Endoscopic endonasal odontoidectomy: a long-term follow-up results for a cohort of 21 patients

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Abstract
Background  Endoscopic endonasal odontoidectomy (EEO) has been described as a potential approach for craniovertebral junction (CVJ) disease which could cause anterior bulomedullary compression and encroaching. Due to the atlantoaxial junction’s uniqueness and complex biomechanics, treating CVJ pathologies uncovers the challenge of preventing C1–C2 instability. A large series of patients treated with endonasal odontoidectomy is reported, analyzing the feasibility and necessity of whether or not to perform posterior stabilization. Furthermore, the focus is on the long-term follow-up, especially those whom only underwent partial C1 arch preservation without posterior fixation.

Methods  This study is a retrospective analysis of patients with ventral spinal cord compression for non-reducible CVJ malformation, consecutively treated with EEO from July 2011 to March 2019. Postoperative dynamic X-ray and CT scans were obtained in each case in order to document CVJ decompression as well as to exclude instability. The anterior atlas-dens interval, posterior atlas-dens interval and C1–C2 total lateral overhang were measured as a morphological criteria to determine upper cervical spine stability.

Results  Twenty-one patients (11:10 F:M) with a mean age of 60.6 years old at the time of surgery (range 34–84 years) encountered the inclusion criteria. For all 21 patients, a successful decompression was achieved at the first surgery. In 11 patients, the partial C1 arch integrity did not require a posterior cervical instrumentation on the bases of postoperative and constant follow-up radiological examination. In 13 cases, an improvement of motor function was recorded at the time of discharge. Only one patient had further motor function improvement at follow-up. Among the patients that did not show any significant motor change at discharge, 4 patients showed an improvement at the last follow-up.

Conclusions  The outcomes, even in C1 arch preservation without posterior fixation, are promising, and it could be said that the endonasal route potentially represents a valid option to treat lesions above the nasopalatine line.

Keywords  Cranio-vertebral junction  ·  Odontoidectomy  ·  Endoscopic endonasal approach  ·  C1 arch preservation

Introduction
Anterior approaches, transoral and endoscopic, offer direct and straightforward access to the bulbomedullary junction without the necessity of neural tissue retraction and consequently low cranial nerve injury.

The endoscopic endonasal odontoidectomy (EEO) has been described both on cadaveric preparation and in few case series as the surgery of choice [1, 2], otherwise, a valid alternative, for irreducible craniovertebral junction (CVJ) malformation, causing anterior bulomedullary compression and encroaching.

Different pathologies may affect the CVJ, leading to impairment/limitation of its physiological function with a loss of mobility and eventually compression of neurovascular structures. Prompt surgical intervention is required when these disorders cause symptomatic high spinal cord or brainstem compression [3, 4].

Even if the endonasal endoscopic approach is considered less invasive compared to the classic transoral approach (TOA), avoiding the need for tongue retraction, upper airway swelling, and the need for palate splitting, it is not spared by few drawbacks and complication [5, 6]. The feasibility
of a proper anterior odontoid decompression depends on the inferior extension of the nasopalatine line or Kassam line (K line) [7]. Because of the unique and complex biomechanics of the atlantoaxial junction, treating CVJ pathologies consequentially exposes the challenge of preventing C1–C2 instability [8]. Limiting the resection of C1 anterior arch, it is recommended to reduce subsequent stability complications and to spare selected patients from posterior fixation, as recently reported [9]. With the EEO partial ligament sparing is feasible, especially the transverse ligament, limiting instability and subaxial atlanto-occipital dislocation. Technically speaking, as the odontoid process is seated in a very deep field, the stereoscopic view obtained in endoscopic procedures improves surgical dexterity and subsequently the possibilities of preserving the C1 arch while completely removing the odontoid process [10].

One of the most important parameters to consider in bulbomedullary junction compression is whether or not the abnormality is reducible. The reducibility, evaluated through dynamic cervical X-ray for stability and motion dynamic, along with ventral encroachment, defines the type of surgical approaches in CVJ pathologies. Recently, a treatment algorithm has been updated [11, 12]. To sum up, in case of reducible lesions, patients may solely undergo a posterior occipital–cervical (OCF), C1–C2 fusion (AAF), or both, otherwise anterior release and decompression is mandatory. Yet, in the case of patients affected by acute spinal cord compression and rapidly deteriorating neurologic function, anterior decompression and posterior fixation is usually required [13].

In this paper, considering as starting point the results of an old cohort of patients [14], we report a large series of patients treated with endonasal odontoidectomy. The feasibility and the necessity to perform or not a posterior stabilization is analyzed. Furthermore, the long-term follow-up of both posteriorly fixed patients and especially those who only underwent partial C1 arch preservation without posterior fixation is reported.

Therefore, positive results may justify any attempts to preserve the C1 arch without limiting the decompression.

**Materials and methods**

This study is a retrospective analysis of patients with ventral spinal cord compression for non-reducible CVJ malformation, consecutively treated with EEO from July 2011 to March 2019.

