Case Report
Application of MSCTA combined with VRT in the operation of cervical dumbbell tumors

Wan Wang¹, Jia Lin², Engelbert Knosp³, Yuanzheng Zhao⁴, Dianhui Xiu⁵, Yongchuan Guo⁶

Departments of ¹Breast Surgery, ⁴Neurosurgery, ⁵Radiology, China-Japan Union Hospital, Jilin University, Changchun, China; ²Department of Neurosurgery, Haikou Municipal Hospital, Haikou, China; ³Department of Neurosurgery, Medical University of Vienna, Vienna, Austria

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Abstract: Cervical dumbbell tumor poses great difficulties for neurosurgical treatment and incurs remarkable local recurrence rate as the formidable problem for neurosurgery. However, as the routine preoperative evaluation scheme, MRI and CT failed to reveal the mutual three-dimensional relationships between tumor and adjacent structures. Here, we report the clinical application of MSCTA and VRT in three-dimensional reconstruction of cervical dumbbell tumors. From January 2012 to July 2014, 24 patients diagnosed with cervical dumbbell tumor were retrospectively analyzed. All patients enrolled were indicated for preoperative MSCTA/VRT image reconstruction to explore the three-dimensional stereoscopic anatomical relationships among neuroma, spinal cord and vertebral artery to achieve optimal surgical approach from multiple configurations and surgical practice. Three-dimensional mutual anatomical relationships among tumor, adjacent vessels and vertebrae were vividly reconstructed by MSCTA/VRT in all patients in accordance with intraoperative findings. Multiple configurations for optimal surgical approach contribute to total resection of tumor, minimal damage to vessels and nerves, and maximal maintenance of cervical spine stability. Preoperative MSCTA/VRT contributes to reconstruction of three-dimensional stereoscopic anatomical relationships between cervical dumbbell tumor and adjacent structures for optimal surgical approach by multiple configurations and reduction of intraoperative damages and postoperative complications.

Keywords: Cervical dumbbell tumors, spinal cord, multi-slice computed tomography angiography, volume rendering technique, three-dimensional reconstruction

Introduction

Cervical dumbbell tumor mainly derives from nervous system and often grows along nerve sheaths or nerve fibers of posterior root at intervertebral foramen [1-5]. Cervical dumbbell tumor is prone to inflict compressions and damages upon cervical spinal cord, nerve root, and vessels. Noted for its high mortality as well as morbidity, cervical dumbbell tumor poses great difficulties for neurosurgical treatment and incurs remarkable local recurrence rate as the formidable problem for both neurosurgery and spinal surgery [6, 7]. However, as the routine preoperative evaluation scheme, magnetic resonance imaging (MRI) and computerized tomography (CT) failed to reveal the mutual three-dimensional relationships between tumor and adjacent structures. Therefore, routine preoperative approach should be improved and modified for more precise three-dimensional assessment of craniocaudal distribution of the tumor and its adjacent structures.

In the present study, we report the clinical application of multi-slice CT angiography (MSCTA) and volume rendering technique (VRT) in three-dimensional reconstruction of cervical dumbbell tumors. From January 2012 to July 2014, we reconstruct three-dimensional images of 24 cases of cervical dumbbell tumor for formulating neurosurgical approach by MSCTA and VRT in accordance with tumor scale by MRI/CT scan. This retrospective study validates the efficacy of preoperative MSCTA/VRT application in diagnosis and surgical management of cervical dumbbell tumors.

Case presentation

Study protocol was approved by our local ethics committee. Potential adverse effects of con-
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Contrast medium injection and radiation exposure were explained to all the patients by a radiologist, and written informed consent was obtained before the procedure.

Patient population

24 consecutive patients (Male: 15, Female: 9, Mean Age: 45) from January 2012 to July 2014, diagnosed with cervical dumbbell tumors by MRI and CT for neurosurgical treatment were included. Fifteen patients were male, and nine were females (ratio = 1.67:1). The ages ranged from 27 to 65 years (Mean Age: 45 years). All patients were diagnosed with cervical dumbbell tumors by MRI and CT, and they were undergoing preoperative MSCTA/VRT for three-dimensional reconstruction prior to surgical tumor resection.

