Endoscopic endonasal odontoid resection with real-time intraoperative image-guided computed tomography: report of 4 cases

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The authors present 4 cases in which they used intraoperative CT (iCT) scanning to provide real-time image guidance during endonasal odontoid resection. While intraoperative CT has previously been used as a confirmatory test after resection, to the authors' knowledge this is the first time it has been used to provide real-time image guidance during endonasal odontoid resection. The operating room setup, as well as the advantages and pitfalls of this approach, are discussed. A mobile intraoperative CT scanner was used in conjunction with real-time craniospinal neuronavigation in 4 patients who underwent endoscopic endonasal odontoidectomy for basilar invagination. All patients underwent a successful decompression. In 3 of the 4 patients, real-time intraoperative CT image guidance was instrumental in achieving a comprehensive decompression. In 3 (75%) cases in which the right nostril was the predominant working channel, there was a tendency for asymmetrical decompression toward the right side, meaning that residual bone was seen on the left, which was subsequently removed prior to completion of the surgery.

Endoscopic endonasal odontoid resection with real-time intraoperative image-guided CT scanning is feasible and provides accurate intraoperative localization of pathology, thereby increasing the chance of a complete odontoidectomy. For right-handed surgeons operating predominantly through the right nostril, special attention should be paid to the contralateral side of the resection, where there is often a tendency for residual pathology.

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THE craniocervical junction (CVJ) is often involved in numerous pathologies such as rheumatoid disease, degenerative fibroconnective disease, osteomyelitis, neoplasms, congenital abnormalities, and traumatic lesions.^{16,19} Microscopic transoral transpharyngeal odontoidectomy has been used to address ventral cervicomedullary compression for decades.¹⁰ However, this approach causes significant swelling in the pharynx, delaying extubation and feeding for several days, and also frequently requires splitting of the soft palate. Alfieri et al. developed the endoscopic endonasal approach (EEA) to the CVJ and odontoid process using cadaveric dissection in 2002.¹ Later, Kassam et al. provided a description of EEA for resection of the odontoid process and rheumatoid pannus in a patient with symptomatic cervicomedullary compression.⁸ Since then, EEA for odontoid resection has

been more widely used, and several studies have evaluated the inferior anatomical extent of odontoidectomy through an endonasal approach,^{3,10,18,20} reporting that this procedure allows for more rapid extubation and earlier time to feeding.^{6,9,11,13}

The lack of a 3D view in endoscopic surgery can lead to errors in depth perception. The radial distortion of the image may obscure anatomy along the periphery. Therefore, image guidance systems have been used for preoperative planning and intraoperative guidance to help increase accuracy and minimize iatrogenic injury to surrounding neurovascular structures. In our original series of 9 cases, we found that a small fragment of bone was left behind on the left side in 57% of cases, which was not discovered until postoperative CT scanning was performed.⁶

In this current series, we used intraoperative CT (iCT)

ABBREVIATIONS CVJ = craniocervical junction; EEA = endoscopic endonasal approach; iCT = intraoperative CT.

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FIG. 1. Photograph of the operating room setup for endonasal odontoidectomy with iCT imaging guidance. Figure is available in color online only.

scanning with real-time image guidance to ensure complete resection of the odontoid. While iCT scanning has previously been used as a confirmatory test after resection,^{2,5,7} this is the first time it has been used to provide real-time image guidance during endonasal odontoid resection. The advantages, pitfalls, and details of the room setup of this approach are discussed.

Methods

Four patients underwent endonasal odontoidectomy using the Airo (Brainlab), a mobile iCT scanner, in conjunction with the Curve (Brainlab) for craniospinal navigation. Communication between Airo and Curve made connection to Brainlab image-guided surgery systems swift and image transfers automatic. All patients had basilar invagination with a retroflexed odontoid, causing compression of the ventral medulla. Posterior occiput-to-cervical-instrumented fusion was performed in all patients prior to the anterior endonasal procedure. The indications for odontoidectomy are varied and controversial and are not the crux of our current paper. In general, if patients have radiographic evidence of brainstem compression but no symptoms, we do a trial of traction and posterior fusion without ventral decompression. If symptoms of ventral brainstem compression exist, however, we prefer to perform a combined posterior-anterior approach.