The irreducibility of the CVJ malformation determining a clinical and radiological evidence of ventral bulbo-medullary compression was considered an indication for EEO. All of the patients who underwent to EEO were considered recruitable. Inclusion criteria were: availability of clinical chart and surgical report, a minimum period of six-month follow-up, pre-operative cervical MRI and cervical spine dynamic X-ray.

A dynamic X-ray of the cervical spine was performed in almost every case to evaluate irreducibility. In case of acute presentation, the examination was not performed.

The compression or the encroachment of the spinal cord, along with radiological sign of myelopathy, was diagnosed with an MRI.

A CT, or CT angiography (CTA), was acquired in order to perform the intraoperative neuronavigation and to accomplish the planning in case of posterior fixation.

Postoperative dynamic X-ray and CT scan were obtained in every case to document CVJ decompression and to exclude instability. The anterior atlantodental interval (AADI) defines the distance between the anterior arch of C1 and the odontoid process of C2, posterior atlas-dens interval (PADI), which is the distance between the posterior arch of C1 and the dens of the axis, and C1–C2 total lateral overhang was measured as morphological criteria to determine the upper cervical spine stability. An atlantoaxial subluxation was defined as the AADI > 3 mm and/or PADI ≤ 14 mm, as reported by Puttlitz et al [15], and the lateral overhang of C1–C2 was considered pathologic when ≥ 7 mm [16].

Nevertheless, a postoperative CT was also performed in order to check the screw trajectory in those cases when posterior fixation was needed.

Patients underwent radiological and clinical follow-up at 1 and 6 months after surgery and then yearly.

**Surgical technique**

The procedure has been previously reported by the senior author (F.Z.); here, the main steps are illustrated [3, 14]. An image-guided endoscopic endonasal odontoidectomy with a 3-dimensional-HD (3D-HD) endoscope was performed. The neurophysiologic monitoring assisted the surgeon in every procedure. Baseline SEPs and MEPs were recorded at the beginning and at the end of patient positioning. A two nostrils-four hands technique was performed, and following the inferior turbinate, the rhino-pharynx mucosa over the CVJ was reached through the choanas. Hence, C1 and C2 vertebras were skeletonized in a sub-periosteal fashion, and then, an ultrasonic bone curette was used to remove the tip and the base of the odontoid process, selectively preserving, when possible, a part of the anterior C1 arch. This technique was found safe and effective, reducing the soft tissue manipulation and without any reported case of thermal injury [17].

The residual shell of the odontoid was removed by sectioning apical and alar ligaments and separating the process from adhesion to surrounding tissues. Finally, the dura covering the pontomedullary junction was exposed after transverse ligament removal.
More recently, at the end of the procedure, an intraoperative CT scan was helpful to assess the effectiveness of decompression by showing the extent of bone removal.

The extension of odontoid resection and removal of the anterior arch of C1 were planned considering the preoperative entity of invagination and the type of craniovertebral malformation. A semi-rigid cervical orthosis (i.e., Philadelphia collar) was placed until a dynamic X-ray scan was performed, usually within the first couple of days after surgery.

Results

Twenty-one patients (11:10 F:M), mean age at surgery 60.6 years (range 34–84 years), encountered the inclusion criteria. Fourteen patients were affected by a complex occipito-cervical junction malformation, two were diagnosed with a Chiari I malformation, one suffered from an odontoid tip chondrosarcoma, two patients had a chordoma, and two patients had a periodontoid rheumatoid pannus with ventral irreducible spinal cord compression. The most common presenting symptoms were neck pain (47.6%) and upper and/or lower-limb weakness (66.6%). These symptoms lasted at least 3 months (15/21 patients, 71.4%); five patients had a sub-acute presentation (23.8%) and two patients presented acute signs (9%) of brainstem compression. In the latter, a preoperative tracheostomy was performed because of respiratory insufficiency (Table 1).

For all 21 patients, a successful decompression was achieved at the first surgery. In 11 patients, the partial C1 arch integrity did not require a posterior cervical instrumentation on the base of post-operative and constant follow-up radiological examination (Fig. 1). In light of the preoperative characteristics of CVJ pathology, partial C1 preservation was not possible in 9 patients: an atlanto-axial fusion (AAF), with lateral mass screws in C1 and transpedicular screws in C2, was the mainstay of posterior fixation; 2 patients additionally underwent occipito-cervical fusion (OCF), further limiting the pathological segments motions seen in postoperative dynamic X-ray.

A single case with a peculiar CVJ complex malformation associated with ventral elements fusion, did not require any subsequent posterior fixation, despite a complete removal of anterior C1 arch.

In 13 cases, improved motor function was recorded at discharge, and only one of them had further improved motor function at follow-up. Among the patients that did not show any significant motor change at discharge, 4 patients showed an improvement at the last follow-up. Two patients were asymptomatic at the time of diagnosis. Five patients spent a period in a rehabilitation setting. One patient died a few months after surgery from pneumonia developed after discharge (Table 2).

Four out of 21 patients (19%) developed a postoperative infection (pneumonia) treated with antibiotics without any sequelae. We reported a 9.5% (2/21) of intraoperative CSF leak, but none of them had developed any signs of postoperative CSF leak.