Multi-slice CT angiography protocols

MSCTA examinations were performed by 320-slice CT scanner (Aquilion ONE; Toshiba; Japan) according to a standardized protocol. The scan parameters were defined by radiological department as follows: tube voltage of 120 kV, effective tube current of 250-300 mAs, rotation rate of 0.6~0.8 s/r, field of view (FOV) 20~30 cm and slice thickness 0.625 mm. Since pre-contrast scanning images were obtained, multi-phase contrast-enhanced CT scan was performed after intravenous administration of 80 ml Iopamidol (Ultravist 370 mgI/ml, Schering, Erlangen, Germany) as nonionic iodinated contrast agent from a power injector at flow rate of 5-6 ml/s. Scan delay time was defined by SureSmart method, and descending aorta was assigned as the region of interest (ROI) for trigger threshold. As soon as the contrast-media signal in ROI reached a predefined threshold of 140 HU, the scan started automatically with a delay of 12-16 s so as to scan the levels from the aortic root to the base of the skull. Vascular reconstruction was performed at commercially available workstation equipped with volume-rendering software (Vitrea Fx; Toshiba; Japan) for reconstruction of mutual anatomical relationships between tumor and adjacent vessels/vertebrae.

Image analysis

Two experienced neuroimaging radiologists reviewed MSCTA imaging of 24 cervical dumbbell tumors cases at workstation with MRI and CT by consensus. Image analysis included defining three-dimensional anatomical location of tumor, evaluating the maximum axial diameter, margin, density of the lesions, and assessing mutual anatomical relationships of feeding arteries and vertebral artery on the pre-contrast images and contrast-enhanced CT images. Two neurosurgeons were in charge for preoperative simulation for optimal neurosurgical approach aimed at dissecting vertebra overlapping superior and inferior borders of tumor, separating and protecting peripheral vessels around tumor, as well as resecting tumor for revealing intratumoral vessels to achieve maximal resection of tumor and minimal damage to spinal cord.

Surgical methods

For 24 cases, neurosurgical approach was applied as posterior approach for 17 cases and posterolateral approach for 7 cases. The neurosurgical corridor was achieved by semi-laminectomy and articular process was routinely preserved. After fully exposed, the tumor was resected from intraspinal part to extraspinal part. Dura mater spinalis adherent to tumor was incised and the tumor was separated from potential space between tumor and spinal cord squashed aside. When the tumor was separated from adhesion to spinal cord, low level electrocoagulation and low intensity suction were performed to avoid spinal cord injury due to improper traction, overheating and excessive suction as the tumor was exposed. For tumors located beneath ventral spinal cord or substantial in size, intratumoral resection was performed step by step for cytoreduction before separated from severe spinal cord adhesion. Nerves and vessels on the surface of tumor were separated and protected carefully as much as possible whereas nerve roots inseparable from tumor could be resected. Forepart of tumor, which protruded into vertebrae, was resected part by part after separated with neural stripping ion. Osseous bleeding was stopped by bone wax sealing or monopolar electrocoagulation. However, hemorrhage from venous plexus was staunchened by fluid gelatin, gelatin sponge or hemostatic gauze instead of electrocoagulation. For vertebral arteries impressed away or partially enwrapped by tumor, separation under microscope was pre-
ferred for total resection. Furthermore, methylprednisolone was applied preoperatively and intraoperatively for minimizing intraoperative spinal cord injury, decreasing spinal stress reaction to damage and accelerating postoperative functional recovery of spinal cord.

**Tumor characteristics and surgical aspects**

Spinal tumor volume ranged from 11.5 cm$^3$ to 53.8 cm$^3$ in 24 cases. Postoperative pathological examination confirmed neurinoma in 16 cases and neurofibroma in 8 cases. MSCTA/VRT three-dimensional reconstruction images revealed anatomical location, contour and size of tumor as well as its mutual spatial relationship with feeding arteries, vertebral artery and vertebrae, thus successfully optimizing clinical neurosurgical strategy and approach, adequately assessing intraoperative risks therefore reducing neurosurgical complications. MSCTA/VRT reconstruction images provided

