A broad spectrum of pathologies, such as congenital abnormalities and inflammatory, neoplastic, infectious, and traumatic lesions, can involve the craniovertebral junction (CVJ) complex. These pathologies may result in cervicomedullary junction (CMJ) compression and resulting myelopathy. The mainstay treatment for irreducible ventral lesions is anterior surgical decompression and occipitocervical fusion. The workhorse approach to the anterior CVJ has been the microscopic transoral-transpharyngeal approach. This approach can be associated with splitting of the mandible (mandibulotomy), splitting of the tongue (glossotomy), splitting of the hard and soft palates (palatotomy), and splitting of the maxillae (maxillotomy). These extensions re...
sult in an increase in surgical exposure but also in concur-
rent increases in the rates of surgical complexity, morbid-
ity, and cosmetic complications.\textsuperscript{37,41,56} These morbidity
have been overcome with the development of minimally
invasive techniques such as the endoscopic endonasal ap-
proach (EEA) to the clivus and cervical spine. The EEA
offers some clear advantages over the traditional oral
route, such as significant reduction of surgical morbidi-
ties, faster patient recovery, and wider, closer, and brighter
views of the surgical area.\textsuperscript{3,21,27,29,42,43,45,49} The main limit
of the EEA to the CVJ is the caudal exposure because of
the presence of nasal and palatal bony and soft tissues su-
periorly and inferiorly, respectively.\textsuperscript{1,10} Thus, preoperative
planning for the feasibility of the transnasal corridor is of
paramount importance in choosing the most suitable ap-
proach for best addressing CVJ pathology. The nasopal-
tine line (NPL) has been described as a good predictor of
the inferior limit of the EEA to the CVJ.\textsuperscript{30} Several studies
affirmed that it overestimates the inferior limit by an av-
erage of 13 mm.\textsuperscript{1,10} In response, a second line was pro-
posed as a more accurate predictor of the inferior limits of
the EEA, namely, the nasoaxial line (NAXL), the starting
point of which is the mid-distance of the nasal aperture.\textsuperscript{1,25}
However, the NAXL was defined in cadaver dissections,
and it is unclear if it accurately predicts the lower limits
of the EEA to the CVJ in practice. The aim of this study
was to evaluate the inferior limits of surgery in a series
of patients who underwent surgery with the EEA to the
CVJ and to determine which of the proposed lines was the
most accurate predictor of our surgical results. As it turns
out, neither line provides a reliable prediction of actual
surgical results; for this reason, we propose a new line, the
rhinopalatine line (RPL), which seems to correlate most
accurately with our surgical results.

Methods

A prospective database of all endoscopic skull base
surgeries performed at Weill Cornell Medical College/
NewYork-Presbyterian Hospital between January 2005
and October 2014 was reviewed retrospectively. Insti-
tutional review board approval was obtained for this
anatomical-radiographic study. Patients who underwent
surgery with an EEA or endoscopic transtoral approach
(ETA) to the CVJ were included, and their radiographic
images were reviewed along with a collection of demo-
ographic, pathology, and surgical-approach data. Other
inclusion criteria were having available adequate radio-
logical studies that showed the pathology and the facial
complex in detail and having had surgery with an anterior
endoscopic approach (EEA or ETA). Nine patients were
identified, but 3 of those 9 were excluded from the study
because of the lack of adequate radiological imaging. The
surgical details and clinical outcomes of the patients who
underwent an endonasal odontoidectomy were presented
in a separate article.\textsuperscript{21}

Radiographic Landmarks and Measurements

The following lines were constructed on midline sagit-
tal CT and MRI scans. The definitions of these lines and
their landmarks were described extensively in a previously
published anatomical paper.\textsuperscript{1} A brief summary is provided
here.

Hard-Palate Line

The hard-palate line (HPL) is defined as the line that
passes through the anterior and posterior edges of the hard
palate (anterior nasal spine of the maxillary bone and pos-
terior nasal spine of the palatine bone, respectively) and
intersects the CVJ posteriorly. This line approximates the
long axis of the hard palate.

Nasopalatine Line

The NPL is defined as the line that passes through
the most inferior point of the nasal bones (rhinion) to the
posterior nasal spine in the midsagittal plane. It is then
extended posteriorly and inferiorly to end at the cervical
spine.