Postoperative dynamic X-ray and CT scans were obtained in every case to document CVJ decompression and to exclude instability.

In patients in which the preservation of the lower portion of C1 arch was achieved, AADI and PADI remained stable after surgery. The total C1–C2 overhang was not more than 7 mm, thus demonstrating no difference in CVJ motility compared to the preoperative images (Fig. 2). Therefore, no posterior cervical stabilization was required. The decision of stabilization was postponed considering the clinical and radiological status during the neurosurgical follow-up. It has to be noted that a single patient developed neck pain after EEA decompression and posterior fixation was suggested from another center. The patient was placed in a Philadelphia collar for 6 months with complete symptoms relief and orthoses removal.

Up to the last follow-up visit, all 11 out of 21 patients (62%) did not show any radiological and clinical features of instability, sparing them a second surgery. For the remaining patients in which the C1 arch was not preserved, the posterior instrumentation, OCF, AAF or both, was planned during the first surgical evaluation.

In the series of patients who underwent endoscopic endonasal odontoidectomy for irreducible ventral brainstem compression, the mean follow-up was 59.8 (SD 32.6; range 98–12). In 20 patients, the follow-up was longer than 12 months. Eleven of them have been being followed for over 5 years. One patient was lost at follow-up (last visit at 39 months).

Considering the eleven patients in which the preservation of the anterior C1 arch was achieved, a minimum follow-up of 12 months has been ascertained (mean FU 61.9 months, range 98–13). Only 9 cases out of 11 have more than 12-month follow-up. The latest postoperative cervical spine radiogram showed no sign of spinal instability in all these patients.

Discussion

The results of our long-term follow-up of nine patients undergoing EEO with partial preservation of C1 anterior arch showed no need of posterior fusion.

Over the years, different authors have demonstrated the effectiveness of the endoscopic endonasal approach and the lower morbidity compared to the traditional transoral approach [1, 2]. Compared to the nasopalatine line (Kassam line or K line), some recent studies proposed other lines,
Table 1  Cohort description

| Patient no | Sex (M:F = 10:11) | Age at surgery (years) (mean 60.6) | Diagnosis | Clinical presentation | Symptoms duration | C1 anterior arch integrity | Posterior instrumentation |
|------------|-------------------|-------------------------------------|-----------|-----------------------|------------------|---------------------------|--------------------------|
| 1          | F                 | 72                                  | Basilar Impression, Chiari Syndrome | Headache, ataxia | > 12 mos            | Yes                       | No                       |
| 2          | F                 | 59                                  | CVJ complex malformation            | Headache, UE weakness (3/5) | > 12 mos            | No                        | Yes, OCF + AAF            |
| 3          | M                 | 42                                  | CVJ complex malformation            | Neck pain, UE and LE weakness (4/5) | < 3 mos            | Yes                       | No                       |
| 4          | F                 | 65                                  | RA, inflammatory pannus             | Neck pain, headache, LE weakness (3/5) | > 12 mos            | No                        | Yes, AAF                 |
| 5          | F                 | 70                                  | CVJ complex malformation            | Neck pain, LE weakness (4/5), respiratory insufficiency | < 48 h            | No                        | Yes, AAF                 |
| 6          | M                 | 53                                  | Basilar invagination, CVJ complex Malformation | Neck pain; headache; gait and sphincter disturbances | > 12 mos            | Yes                       | No                       |
| 7          | F                 | 51                                  | Chiari Syndrome; Syringomyelia/ hydromyelia | Sensory loss; gait disturbances; cerebellar dysfunction | > 12 mos            | Yes                       | No                       |
| 8          | M                 | 66                                  | CVJ complex malformation            | Neck pain; headache; sensory loss; LE weakness (2/5) and UE weakness (3/5); sphincter disturbances; respiratory insufficiency | 3–12 mos        | No                        | Yes, AAF                 |
| 9          | F                 | 71                                  | Chondrosarcoma G2 (odontoid tip)    | Limb Paresthesia; LE and UE weakness (4/5); gait and sphincter disturbances | > 12 mos            | No                        | Yes, OCF + AAF            |
| 10         | F                 | 70                                  | CVJ complex malformation            | Neck and radicular pain; limb paresthesia; sensory loss; gait impairment | > 12 mos            | Yes                       | No                       |
| 11         | M                 | 62                                  | CVJ complex malformation            | Neck pain; LE and UE weakness (4/5); sensory loss; | 3–12 mos        | Yes                       | No                       |
| 12         | M                 | 55                                  | CVJ complex malformation            | Neck pain; mild sensory loss; LE and UE weakness (4/5) | > 12 mo            | Yes                       | No                       |
| 13         | F                 | 68                                  | CVJ complex malformation            | Limb paresthesia; sensory loss; unilateral LE and UE weakness (4/5); gait disturbances | 3–12 mos        | No                        | No                       |
such as the rhinopalatine line, as more accurate predictors to define the caudal limit of craniocervical lesions that can be reached via EEA [18–20].