*Figure 1.* Preoperative images of patient 1. Plain and enhanced MRI showed that the tumor is located in the left of the atlantoaxial, spinal cord was compressed and shifted significantly, the intervertebral space was widen (A, B). MSCTA/VRT reconstruction image, seen from the left side, displayed the vertebral artery was in the anterolateral but not wrapped by tumor (C). Posterior image of MSCTA-VRT, The tumor was located between C$_1$ and C$_2$, dumbbell type, the posterior arch of the atlas was partly wrapped by the tumor. And the simulated surgery indicated that the upper portion of the spinous process deterred the exposure of tumor (D).
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adequate visual field and neurosurgical corridor as well as vascular/osseous structures, which were identical with operative findings for neurosurgeons (Figures 1-4). MSCTA/VRT reconstruction images effectively contributed to intraoperative evasion and dissection of important vessels in 15 cases whose vertebral arteries were compressed and dislocated by tumor. For 24 cases, neurosurgical approach was applied as posterior approach for 17 cases and posterolateral approach for 7 cases. The average duration of operation was 3.5 hours and blood loss was minimal (average, 80 ml). No postoperative complications were witnessed and postoperative MRI and MRSCTA/VRT examinations confirmed total resection in 23 cases and subtotal resection in 1 case. Neurological functions were remarkably improved in all 24 cases.

Patient follow-up

A total of 24 patients were followed for a median of 16.5 months (range, 6-36 months). Postoperative 6-month follow-up period was uneventful with no newly developed spinal instability or activity limitation in all the cases.

Discussion

As a special subtype which mainly derives from posterior spinal root or its nerve sheath, cervical dumbbell tumor accounts for 15% to 38% of all intraspinal tumors [8]. For all cervical dumbbell tumors, 60% (75% in this study) are schwannoma as major pathological constitution followed by neurinoma [9-12]. Noted for its special dumbbell-shape which consists of intraspinal, intervertebral and extraspinal part, cervical dumbbell tumor extends along nervous sheath or spinal root fibers, through foramen intervertebral thus finally bulges out from spinal canal. Usually misdiagnosed as cervical ache or discomfort at its early stage, growing cervical dumbbell tumor is prone to inflict compression and destruction upon cervical spinal cord, nerve root, vertebrae and vessels, thereby endangering patients with high mortality and morbidity [5, 12]. As the lesion generally enclosed by important anatomical structures,
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For decades, neurosurgeons have been dedicating to formulate classification criteria for neurosurgical strategy of cervical dumbbell tumors. However, new techniques and clinical practice have placed greater demands for more manageable classification. As neurosurgery ushers into the age of CT and MRI, Eden’s classification for cervical dumbbell tumors was proved of little clinical use thus decreased in popularity since its advent in 1958 [1]. In 1992, a more detailed and practical classification proposed by Toyama [3]. In 2004, Toyama and Asazuma proposed a detailed yet excessively specified classification system which provided limited suggestions for neurosurgical approach and classification for cervical dumbbell tumors after studying the locations and shapes of tumor [13]. In comparison with Toyama’s classification, Peking University Third Hospital has achieved improvements in defining tumor invasion and compression upon vertebra by neural imaging [14], thereby contributing to defining preoperative neurosurgical approach preoperative and evaluating postoperative cervical stability. According to varied MRI images and accumulated neurosurgical experiences, JR Xiao proposed their scale system and highlighted prospects for classification of cervical dumbbell tumors in 2006 [15]. However, for lack of related three-dimensional information from CT and MRI, these classifications were confined to transverse sections of CT and MRI at tumor region and incompetent in revealing mutual spatial relationships between cervical dumbbell tumor and related structures including inflicted or enwrapped vertebrae as well as vertebral arteries. With the help of MSCTA, we perform VRT reconstruction for image data at later phase to reveal mutual spatial relationships between cervical dumbbell tumor and related structures thus providing important directions for total resection of tumor, utmost reduction of complications and maximal maintenance of cervical stability.

**Advantages of MSCTA/VRT on cervical dumbbell tumor**

MSCTA/VRT contributes to revealing the contour of tumor as well as compression upon spinal cord, the extent of spinal edema as well as mutual relationships among tumor, dura mater and nerve root [16, 17]. At the same time, MSCTA/VRT is conducive to analyzing tumor at cervical dumbbell tumor amounts to remarkable difficulties and risks for both neurosurgical and spinal surgical operation apart from its frequent relapse after operation. Accordingly, it is necessary to define the contour of tumor and its mutual relationship with adjacent structures including spinal cord, vertebral artery as well as adjacent vertebrae to achieve optimal neurosurgical approach for total resection of tumor and maximal protection of vessels, spinal cord as well as cervical joint.

