) Surgical strategies for removal of intra- and extraforaminal dumbbell-shaped schwannomas in the subaxial cervical spine. European spine J : official publ Eur Spine Soc, Eur Spinal Deform Soc Eur Sec Cerv Spine Res Soc 24:2114–2118. https://doi.org/10.1007/s00586-014-3458-9
4. Ozawa H, Kokubun S, Aizawa T, Hoshikawa T, Kawahara C (2007) Spinal dumbbell tumors: an analysis of a series of 118 cases. J neurosurg Spine 7:587–593. https://doi.org/10.3171/spi-07/12/587
5. Nakamura M, Iwanami A, Tsuji O, Hosogane N, Watanabe K, Tsuji T, Ishii K, Toyama Y, Chiba K, Matsumoto M (2013) Long-term surgical outcomes of cervical dumbbell neurinomas. J orthop sci Off J Japanese Orthop Assoc 18:8–13. https://doi.org/10.1007/s00776-012-0300-2
6. Abe J, Takami T, Naito K, Yamagata T, Arima H, Ohata K (2014) Surgical management of solitary nerve sheath tumors of the cervical spine: a retrospective case analysis based on tumor location and extension. Neurol Med Chir 54:924–929. https://doi.org/10.2176/nmc.oa.2014-0158
7. Safavi-Abbasi S, Senoglu M, Theodore N, Workman RK, Gharabaghi A, Feiz-Erfan I, Spetzler RF, Sonntag VK (2008) Microsurgical management of spinal schwannomas: evaluation of 128 cases. J neurosurg Spine 9:40–47. https://doi.org/10.3171/spi/2008/9/7/040
8. Jiang L, Lv Y, Liu XG, Ma QJ, Wei F, Dang GT, Liu ZJ (2009) Results of surgical treatment of cervical dumbbell tumors: surgical approach and development of an anatomic classification system. Spine 34:1307–1314. https://doi.org/10.1097/BRS.0b013e3181a27a32
9. McCormick PC (1996) Surgical management of dumbbell tumors of the cervical spine. Neurosurgery 38:294–300. https://doi.org/10.1097/00006123-199602000-00012
10. Raynor RB, Pugh J, Shapiro I (1985) Cervical facetectomy and its effect on spine strength. J Neurosurg 63:278–282. https://doi.org/10.3171/jns.1985.63.2.0278
11. Zdeblick TA, Abitbol JJ, Kunz DN, McCabe RP, Garfin S (1993) Cervical stability after sequential capsule resection. Spine 18:2005–2008. https://doi.org/10.1097/00007632-199310001-00013
12. Sakaura H, Ohshima K, Iwasaki M, Yoshikawa H (2007) Intra-extradural plexiform schwannoma of the cervical spine. Spine 32:E611-614. https://doi.org/10.1097/BRS.0b013e31815583b4
13. Ando K, Imagama S, Ito Z, Kobayashi K, Ukai J, Muramoto A, Shinjo R, Matsumoto T, Nakashima H, Nishida Y, Ishiguro N (2014) Unilateral instrumented fixation for cervical dumbbell tumors. J orthop surg res 9:2. https://doi.org/10.1186/1749-799x-9-2
14. Huang Y, Wang Z, Chen Z, Wu H, Jian F (2017) Posterior Hemi-/Laminectomy and Facetectomy Approach for the Treatment of Dumbbell-Shaped Schwannomas in the Subaxial Cervical Spine: A Retrospective Study of 26 Cases. Eur Neurol 78:188–195. https://doi.org/10.1159/000479814
15. Ahmad FU, Frenkel MB, Levi AD (2017) Spinal stability after resection of nerve sheath tumors. J Neurosurg Sci 61:355–364. https://doi.org/10.23736/s0390-5616.16.03462-7
16. Iacopino DG, Giugno A, Guli C, Basile L, Graziano F, Maugeri R (2016) Surgical nuances on the treatment of giant dumbbell cervical spine schwannomas: description of a challenging case and review of the literature. Spinal cord ser cases 2:15042. https://doi.org/10.1038/scsandc.2015.42
17. Goertzen DJ, Kawchuk GN (2009) A novel application of velocity-based force control for use in robotic biomechanical testing. J Biomech 42:366–369. https://doi.org/10.1016/j.jbiomech.2008.11.00618
18. Wilke HJ, Wenger K, Claes L (1998) Testing criteria for spinal implants: recommendations for the standardization of in vitro stability testing of spinal implants. Eur Spine J 7(2):148–154. https://doi.org/10.1007/s005860050045
19. Iwasaki Y, Hida K, Koyanagi I, Yoshimoto T, Abe H (1999) Anterior approach for dumbbell type cervical neurinoma. Neurol Med Chir 39:835–839. https://doi.org/10.2176/nmc.39.835
20. Ohnishi Y, Iwatsuki K, Ohkawa T, Ninomiya K, Moriwaki T, Yoshimine T (2015) Differences between cervical schwannomas of the anterior and posterior nerve roots in relation to the incidence of postoperative radicular dysfunction. Asian Spine J 9:263–270. https://doi.org/10.4184/asj.2015.9.2.263
21. Yasuda M, Bresson D, Cornelius JF, George B (2009) Anterolateral approach without fixation for resection of an intradural schwannoma of the cervical spinal canal: technical note. Neurosurgery 65:1178–1181. https://doi.org/10.1227/01.neu.0000360131.78702.9b
22. Asazuma T, Toyama Y, Maruiwa H, Fujimura Y, Hirabayashi K (2004) Surgical strategy for cervical dumbbell tumors based on a three-dimensional classification. Spine 29:E10-14. https://doi.org/10.1097/01.brs.0000103662.13689.76
23. Avila MJ, Walter CM, Skoch J, Abbasifard S, Patel AS, Sattarov K, Baaj AA (2015) Fusion after intradural spine tumor resection in adults: a review of evidence and practices. Clin Neurol Neurosurg 138:169–173. https://doi.org/10.1016/j.clineuro.2015.08.020
24. Shi L, Shen K, Chu L, Yu KX, Yu QS, Deng R, Deng ZL (2019) Biomechanical study of novel unilateral fixation combining unilateral pedicle and contralateral translaminar screws in the subaxial cervical spine. World Neurosurgery 121:e684–e690. https://doi.org/10.1016/j.wneu.2018.09.191
25. Matsubara T, Mizutani J, Fukuoka M, Hatoh T, Kojima H, Otsuka T (2007) Safe atlantoaxial fixation using a laminar screw (intralaminar screw) in a patient with unilateral occlusion of vertebral artery: case report. Spine 32:E30-33. https://doi.org/10.1097/01.brs.0000250994.24462.ec
26. Taneichi H, Suda K, Kajino T, Kaneda K (2005) Traumatically induced vertebral artery occlusion associated with cervical spine injuries: prospective study using magnetic resonance angiography. Spine 30:1955–1962. https://doi.org/10.1097/01.brs.0000176186.64276.d4