Nasoaxial Line

The NAxL is defined as the line constructed in the mid-
sagittal plane by using a starting point that corresponds to
the midpoint of the distance from the rhinion to the ante-
rior nasal spine of the maxillary bone and a second point
at the tip of the posterior nasal spine of the palatine bone.
It is then extended posteriorly and inferiorly to end at the
cervical spine.

Rhinopalatine Line

The RPL is defined as the line constructed in the mid-
sagittal plane by using a starting point that corresponds to
the two-thirds point of the distance from the rhinion to the
anterior nasal spine of the maxillary bone and a second
point at the posterior nasal spine of the palatine bone. The
line is then extended posteriorly and inferiorly to end at the
cervical spine (Fig. 1).

Using the preoperative and postoperative CT and MRI
scans that show the facial complex, because they are es-
ential for making the radiological measurements, the

![FIG. 1. RPL. Left: Cranio}\textsuperscript{meric landmarks useful for the prediction of the inferior limit of endoscopic endonasal odontoidectomy on a sagi-
ttal CT scan. The rhinion (Rh) represents the most inferior point of the internasalis suture. The anterior nasal spine (ANS) of the maxillary bone
represents the most anterior process of the hard palate, whereas the posterior nasal spine (PNS) of the palatine bone represents its most
posterior process. Right: The starting point of the RPL is the two-thirds point of the Rh-to-ANS distance, and a second point at the PNS is
added. The line between these 2 points is then extended posteriorly and inferiorly to end at the CVJ.}
HPL and the different predictive lines (NPL, NAxL, and RPL) were constructed on midline images. The points at which the predictive lines intersected the cervical spine were identified, and their distances below the HPL were measured in millimeters. The actual most inferior surgical extent at the cervical spine was identified, and its distances from the HPL and the predictive lines were measured. The inferior extent of the lesions (a tumor and a rheumatoid arthritis pannus) and the height of the odontoid tip (basilar invagination) were also measured from the HPL. Radiological measurements on the workstation were taken electronically twice by the same operator. The average of the 2 different measurements was used.

**Statistical Analysis**

Means, standard deviations, and ranges were used to describe the points of the intersection predicted by the NPL, NAxL, and RPL with the CVJ, as well the inferior actual extent of the surgery. The difference of the means was also calculated, as a descriptive tool of the deviation of the predictive methods from the surgery. A Wilcoxon matched-pair signed-ranks test was also performed to compare the predictive lines (NPL, NAxL, and RPL) with the actual surgical extent. All the analyses were run on GraphPad (GraphPad Software, Inc.).

**Results**

**Demographics**

Six patients (4 female, 2 male) underwent surgery with an EEA to the CVJ and were included in this study. There were 4 adult and 2 pediatric patients. The mean age of the adults was 56 years (range 20–78 years); the pediatric patients were 7 and 15 years old. A summary of the clinical and pathological features of the patients is shown in Table 1. Data from 2 other patients who underwent surgery, one with an ETA and the other with a microscopic extended approach, are also presented here as illustrative cases for comparison with those from patients who underwent surgery with the EEA and to show pathology that lies below the limits of the EEA to ensure that the lines were predictive of unsuitable pathology.

**Radiological Analysis**

The mean points of intersection between the NPL, NAxL, and RPL and the cervical spine were 32.1 ± 10.5, 17.0 ± 5.6, and 11.9 ± 4.1 mm below the HPL, respectively (Table 2). The NPL overestimated the inferior extent of the surgery by an average of 21.9 ± 8.1 mm (range 14.7–32.5 mm). The NAxL and RPL overestimated the inferior limit of surgery by averages of 6.9 ± 3.8 mm (range 3.7–13.3 mm) and 1.7 ± 3.7 mm (range −2.8 to 8.3 mm), respectively. The median difference between the NPL and the actual surgery was statistically significant (p = 0.0313), as was the difference between the NAxL and the actual surgery (p = 0.0313). In contrast, there was no statistically significant difference between the RPL and the inferior limit of the EEA to the CVJ (p = 0.4375) (Fig. 2).