However, it is currently thought that the surgical approach must be tailored to the unique anatomical characteristics of each patient and the features of the lesion. Drilling the posterior nasal spine, located between the soft and the hard palate, could be useful to widen the route of access to the CVJ, as already reported [14].

Once the decompression is obtained, the necessity to perform an instrumented fixation of the craniovertebral joints complex has to be reasonably weighed. On the one hand, there is the risk of instability, especially if no bony structures are preserved. For instance, the odontoidectomy followed by the partial or complete excision of different primary and secondary elements of stabilization of a complex and high degree of ROM joints, brings, inevitably, a certain risk of instability of the CVJ [4, 21, 22]. On the other hand, fixation extremely reduces the range of movements (ROMs) of wide movable joints, limiting daily activity like eating. Nevertheless, these limitations are less impacting on the elderly; in fact, in this age group, there is a decrease in mobility of the cervical spine, as demonstrated by several studies [23–25].

Indeed, the CVJ is characterized by a great degree of motion compared to the rest of the spine. ROMs in the physiologic range are guaranteed by bony and ligamentous structure, avoiding joint stress and muscular effort to maintain the erect posture. The primary movement of Oc-C1 is flexion–extension of the skull (23° to 24.5°), and an additional 10.1° to 22.4° is provided by C1–C2 joints. Less degree of lateral bending and axial rotation is guaranteed by bony structures. The axial rotation is the primary movement of

| Table 1 | (continued) |
|---------|-------------|
| Patient no | Sex (M:F = 10:11) | Age at surgery (years) (mean 60.6) | Diagnosis | Clinical presentation | Symptoms duration | C1 anterior arch integrity | Posterior instrumentation |
| 14 | F | 66 | CVJ complex malformation | Radicular pain; Limb paresthesia; sensory loss; unilateral UE weakness (3/5); gait impairment | 3–12 mos | No | Yes, AAF |
| 15 | M | 84 | CVJ complex malformation | Neck pain; Limb paresthesia; LE weakness (4–5) and UE weakness (3/5); gait impairment | 3–12 mos | No | Yes, AAF |
| 16 | M | 73 | Klippel–Feil Syndrome; CVJ complex malformation | Dysphagia; Dysphonia; LE and UE weakness (2/5); respiratory insufficiency; consciousness impairment; | <48 h | No | Yes, AAF |
| 17 | M | 16 | Chordoma | None | 3–12 mos | Yes | No |
| 18 | M | 34 | Chordoma | Neck pain | >12 mos | Yes | No |
| 19 | F | 68 | CVJ complex malformation; basilar invagination | Limb paresthesia; sensory loss; gait disturbances; dysphagia; LE and UE weakness (4–5) | >12 mos | Yes | No |
| 20 | M | 73 | CVJ complex malformation | Neck pain | <3 mos | Yes | No |
| 21 | F | 78 | RA, inflammatory pannus | UE weakness (2/5); LE weakness (1/5) | <3 mos | No | Yes, AAF |

RA, Rheumatoid arthritis; UE, upper extremities; LE, lower extremities; AAF, atlantoaxial fixation; OCF, occipito-cervical fusion

In bold the patients already reported in “Zenga F, Pacca P, Tardivo V, et al. Endoscopic Endonasal Approach to the Odontoid Pathologies. World Neurosurg. 2016;89:394–403. https://doi.org/10.1016/j.wneu.2016.02.011”
C1–C2 (23.3° to 38.9°), and other movements are constrained by ligamentous structures, namely the ipsilateral transverse and the contralateral alar ligaments, with support from the joint capsules of the occipitoatlantal and atlantoaxial junctions [26, 27].

Dickman et al. was the first to describe the biomechanical consequences of the endoscopic odontoidectomy performed trans-orally. Seeking the impact of surgery on animal and cadaveric models, they found a significant increase in anteroposterior, lateral and vertical subluxations, promoting the so-called cranial settling; additionally, the odontoidectomy led to unconstrained and hypermobile motion, greatly increasing the susceptibility to clinical instability [21]. Primary and secondary (including the dens, the alar ligaments, and the transverse ligament) stabilizers of the Oc–C1–C2 complex are usually detached or completely removed during surgery. A way to reduce the postoperative risk of spinal instability is to preserve as much normal osseous architecture as possible [6]. It was demonstrated that the complete or partial anterior C1 arch preservation reduces the lateral displacement of the C1 lateral masses. When not preserved, the axial or vertical load—that is the main mode of loading at the CVJ in the upright neutral position—increases the lateral mass offset and the horizontal spreading of C1, causing a movement of the occiput toward C1 (namely cranial settling) [22]. Hence, the complete or partial preservation of the anterior C1 arch, acting as cross-link between lateral masses, may decrease the incidence of postoperative instability, avoiding a posterior fixation. Moreover, capsular ligaments, paraspinal muscle, tectorial membrane, anterior longitudinal ligament, and ligamentum flavum play an important role of second stabilizers, whose action can be negatively affected by the loss of integrity of the C1 ring.