The head was pinned in 3-point fixation in a radiolu-

cent Mayfield head holder. The 3-prong reference array (for image guidance) was attached to the Mayfield clamp in direct line of sight to the infrared camera, which was set up at the foot of the bed (Figs. 1 and 2 right). Anesthesia setup was behind the x-ray detector ring of the CT scanner, with the endotracheal tube and intravenous line connections passing through the ring. The surgeon and assistant stood on one side of the patient, and the image guidance and endoscopic monitor screens were placed on the opposite side (Figs. 1 and 2 right).

Once the patient was secured with Mayfield 3-point fixation, a CT scan was obtained for registration of the image guidance software. Surgery then proceeded, and, following an initial assessment that the odontoidectomy was deemed complete, a second CT scan was obtained and new registration coordinates were acquired. If the decompression was satisfactory, surgery was completed and closure was performed. If, however, residual odontoid bone was seen on the CT scan, additional decompression was pursued using the newer registration coordinates to accurately identify and remove the residual bone.

Figure 2 left shows a typical schematic of operating room setup for endonasal odontoidectomy with image guidance using preoperative MRI/CT imaging. Note that the surgeon and assistant stand opposite each other, and the endoscope and image guidance monitors are placed toward the head of the patient. The infrared camera for

FIG. 2. **Left:** Schematic of the operating room setup for endonasal odontoidectomy with image guidance using preoperative MRI/CT imaging. **Right:** Schematic of the operating room setup for endonasal odontoidectomy with imaging guidance using iCT imaging. tech. = technician. Figure is available in color online only.

tracking image guidance is also placed toward the patient's head. Anesthesia is set up behind the assistant.

Figure 2 right shows a schematic of the operating room setup for endonasal odontoidectomy with image guidance using iCT. To accommodate the ring of the CT scanner, the surgeon and assistant stand on one side of the patient, and the endoscope and image guidance monitors are placed on the opposite side. The anesthesia setup is behind the ring of the CT scanner. A key point is the placement of the infrared camera. It must be placed at the foot of the bed so that it is in direct line of sight to the 3-prong reference array, as well as to the localization markers on the face of the CT scanner ring, to allow for image guidance registration in real time. The downside of this setup is that only one surgeon can operate at a time while using an endoscope holder placed on the contralateral side (Fig. 1).

Results

Case 1

A 61-year-old man with basilar invagination underwent a posterior cervical decompression and anterior endonasal odontoidectomy at another institution several years prior to presentation. The patient continued to experience progressive neurological deterioration with gait imbalance, dysphagia, and diplopia. Imaging showed persistent invagination with cervicomedullary compression (Fig. 3A

and B). The patient underwent occipitocervical fusion, followed by a repeat endonasal odontoidectomy using iCT image guidance.

After the odontoidectomy was deemed complete, a second CT scan was obtained while acquiring new registration coordinates. A small prominence of residual odontoid was seen on the left side (Fig. 3C). Further decompression was pursued, and a complete resection was obtained. There was no significant metal artifact from the posteriorly placed occipitocervical hardware (Fig. 3D).

Case 2

A 35-year-old man presented with neck pain, hand weakness, and left arm paresthesias on neck extension. Imaging showed basilar invagination and foramen magnum stenosis. The patient underwent occipitocervical fusion, followed by endonasal odontoidectomy using iCT image guidance.

After the odontoidectomy was deemed complete, a second CT scan was obtained while acquiring new registration coordinates. The odontoid was shown to be completely resected. There was asymmetrical resection of the C-1 anterior ring on the left (Fig. 4). Since the C-1 ring was not causing any ventral compression, no further resection was performed. Once again, no significant beam-hardening artifact from the posterior cervical instrumentation was seen on the scan.

FIG. 3. Case 1. **A:** Preoperative coronal CT scan showing the odontoid tip. **B:** Preoperative sagittal CT scan showing basilar invagination. **C:** Intraoperative coronal CT scan showing residual odontoid on the left (*circle*). **D:** Intraoperative sagittal CT scan showing resection of the odontoid. Posterior occipitocervical fusion hardware can also be seen.