**Illustrative Cases**

**Case 1: EEA**

A 51-year-old woman presented with neck pain and stiffness, gait disturbances, and progressive quadriplegia. Her medical history was remarkable for previous traumatic spine injury and unclear cervical surgery during child-

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**TABLE 1. Patient demographics**

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Platybasia</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>51, F</td>
<td>Basilar invagination</td>
<td>No</td>
<td>EEA</td>
</tr>
<tr>
<td>2</td>
<td>15, M</td>
<td>Basilar invagination</td>
<td>Yes</td>
<td>EEA</td>
</tr>
<tr>
<td>3</td>
<td>78, F</td>
<td>Cranial settling (RA)</td>
<td>No</td>
<td>EEA</td>
</tr>
<tr>
<td>4</td>
<td>75, M</td>
<td>Cranial settling (RA)</td>
<td>No</td>
<td>EEA</td>
</tr>
<tr>
<td>5</td>
<td>20, F</td>
<td>Basilar invagination</td>
<td>No</td>
<td>EEA</td>
</tr>
<tr>
<td>6</td>
<td>7, F</td>
<td>Basilar invagination</td>
<td>No</td>
<td>EEA</td>
</tr>
<tr>
<td>7</td>
<td>78, F</td>
<td>Cranial settling (RA)</td>
<td>No</td>
<td>ETA</td>
</tr>
<tr>
<td>8</td>
<td>55, F</td>
<td>Chordoma</td>
<td>No</td>
<td>Extended TA</td>
</tr>
</tbody>
</table>

RA = rheumatoid arthritis; TA = transoral approach.

**TABLE 2. Radiographic measurements in patients in the EEA group**

<table>
<thead>
<tr>
<th>Predictive Line &amp; Surgery</th>
<th>Mean ± SD (mm)</th>
<th>Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPL</td>
<td>32.1 ± 10.5</td>
<td>21.6–46.2</td>
</tr>
<tr>
<td>NAxL</td>
<td>17.0 ± 5.6</td>
<td>11.0–24.6</td>
</tr>
<tr>
<td>RPL</td>
<td>11.9 ± 4.1</td>
<td>7.0–16.9</td>
</tr>
<tr>
<td>Inferior surgical extent</td>
<td>10.2 ± 5.1</td>
<td>5.4–18.0</td>
</tr>
</tbody>
</table>

* All measurements are relative to the HPL.
hood. A CT scan of the cervical spine showed posterior subluxation of the occiput with substantial narrowing of the spinal canal at C1–2 along with an odontoid mass and compression of the cervical spinal cord (Fig. 3 left). The most superior extent of the basilar impression resided above the HPL. The most inferior limit of the EEA (9.5 mm below the HPL) was predicted by the RPL. The distances between the NAXL and HPL and between the NPL and HPL were 12.8 and 22.6 mm, respectively. The entire extension of the brainstem compression resided above the RPL. A C-1 laminectomy, an occiput–C5 fusion, and an endoscopic endonasal odontoidectomy were performed in the same operative setting. The inferior extent of the EEA was 7.9 mm below the HPL; thus, the RPL overestimated it by 1.6 mm. The patient was extubated and resumed oral feeding on the 1st postoperative day. Her postoperative course was uneventful. A postoperative CT scan revealed satisfactory brainstem decompression, and at the 3-month follow-up, she showed clear improvements in her motor functions and gait (Fig. 3 right).

Case 2: ETA
A 78-year-old woman presented with progressive left-sided weakness. Imaging of the cervical spine revealed a retro-odontoid partially cystic mass with rightward displacement of the spinal cord and associated signal change, consistent with a rheumatoid arthritis pannus (Fig. 4A and B). Her medical history was positive for right-knee arthritis and surgical replacement. The inferior extent of the lesion was 23.6 mm below the HPL. The most inferior limit of the EEA (9.8 mm below the HPL) was predicted by the RPL. The distances between the NAXL and HPL and between the NPL and HPL were 15.3 and 25.0 mm, respectively. Thus, according to the prediction made by the NPL, this lesion could have been reached by using an EEA. There was an attempt to use the nasal corridor, but intraoperative neuronavigation showed that the target was much too inferior to reach through the EEA. Thus, an endoscopic transoral odontoidectomy was performed to decompress the CMJ. A C-1 laminectomy and an occipitocervical fusion were performed 5 days later after cervical instability was confirmed. The patient was extubated and resumed oral feeding on the 2nd postoperative day. Her postoperative course was characterized by a posterior occipital collection and wound infection, which resolved after surgical drainage and an antibiotic cycle. A postoperative CT scan revealed satisfactory brainstem decompression and complete restoration of left-side motor function (Fig. 4C).