The iatrogenic nature is not the only cause of Oc–C1–C2 complex impairment. For instance, it can be observed in systemic inflammatory state, like rheumatoid arthritis, which most commonly affects the cervical spine [28]. An uncontrolled inflammatory process of the cervical spine could lead to ligaments erosion, and even the unique involvement of the transverse ligament affects the
stability of the joint complex, with anterior atlantoaxial subluxation. Because of an increased instability of the joints complex, a posterior instrumentation is indisputable after odontoidectomy with C1 arch complete resection.

Posterior fixation leads to a great limitation in ROMs which have been calculated: In cadaveric models, normal axial rotation, flexion–extension and lateral bending were reduced to 90% after posterior fixation, where occiput-C1 constructs (OCF) mainly limit the flexion–extension and C1 lateral mass screws and C2 pedicle or transarticular screws in atlantoaxial fusion (AAF) limit the axial rotation [29].

More specifically, a C1–C2 construct with transarticular screws was found to decrease 61.4% in flexion, 82.7% in lateral bending and 94.8% during axial rotation which is less affected when a different type of construct, such as the one that was used in our cases, is implanted [30, 31].

The selection of either OCF or AAF depends on the degree of spine instability.

Again, in patients with rheumatoid arthritis, other structures, both ligamentous and bony elements, could be affected by a degenerating process as well, causing ventral encroaching and spinal cord compression. If, additively, other elements of CVJ (i.e., lateral masses of occipit and atlas) are progressively deteriorated, an atlantoaxial impact occurs due to a complete collapse of the lateral masses determining cranio cervical instability and promoting, occasionally, spine ankylosis [32]. This process leads to a spontaneous stabilization of C1 and C2 and paradoxically reduces the instability, influencing the decision process for posterior

### Table 2 Long-term follow-up

| Patient no | Tracheostomy/ Extubation*(days) | Restart Oral Feeding (days) | Clinical Examination at hospital discharge | Follow-up (months) | Clinical Examination at last follow-up visit |
|------------|-------------------------------|-----------------------------|-------------------------------------------|--------------------|---------------------------------------------|
| 1          | No/0                          | 1                           | Asymptomatic                               | 98                 | No changes                                  |
| 2          | No/0                          | 2                           | Pain and motor function improvement        | 96                 | No changes                                  |
| 3          | No/0                          | 1                           | Pain and motor function improvement        | 95                 | No changes                                  |
| 4          | No/0                          | 1                           | Pain and motor function improvement        | 93                 | No changes                                  |
| 5          | Yes                           | 1                           | Motor function improvement                 | 39 †               | Lost at FU                                   |
| 6          | No/0                          | 1                           | Pain Improvement                            | 90                 | No changes                                  |
| 7          | No/0                          | 1                           | No Changes in pain, sensory and motor      | 89                 | Pain, sensory and motor function improvement |
|            |                               |                             | functions                                   |                    |                                             |
| 8          | Yes/5                         | 5                           | Motor function improvement                 | 84                 | Occasional Right UE paresthesia; mild dysphagia |
| 9          | No/1                          | 2                           | Sensory function improvement; no change in motor function | 84                 | LE motor function improvement; No change in UE motor function; Sensory function improvement |
| 10         | No/0                          | 2                           | Pain and motor function improvement        | 81                 | No changes                                  |
| 11         | No/0                          | 1                           | Pain and motor function improvement        | 80                 | No changes                                  |
| 12         | No/0                          | 1                           | Motor function Improvement                 | 72                 | No changes                                  |
| 13         | No/0                          | 0                           | Sensory and motor functions improvement    | 46                 | No changes                                  |
| 14         | No/0                          | 1                           | No Changes in pain, sensory and motor      | 34                 | Distal UE paresthesia; motor function        |
|            |                               |                             | functions                                   |                    | improvement                                  |
| 15         | No/0                          | 1                           | Pain, sensory and motor function improvement; | 30                 | Distal UE paresthesia; motor function        |
|            |                               |                             |                                            |                    | improvement                                  |
| 16         | No/0                          | PN/PEG                      | Motor function improvement (global         | 27                 | No changes                                  |
|            |                               |                             | improvement)                                |                    |                                             |
| 17         | No/0                          | 4                           | Asymptomatic                               | 24                 | No changes                                  |
| 18         | No/0                          | 2                           | Pain improvement                            | 24                 | No changes                                  |
| 19         | No/0                          | 2                           | Sensory function improvement; no change in motor function | 15                 | Motor function improvement                   |
| 20         | No/0                          | 1                           | Global improvement                          | 13                 | No changes                                  |
| 21         | No/0                          | 9                           | Mild motor function improvement of UE      | 12                 | Exitus                                      |

*extubation after surgical procedure corresponds to day 0
†FU months referred to November 2015, considering the paper [Zenga F, Pacca P, Tardivo V, et al. Endoscopic Endonasal Approach to the Odontoid Pathologies. World Neurosurg. 2016;89:394–403. https://doi.org/10.1016/j.wneu.2016.02.011]
instrumentation. In the current study, anterior decompression was never jeopardized by trying to preserve C1 anterior arch; indeed, when decompression was not satisfactory, the anterior C1 arch was sacrificed and then posterior fixation was required.