Case 3

A 55-year-old woman with a history of long-standing severe rheumatoid arthritis and basilar invagination was treated 6 years earlier with occipitocervical fusion at another institution. The patient presented in 2016 with 1 year of progressive frontal headaches, vertigo, tinnitus, difficulty swallowing, loss of dexterity in hands, balance instability, and urinary incontinence. The examination was significant for motor strength of 4/5 bilaterally, hyperreflexia in the upper and lower extremities, abnormal coordination, and cerebellar function. A sleep study revealed severe obstructive sleep apnea. Imaging demonstrated multiple developmental abnormalities of the CVJ with marked basilar invagination and the dens extending 1.9 cm above the foramen magnum (Fig. 5A and B).

Due to the extreme basilar invagination and the mild ventriculomegaly in this case, the risk of incurring a CSF leak while trying to disarticulate the odontoid tip from the dura was felt to be substantial. Therefore, we did not try to remove the tip of the odontoid but rather removed about 2 cm of the base so the tip would decompress from the brainstem. The middle third of the odontoid was removed to disconnect the tip from the rest of C-2. After the odontoidectomy was deemed complete, a second CT scan was obtained while acquiring new registration coordinates. A small shelf of residual bone was seen on the left side, and this was then removed until the tip of the dens was free floating and decompressed from the ventral brainstem. Postoperative CT and MRI showed expected partial resection of the C-2 vertebra with significant inferior migration of the upper portion of the odontoid process resulting in excellent decompression of the brainstem (Fig. 5C and D).

Case 4

A 22-year-old man with severe Chiari malformation and basilar invagination, who had medullary compression from the retroflexed odontoid resulting in a cervical syr-

FIG. 4. Case 2. Pre- and postoperative axial CT sequences showing the extent of odontoid resection. Note the asymmetrical resection of the C-1 anterior ring on the left (*circle*).

inx, presented with severe occipital headaches associated with straining (Fig. 6A and B). The patient underwent occipitocervical decompression and fusion, followed by endonasal odontoidectomy using iCT image guidance.

After the odontoidectomy was deemed complete, a second CT scan was obtained while acquiring new registration coordinates. A small inferior posterior right-sided residual was identified (Fig. 6C) and subsequently removed, and complete resection was attained (Fig. 6D).

All of our endoscopic odontoid resection patients who did not have occipitocervical fusion performed under the same anesthesia session were extubated in the operating room. Patients who underwent combined fusion and decompression were electively extubated on the morning of postoperative Day 1 to allow airway edema to subside after 8–10 hours of surgery, much of it in the prone position for the fusion portion of the case. All patients remained symptom free at the 6-month follow-up.

Discussion

Intraoperative imaging with real-time navigation is useful in situations in which subtotal resection is frequent enough to justify the cost of the equipment and where it impacts the outcome of the surgery. In our previous series of endonasal odontoid resections, a small fragment was left on the left side in 57% of cases.⁶ Intraoperative CT scanning has proven useful for delineating the adequacy of surgical decompression at the cervicomedullary junction.^{5,7,17} In 1 case series, iCT scanning showed inadequate decompression of the cervicomedullary junction in up to 36% of cases.⁵ In our current series, we were able to find a residual fragment of odontoid that was removed with further intraoperative localization and surgery in 3 of 4 cases. Whether these small residual fragments are clinically significant is unknown, but complete resection of the odontoid is more likely to relieve symptoms than a partial resection. Ongoing clinical assessments will try to elucidate these questions further.

In most cases in which image guidance is used, the scan is obtained in a preoperative setting. Those images are then transferred to the intraoperative setting and used for image guidance. However, the patient might be positioned differently in the operating room from how the patient was in the scanner, introducing errors into the system. Using iCT with image guidance coregistration eliminates that variable for more accurate localization. This might be especially pertinent in cases in which the patient undergoes

FIG. 5. Case 3. **A:** Preoperative sagittal CT scan showing extension of the dens 1.9 cm above the foramen magnum. **B:** Preoperative sagittal T2-weighted MR image showing indentation of the medulla by the retroflexed odontoid tip. **C:** Postoperative sagittal CT scan showing resection of the middle third of the odontoid, allowing the odontoid tip to descend out of the medulla. **D:** Immediate postoperative sagittal T2-weighted MR image showing partial decompression of the brainstem.

a posterior occipitocervical fusion, altering spinal alignment, prior to the endonasal odontoidectomy.