Case 3: Extended Transoral Approach
A 55-year-old woman presented with neck pain, progressive dysphagia, and dysphonia. A CT scan of the cervical spine revealed a large lytic C-2 lesion with ventral extraosseous extension into the prevertebral soft tissues...
and a significant mass effect on the oropharynx (Fig. 5 left). The inferior extent of the lesion was 57.8 mm below the HPL. The most inferior limit of the EEA (8.3 mm below the HPL) was predicted by the RPL. The distances between the NAxL and HPL and between the NPL and HPL were 12.6 and 22.0 mm, respectively. After an unfruitful attempt to address the lesion by using the endonasal route, an endoscope-guided transpharyngeal biopsy was performed, and the histopathology results were consistent with chordoma. A prophylactic occipitocervical fusion to C-5 was also performed. Two weeks later, the patient underwent an extended transoral approach (transcervical, mandibulotomy) to remove the neoplastic lesion, and a tracheotomy was placed. She was extubated on postoperative Day 9 and started on oral feeding on postoperative Day 10. Her postoperative course was uneventful. Postoperative imaging showed gross-total removal of the lesion and good decompression of the oropharynx (Fig. 5 right).

Discussion

The transoral-transpharyngeal approach has been considered the traditional approach for treating ventrally irreducible lesions of the CVJ. Because of the extent of the lesion and individual anatomical variables, an “extended transoral approach” (i.e., mandibulotomy and/or glossotomy and/or palatotomy and/or maxillotomy) may be needed to gain a more superior and inferior surgical window. Although these extended approaches can lead to significant enhancement of the surgical exposure, they also significantly increase surgical complexity and the depth of the operative corridor, rates of morbidities such as infections from bacterial oral flora, velopharyngeal insufficiency, hypernasal speech, nasal regurgitation, soft palate dehiscence, tongue edema, and necrosis, and the potential need for tracheotomy and nasogastric feeding tube, resulting in a longer hospital recovery time.

In the last decade, some minimally invasive endoscopic approaches, such as the EEA, have been adopted to address CVJ pathology. Some disadvantages of endonasal odontoidectomy include the long learning curve, the use of dedicated instrumentation, and, above all, the caudal exposure of the surgical corridor, which may explain these clinical findings. One advantage of endoscopic endonasal odontoidectomy is its top-down trajectory and the chance to drill the dens and preserve the anterior atlas rim in selected cases and, thus, potentially reduce the rate of cervical instability.

Some disadvantages of endonasal odontoidectomy include the long learning curve, the use of dedicated instrumentation, and, above all, the caudal exposure of the surgical corridor. Thus, accurate preoperative planning of the best approach (EEA vs ETA vs combined) for addressing the pathology at this transitional area remains essential. There have been great efforts from different groups to study the inferior limit of the EEA. De Almeida et al. first described the NPL as a good and accurate predictor of the inferior limit of the EEA, but in their own study, the NPL was always below the inferior extent of surgical dissection by a mean value of 12.7 mm. Consequently, a second line named the NAxL was described in a radiographic-cadaveric study that seemed to predict more accurately and reliably the inferior caudal exposure of the EEA to the CVJ. This result was supported by the comparison between the NAxL and the actual surgical extent on CT imaging and by a statistical analysis that showed that the inferior limit predicted by the NAxL was not statistically different from the actual inferior limit of the EEA (p = 1.0). This study also showed that the NPL overestimated the inferior limit by an average of 13 mm. The HPL was used as a reference line, rather than the base of C-2, for all the measurements in the previous study and in the current study as well. The HPL approximates the long axis of the hard palate and has been shown to be another reasonable predictor for the lower limit of the endoscopic approaches to the CVJ. The features of the hard palate,
such as its length and spatial relationship with the CVJ complex, represent a limiting factor of the endoscopic en-
donosal route.\textsuperscript{5,12,13,46} Defining the lower limit of the EEA is critical for choosing the most suitable approach for ad-
ressing pathology at this transitional area between the nasal and oral corridors.