Both in those patients where a posterior fixation was performed and in those which were spared of a second surgical procedure by preserving C1 arch, the duration of the follow-up is still a matter of debate. Analyzing the literature, the low number of cases reported makes it difficult to reach an agreement. Twenty-eight cases of documented anterior C1 arch integrity without posterior or anterior fixation are currently reported [9, 33–41]. Only four studies, along with the current one, reported a follow-up longer than 24 months [9, 37, 40, 41] (Fig. 3).

In the current study, every patient in which a part of C1 anterior arch was preserved has been followed with clinical and radiological evaluation to detect early possible instability (mean FU 61.9 months, range 98–13). So far, no patient needed a delayed posterior instrumentation. This finding strongly supports the strategy of preserving C1 arch in every case where it is possible. Indeed, avoiding the second surgery not only means a shorter anesthesiological time but also removes all the risks connected with the posterior approach leading to a faster postoperative recovery. The drawback from posterior fixations, such as decreased cranio-cervical ROM, increased risk of adjacent segment disease and construct failure are virtually canceled. However, it has been postulated that the area of decompression is greater in case of posterior fixation. However, it can be argued that decompression must be correlated with clinical outcomes more than volume of decompression. Furthermore, an intra-operative CT scan, where it is available, has emerged as useful tool along with the neuronavigation system to actively guide and control the endoscopic odontoidectomy. In this way, it is possible to provide a real-time image guidance and a double-check before closing the rhino-pharyngeal flap, evaluating the extent of bony decompression and possibly pushing C1 arch drill to the maximum safe resection.

It must be noted that in all the non-fixated cases, clinical and radiological follow-up should not be stopped. Even in the longest series, where the follow-up is only about 5 years, there is not enough data that allow the definition of definitive stability [40].

As described by several authors and reported in this series, the endoscopic endonasal route allows a rapid removal of the orotracheal tube with a prompt resumption of oral feeding. The approach spares the soft and hard palate integrity and avoids the risk of velopharyngeal insufficiency. In this series, 18 patients were extubated in the immediate postoperative period. 17 patients were able to ingest liquid and fluid from the third post-operative day.

The safety and effectiveness of this approach has been highlighted in different papers. In the review by Morales et al., indications, outcome, and complications of the endoscopic endonasal approach in the treatment of CVJ...
pathology have been analysed [22]. As they pointed out, in accordance with the complication rate reported for this series, only 1 of 72 patients developed postoperative meningitis, and although there was 18% rate of intraoperative CSF leak, the rate of postoperative CSF leak was only 4.2%, probably because this approach allows the surgeon to perform an effective multilayer dural repair.

Despite the wide spread of endoscopic endonasal approaches in the last 20 years, there are still few centers performing relatively high volume endoscopic endonasal odontoidectomies [42–45]. Although there are several studies focusing on surgeons’ learning curve in endoscopic endonasal approach, to the authors’ best knowledge, there are no specific studies on EEO learning curve. The main differences regard the use of longer instruments and the extremely caudal working angle. However, there are no differences in the learning curve of the reconstructive surgical steps: On the one hand, the risk for CSF leak in EEO is relatively low considering the extradural nature of the approach, while on the other hand, even if intraoperative CSF leak ensues, the reconstruction should be performed following the same rules of clival reconstruction, preferring the reverse U-shaped rhinopharyngeal flap over the Hadad nasoseptal flap [45].

In our experience, the endoscopic endonasal approach, with its shorter surgical working distance, a wide and panoramic view, and the vertical trajectory, promotes the attempt of anterior C1 arch preservation. Still the corridor brings to a very deep field where only few instruments allow good maneuverability.

In the recent years, the use of intraoperative CT scan helped the surgeons to perform a customized, case by case, surgery and to push the limits of C1 drill while preserving its integrity and achieve a complete odontoid resection.

Nevertheless, endoscopic endonasal odontoectomy remains a challenging procedure even when performed by a well-trained surgeon; therefore, a preoperative selection of suitable cases is paramount.

Limitations

Main limitations of the study are its retrospective/observational nature, the risk of selection bias and the low number of patients recruited. However, it is one of the few studies that reports the results of a long-term follow-up, despite being relatively short, in patients where the anterior C1 arch was preserved.

Conclusion

In this paper, the result of a long-term follow-up was presented. The outcomes, even in C1 arch preservation without posterior fixation, are promising, and it can be said that the endonasal route could represent a valid option to treat lesions above the nasopalatine line. More studies, especially conducted with a longer follow-up, are necessary to consider those who did not undergo posterior instrumentation as stable.
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Data availability Data are not publicly available due to ethical/privacy restrictions. Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data are not available.

Declarations

Conflict of interest The authors have no conflict of interest to disclose.

Ethical approval All clinical and radiological data were collected and retrospectively analyzed. This study does not require any variations in patient’s treatment, and no formal ethics committee approval was required.

Consent to participate Consent was obtained to use clinical information for research purposes.