**Figure 3.** Postoperative images of patient 1. MRI showed that the tumor was completely resected, spinal cord compression was relieved (A). MSCTA/VRT showed that the tumor was fully resected. Vertebral artery and vertebra were intact; along with the defect of the upper part of the Axis spinous process (B).
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Figure 4. Preoperative images of patient 2. MRI showed a tumor involved C1 and C2, right side. Spinal cord was compressed and left shifted (A); MSCTA/VRT and MSCTA/MIP together showed that the vertebral artery was partly wrapped and compressed to the anterolateral (B); MSCTA/VRT clearly showed the positional relationship among tumor, the vertebral body and the vertebral artery (C, D).

MSCTA images post-processing reconstruction by VRT

Currently MSCTA has been applied for late-phase image reconstruction in the following ways [18]: multiplanar reconstruction (MPR), shaded surface display (SSD), maximum intensity projection (MIP), and recently volume rendering technique (VRT) which surpass its predecessors as supreme technique in reconstructing three-dimensional spatial relationships. VRT transforms all MSCTA voxels data into different transparency settings, ranging from opacity to transparency; meanwhile, con-
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vertoring different transparency settings into varied gray values and encoding these values into perspective visualized images with different depths and colors. Integrated advantages of SSD with MIP in vivid stereo perception and varied vision depth, VRT surpasses MIP and MPR in visualizing vascular integrity and translocation of vertebral artery due to compression from cervical dumbbell tumor. Theoretically, compared with other image reconstruction techniques, VRT formulates three-dimensional images based upon veritable adjacent relationships among tumor, vessels and cervical vertebrae from different perspectives within volume data.

We chose reconstruction techniques in accordance with the following considerations that blood flow of cervical dumbbell tumor is mainly supported by feeding arteries of nerve roots rather than branches from vertebral artery. Our previous neurosurgical data suggested that most of inflicted vertebral arteries were compressed yet rarely wrapped by tumor; even if the vertebral arteries were wrapped by tumor, there also existed intact tumor capsule between tumor tissue and vertebral arteries which facilitated separating tumor from vessels. Accordingly, there is no better technique other than VRT for image reconstruction to visualize feeding arteries of cervical dumbbell tumor. Besides, VRT shares advantages of other techniques which entitled itself as the only choice for image reconstruction. However, other techniques assisted by VRT are preferred for more detailed information to reconstruct images of large or massive tumors. Furthermore, VRT has great advantages in revealing three-dimensional contours of different structures which vitrified tumor and vertebrae by revolving and dissection for optimally detailed neurosurgical approach as well as postoperative evaluation.

Preoperative preparations

Tumor images were evaluated for attribute, quality, inflection area (nerve root & spinal cord) and accumulated volume at cross section and then reconstructed by MSCTA/VRT for three-dimensional image before operation. Accordingly, optimal neurosurgical approach was chose for defining mutual spatial relationships, evaluating extent of inflection thereby simulating the best approach for minimal resection of vertebrae, maximal protection of articular process, vertebral artery and spinal cord as well as total resection of tumor. Guidelines of neurosurgical treatment for cervical dumbbell tumors could be concluded as: 1. Resecting cervical dumbbell tumors as much as possible; 2. Protecting spinal cord; 3. Protecting vertebral artery; 4. Securing stability and flexibility of cervical vertebrae [19, 20].

Neurosurgical approach

We formulated individualized neurosurgical approach according to preoperative reconstruction images from CT, MRI and MSCTA/VRT for tumor size, location and lateral expansion scale. According to our experience, cervical dumbbell tumors were prone to follow lateral growth route in extended spinal canal [21, 22]; intraspinal or intervertebral foramcn cervical dumbbell tumors, and even tumors beyond intervertebral foramcn could be totally resected via posterior hemi-semi-laminectomy while protecting facet joints, spinous process, supraspinous and interspinous ligament and end point of contralateral paraverterbral muscle at the same time, thus maintaining stability and flexibility of cervical vertebrae and alleviating cervical stiffness. The extraforaminal part of cervical dumbbell tumor which exceeded 4 cm away from dura can be completely resected by transecting part of cervical muscles and adjusting vision angle between microscope and operating table.

Protection for nerve roots

Some neurosurgeons believe that serious and permanent neural functional losses were doomed once nerve roots were transected thus total resection of cervical dumbbell tumors could not be guaranteed for all cases whereas others argued that only minor neural functional losses would be incurred for enwrapped nerve roots once resected [8, 12]. Relationship between cervical dumbbell tumor and nerve root is the major consideration for sparing nerve roots: nerve roots above the tumor or enwrapped by the tumor could be dissected and protected, while nerve root coursing through the tumor should be resected due to their involvement in tumor original. Agrawal reported dyskinesia occurred in 1 out of 10 patients whose inflicted nerve roots were transected during resection of schwannoma [23].
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Our experience suggested that no serious damage was witnessed when no more than two unilateral spinal nerve roots were resected. In this study, no neural functional degeneration was witnessed in 22 patients whose parent nerve roots were resected.