Intraoperatively, when the base of the odontoid is disconnected from the body of the axis (C-2), there could be significant displacement of the dens from its preoperative location. During resection, a small fragment of the displaced dens might be obscured from endoscopic view due to thick pharyngeal musculature and/or presence of thick pannus. Although a regular iCT scan might show us the residual fragment, preoperative image guidance will not be very helpful in localization of this fragment due to intraoperative displacement of the dens. In these cases, a second iCT scan with image guidance coregistration can be obtained, and new coordinates can be used to accurately and precisely identify the residual fragment, increasing completeness of resection.

While there are distinct advantages to using an iCT coupled with image guidance, there are also some disadvantages. The operating room setup has to be significantly altered to accommodate the CT scanner as well as the image guidance system and to enable them to communicate with one another. The operating room setup and workflow that we have described adds 10–15 minutes per case. However, during complex cases, revision cases, or during intraoperative complications, the use of live CT neuronavigation gives the surgeon added reassurance regarding the surrounding anatomy. For low- to mid-volume endonasal endoscopy practitioners, this could mean the difference between a complete decompression versus a partial decompression.

We also identified that in 3 of 4 cases, there was a tendency for asymmetrical decompression toward the right side, meaning residual bone was seen on the left (Figs. 3C and 4). We hypothesize that this is because, in most cases, the endoscope was placed in the left nostril and the working instrument channel was predominantly the right

FIG. 6. Case 4. **A:** Preoperative sagittal CT scan showing the retroflexed odontoid. **B:** Preoperative sagittal T2-weighted MR image showing medullary compression and the associated syrinx. **C:** Intraoperative axial CT scan showing the residual odontoid on the right side (circle). **D:** Immediate postoperative sagittal T2-weighted MR image showing the resection of the odontoid tip.

nostril. It was easier to retract the posterior pharyngeal musculature (using suction) and drill the C-1 ring and odontoid on the right rather than on the left where there was continuous overhang of the pharyngeal musculature. Thus, special attention must be paid to adequately decompressing the contralateral side when working predominantly through the ipsilateral nostril.

There is also discussion in the literature of beam-hardening artifact, in scans of patients with previously instrumented spines, obscuring the view of the odontoid.^{4,12} We did not find this to be the case. Technically advanced portable CT scanners like Airo with full Hounsfield soft-tissue imaging offer better definition of the spine. Artifact due to posterior fixation implants is less because the device is a high-definition 32-slice CT scanner, and also because the odontoid is in the midline and quite anterior to the posteriorly placed implants (Fig. 3D).

Endoscopic endonasal odontoidectomy offers significant reduction in surgical morbidity and hospital stay compared with transoral approaches,^{6,9,10} which can lead to significant postoperative morbidity such as dysphagia, tongue or teeth damage, and nasal regurgitation from velopharyngeal insufficiency.^{14,15,22} Mean times to extubation and oral feeding occur as early as postoperative Days 0.3 and 1, respectively, compared with postoperative Days 3.58 and 5.24 for transoral surgery.^{6,9} Endoscopic endonasal odontoidectomy also provides distinct optical advantages, wider optical field, closer view, and elimination of a wide approach corridor.^{1,15} There is minimal risk of injuring structures such as the vidian nerve, carotid artery, and eustachian tube.²¹

Conclusions

Endoscopic endonasal odontoid resection with real-time intraoperative image-guided CT is feasible and provides accurate intraoperative localization of pathology, thereby increasing the chance of a complete odontoidectomy. Whether this improved localization leads to better operative and postoperative outcomes needs to be prospectively studied in a larger series of patients. For right-handed surgeons operating predominantly through the right nostril, special attention should be paid to the contralateral (left) side of the resection, where there is often a tendency for residual pathology.

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Disclosures

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Author Contributions

Conception and design: Schwartz, Singh, Greenfield. Acquisition of data: Singh, Rote, Jada, Bander, Almodovar-Mercado, Essayed, Härtl, Anand, Greenfield. Analysis and interpretation of data: Singh, Rote, Greenfield. Drafting the article: Singh, Greenfield. Critically revising the article: Schwartz, Greenfield. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Schwartz.

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