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References

1. Altiere A, Jho H-D, Tschabitscher M (2002) Endoscopic endonasal approach to the ventral cranio-cervical junction: anatomical study. Acta Neurochir (Wien) 144(3):219–225. https://doi.org/10.1007/s007010200029
2. Kassam AB, Abla A, Snyderman C, Carrau R, Sپri R (2005) An endoscopic transnasal odontoidectomy to treat cervicomedullary compression with basilar invagination. Oper Tech Neurosurg 8(4):198–204. https://doi.org/10.1055/s-0025-10002
3. Pacca P, Tardivo V, Pecorari G, Garbossa D, Ducati A, Zenga F (2019) The endoscopic endonasal approach to craniovertebral junction pathologies: surgical skills and anatomical study. Acta Neurochir Suppl 125:25–36. https://doi.org/10.1007/978-3-319-62951-5_5
4. Morales-Valero SF, Serchi E, Zoli M, Mazzatenta D, Van Gompel JJ (2015) Endoscopic endonasal approach for craniovertebral junction pathology: a review of the literature. Neurosurg Focus 38(4):1–5. https://doi.org/10.3171/2015.1.FOCUS14831
5. Shriver MF, Kshettry VR, Sindwani R, Woodard T, Benzel EC, Recinos PF (2016) Transoral and transnasal odontoidectomy complications: a systematic review and meta-analysis. Clin Neurosurg 148:121–129. https://doi.org/10.1016/j.clineuro.2016.07.019
6. Tubbs RS, Demerdash A, Rizk E, Chapman JR, Oskouian RJ (2016) Complications of transoral and transnasal odontoidectomy: a comprehensive review. Child’s Nerv Syst 32(1):55–59. https://doi.org/10.1007/s00381-015-2864-6
7. de Almeida JR, Zanation AM, Snyderman CH et al (2009) Defining the nasopalatine line: the limit for endonasal surgery of the spine. Laryngoscope 119(2):239–244. https://doi.org/10.1002/lary.2108
8. Dickman CA, Locanto J, Fessler RG (1992) The influence of transoral odontoid resection on stability of the craniovertebral junction. J Neurosurg 77(4):525–530. https://doi.org/10.3171/jns.1992.77.4.0525
9. Re M, Iacoangeli M, Di Somma L et al (2016) Endoscopic endonasal approach to the craniovertebral junction: the importance of anterior C1 arch preservation or its reconstruction TT - Approccio endoscopico endonasale alla giunzione cranio-cervicale: l’importanza di preservare o ricostruire l’arco ant. Acta Otorhinolaringol Ital 36(2):107–118. https://doi.org/10.14639/0392-100X-647
10. Altieri R, Tardivo V, Pacca P et al (2016) 3D HD endoscopy in skull base surgery: from darkness to light. Surg Technol Int 29:359–365
11. Menezzah AH, Graf CJ, Hibri N (1980) Abnormalities of the cranio-vertebral junction with cervico-medullary compression. Pediatr Neurosurg 7(1):15–30. https://doi.org/10.1159/000119926
12. Dlohouy BJ, Dahdaleh NS, Menezzah AH (2015) Evolution of transoral approaches, endoscopic endonasal approaches, and reduction strategies for treatment of craniovertebral junction pathology: a treatment algorithm update. Neurosurg Focus 38(4):E8. https://doi.org/10.3171/2015.1.focus14837
13. Pacca P, Marengo N, Di Perna G et al (2019) Endoscopic endonasal approach for urgent decompression of craniovertebral junction in syringobulbia. World Neurosurg 130:499–505. https://doi.org/10.1016/j.wneu.2019.07.004
14. Zenga F, Pacca P, Tardivo V et al (2016) Endoscopic endonasal approach to the odontoid pathologies. World Neurosurg 89:394–403. https://doi.org/10.1016/j.wneu.2016.02.011
15. Puttlitz CM, Goel VK, Clark CR, Traynelis VC, Scifert JL, Grosland NM (2000) Biomechanical rationale for the pathology of rheumatoid arthritis in the craniovertebral junction. Spine (Phila Pa 1976) 25(13):1607–1616. https://doi.org/10.1097/00007632-200007010-00003
16. Sell KSD (1970) Bursting atlantal fracture associated with rupture of the transverse ligament. J Bone Jt Surg 52(3):543–549
17. Zenga F, Villaret A, Fontanella M, Nicolaí P (2013) Endoscopic transnasal odontoidectomy using ultrasonic bone curette: technical case report. Neurol India 61(1):69. https://doi.org/10.4103/0028-3886.108015
18. Aldana PR, Naseri I, La Corte E (2012) The naso-axial line: a new method of accurately predicting the inferior limit of the endoscopic endonasal approach to the craniovertebral junction. Neurosurgery. https://doi.org/10.1227/NEU.0b013e318266e488
19. Liu JK, Patel J, Goldstein IM, Eloy JA (2015) Endoscopic endonasal transclival transodontoid approach for ventral decompression of the craniovertebral junction: operative technique and nuances. Neurosurg Focus 38(4):1–8. https://doi.org/10.3171/2015.1.FOCUS14813
20. La CE, Aldana PR, Ferroli P et al (2015) The rhinopalatine line as a reliable predictor of the inferior extent of endonasal odontoidectomies. Neurosurg Focus 38(4):1–8. https://doi.org/10.3171/2015.1.FOCUS14777
21. Dickman CA, Crawford NR, Brantley AGU, Sonntag VKH (1995) Biomechanical effects of transoral odontoidectomy. Neurosurgery 36(6):1146–1153. https://doi.org/10.1227/00006123-199506000-00013
22. Naderi S, Crawford NR, Melton MS, Sonntag VKH, Dickman CA (1999) Biomechanical analysis of cranial settling after transoral
30. Paramore CG, Dickman CA, Sonntag VKH (1996) The aging changes in the cervical spine. Clin Orthop Relat Res 214(214):200–209. https://doi.org/10.1007/0003086-19870-10000-029