Cervical stability and flexibility

In general, muscles, vertebrae, intervertebral discs and fibrous rings play an essential role in maintaining spinal stability; moreover, anterior longitudinal ligament, posterior longitudinal ligament and facet joints also ensure spinal stability in case of spinal malformation and even spondylexarthrosis which impair living quality and incur serious complications. For cervical dumbbell tumors stretching over several vertebrae, excessive resection of vertebrae would impair spinal stability and lead to cervical kyphosis which reaches 25% (for juvenile patients: 49%-100%) within two years after multiple laminectomy [24].

Traditional neurosurgical corridor for cervical dumbbell tumors aimed at resection of interspinous ligament, supraspinous ligament, lamina as well as part of facet joint which make enormous contributions to maintaining spinal stability usually jeopardized by excessive resection. Detailed analysis of neural image data, in special MSCTA/VRT before operation contributes to defining relationships between cervical dumbbell tumors and fact joint, optimizing neurosurgical approach thus totally resecting cervical dumbbell tumors rather than facet joint by adjusting intraoperative position and microscopic vision angle for most patients except that part of facet joint was removed for resecting isthmus of cervical dumbbell tumors in a small number of patients.

By common consent, it is necessary to maintain cervical stability during neurosurgical treatment for cervical dumbbell tumors meanwhile it is noteworthy that cervical flexibility should be protected. An influential view argues that rather than internal fixation or intervertebral body fusion, multiple laminectomy and resection of facet joint would weaken spinal stability thus increasing risks of postoperative cervical kyphosis [25, 26]. However, preoperative MSCTA/VRT in this study revealed that vertebrae were prone to be compressed or eroded by cervical dumbbell tumors stretching over vertebrae which in return extended intervertebral space thus facilitating total resection by partial resection from different intervertebral spaces; accordingly, vertebral flexibility was preserved rather than impaired by internal fixation or intervertebral body fusion. In this way, vertebrae and facet joint under maximum protection provided guarantee for cervical stability and flexibility after operation.

Protection of the vertebral artery

It is necessary to evaluate MSCTA/VRT before operation to define relationships between cervical dumbbell tumors and vertebral artery since feeding branches of tumors deriving from vertebral artery is of pivotal importance for intraoperative protection of vertebral artery. As vertebral artery usually located ahead of nerve root, it was prone to be compressed anteriorly and laterally by cervical dumbbell tumors.

Once intervertebral venous plexus was impaired during operation, bipolar coagulation directed by direct vision or hemostatic compression from fluid gelatin, gelatin sponge or hemostatic gauze was ordered rather than aimless bipolar coagulation in case of accidental injury. Sometime transverse process foramen could be drilled away to separate and relocate vertebral artery for exposure of cervical dumbbell tumors. Under most circumstances, vertebral artery was merely pushed aside or partially enwrapped by cervical dumbbell tumors. Even completely enwrapped by cervical dumbbell tumors, vertebral artery could be dissociated from cervical dumbbell tumors via tumor capsule between them under microscope for total resection of cervical dumbbell tumors at first stage.

For 24 cases evaluated by MSCTA/VRT before operation, postoperative MRI/CT scan confirmed satisfactory resection of cervical dumbbell tumors in all cases. With effective intraoperative vascular protection guided by MSCTA/VRT, preoperative neural dysfunction rehabilitated satisfactorily while postoperative spinal ischemic rate as well as other complication rates decreased remarkably after operation which exceeded similar results from recent reports.

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Disclosure of conflict of interest

None.

Abbreviations

MSCTA, multi-slice computed tomography angiography; VRT, volume rendering technique; MRI, magnetic resonance imaging; CT, computerized tomography; FOV, field of view; ROI, region of interest; MPR, multiplanar reconstruction; SSD, shaded surface display; MIP, maximum intensity projection.

Address correspondence to: Dr. Yongchuan Guo, Department of Neurosurgery, China-Japan Union Hospital, Jilin University, 126 Xiantai Blvd, Changchun 130033, China. Tel: +86-431-84995125; E-mail: guoyongchuan@yahoo.com

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