31. Richter M, Schmidt R, Claes L, Puhl W, Wilke HJ (2002) Posterior atlantoaxial fixation: biomechanical in vitro comparison of six different techniques. Spine (Phila Pa 1976) 27(16):1724–1732. https://doi.org/10.1097/00007632-200208150-00008

32. Kauppi MJ, Sakaguchi M, Konttinen YT, Hämäläinen M, Hakala M (1996) Pathogenetic mechanism and prevalence of the stable atlantoaxial subluxation in rheumatoid arthritis. Undefined

33. Gepp J, Lehmburg J, Grams AE, Berends L, Meyer B, Stoffel M (2011) Endoscopic transnasal resection of the odontoid: case series and clinical course. Eur Spine J 20(4):661–666. https://doi.org/10.1007/s00586-010-1629-x

34. Gladi M, Iacoangeli M, Specchia N et al (2012) Endoscopic transnasal odontoid resection to decompress the bulb-medullary junction: a reliable anterior minimally invasive technique without posterior fusion. Eur Spine J 21(Suppl 1):S55-60. https://doi.org/10.1007/s00586-012-2220-4

35. Choudhri O, Mindea SA, Feroze A, Soudry E, Chang SD, Nayak JV (2014) Experience with intraoperative navigation and imaging during endoscopic transnasal spinal approaches to the foramen magnum and odontoid. Neurosurg Focus 36(3):E4. https://doi.org/10.3171/2014.1.FOCUS13533

36. Duntze J, Eap C, Kleiber JC et al (2014) Advantages and limitations of endoscopic odontoidectomy. A series of nine cases. Orthop Traumatol Surg Res 100(7):775–778. https://doi.org/10.1016/j.otsr.2014.07.017

37. Mazzatenta D, Zoli M, Mascari C, Pasquini E, Frank G (2014) Endoscopic odontoidectomy: clinical series. Spine (Phila Pa 1976) 39(10):846–853. https://doi.org/10.1097/BRS.0000000000000271

38. Ponce-Gomez JA, Ortega-Porcayo LA, Soriano-Baron HE et al (2014) Evolution from microscopic transoral to endoscopic endonasal odontoidectomy. Neurosurg Focus 37(4):E15. https://doi.org/10.3171/2014.7.focus14301

39. Fujii T, Platt A, Zada G (2015) Endoscopic endonasal approaches to the craniovertebral junction: a systematic review of the literature. J Neurol Surg Part B Skull Base 76(6):480–488. https://doi.org/10.1055/s-0035-1554904

40. Iacoangeli M, Nasi D, Colasanti R et al (2017) Endoscopic odontoidectomy with anterior C1 arch preservation in rheumatoid arthritis: long-term follow-up and further technical improvement by anterior endoscopic C1–C2 screw fixation and fusion. World Neurosurg 107:820–829. https://doi.org/10.1016/j.wneu.2017.08.063

41. Chibbaro S, Cebula H, Aldesa S et al (2017) Endonasal endoscopic odontoidectomy in ventral diseases of the craniovertebral junction: results of a multicenter experience. World Neurosurg 106:382–393. https://doi.org/10.1016/j.wneu.2017.06.148

42. Koutourousiou M, Gardner PA, Tormenti MJ et al (2012) Endoscopic odontoidectomy for resection of cranial base chordomas: outcomes and learning curve. Neurosurgery 71(3):614–625. https://doi.org/10.1227/NEU.0b013e31825e3e0

43. Younis I, Gerges MM, Uribe-Cardenas R et al (2020) The slope of the learning curve in 600 consecutive endoscopic transsphenoidal pituitary surgeries. Acta Neurochir (Wien) 162(10):2361–2370. https://doi.org/10.1007/s00701-020-04471-x

44. Younis I, Gerges MM, Uribe-Cardenas R et al (2020) How long is the tail end of the learning curve? Results from 1000 consecutive endoscopic odontoidal skull base cases following the initial 200 cases. J Neurosurg 134(3):750–760. https://doi.org/10.3171/2019.12.JNS192600

45. Di Perna G, Penner F, Cofano F et al (2021) Skull base reconstructions: A question of flow? A critical analysis of 521 endoscopic odontoidal surgeries. PLoS ONE 16(3):e0245119. https://doi.org/10.1371/journal.pone.0245119

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