Because we described the N\textsubscript{A}xL in a cadaveric study, we sought to define its usefulness in a clinical series of patients with CVJ pathology who were treated through an EEA. In this small series of cases, we found that the N\textsubscript{A}xL also overpredicted the lower limits of the approach; thus, we introduced another line, which seemed to be the most accurate predictor. In our radiographic analysis, we demonstra-
nted that the RPL reliably predicts the most caudal limit of the EEA to the upper cervical spine. The RPL is defined as the line constructed in the midsagittal plane by using a starting point that corresponds to the two-thirds point of the distance from the rhinion to the anterior nasal spine of the maxillary bone and a second point at the posterior nasal spine of palatine bone (Fig. 1). The line is then extended posteriorly and inferiorly to end at the cervical spine. The close correspondence on CT/MR images between the intersection of the RPL to the CVJ and the actual surgical extent and results of further statistical analysis confirmed its accuracy and reliability (Fig. 2). This predic-
tor accounts also for patient anatomical variability, such as the presence of nasal and palatal osseous and soft structures, together with the hard palate’s direction and length, which represent the most significant factors that limit the inferior extension of the EEA.\textsuperscript{1,10,44} As we have shown, the N\textsubscript{A}xL and NPL both overestimated the inferior limit of our surgery by mean values of approximately 7 and 22 mm, respectively (\(p = 0.0313\)). Moreover, we present here a case in which the NPL should have predicted the EEA effectively, and yet it was not appropriate. Although the lesion was located above the NPL, an EEA was not feasible. Conversely, the RPL favored the transoral route, and an ETA was performed and resulted in good decompression of the brainstem (Fig. 4).

In some sense, it is a bit surprising that the cadaveric line, the N\textsubscript{A}xL, overpredicted the lower limit of our sur-
gery. Cadavers are known to have thick immovable tissue, which can restrict surgical access more than live tissue. One possible reason is that a more invasive and extended approach, such as complete drilling of the maxillary crest and complete retraction of the nasal and palatal soft tissues, was applied in the cadaver dissections and may not have been done as aggressively intraoperatively.\textsuperscript{1} Another possibility is that the presence of the endotracheal tube may have limited the inferior exposure and maneuver-
ability in the operative room. Likewise, the goals of surgery were not necessarily to achieve the lowest possible exposure but rather to decompress the cervical spine, and the surgeon may have felt that this could be accomplished without reaching the inferior-most limit of the approach. Perhaps those who perform future cadaver studies should take into account the presence of an endotracheal tube when making surgical predictions. Finally, this series included 2 pediatric patients, which also may have limited the inferior extent of the surgery compared with that in the adult cadavers. The use of dedicated angled and longer instruments and more flexion of the head may also im-
prove the inferior surgical exposure.\textsuperscript{10,31,47} A midline verti-
cal incision in the nasopharynx may be performed to gain more inferior exposure while avoiding the bulging of the U-shaped muscle-mucosal flap in the surgical field.\textsuperscript{38} On the other hand, a U-shaped muscle-mucosal flap could be chosen for lesions that extend more laterally.

The main limitations of our study include the small number of patients in the series, the retrospective study de-
sign, and the fact that all of the patients underwent surgery by a single surgical team. Although the work was done on 6 patients, the results are statistically significant. However, the reliability of the RPL could be more validated in larger and prospective clinical series of patients. Although the study was performed in a retrospective fashion, the sen-
ior surgeon (T.H.S.) pursued the most inferior limit of the exposure in the patients with a basilar invagination and those with a basilar impression to accomplish good decompression of the CMJ, as revealed in postoperative imaging. Because the caudal extent of the EEA to the CVJ depends on the surgical team, the RPL probably provides a good estimation of the minimal amount of bone that can be reliably resected. The RPL cannot be used to predict the lateral limits of the EEA to the CVJ. The EEA to the upper cervical spine requires strong anatomical knowl-
dge and technical skills and, thus, should be performed by experienced surgical teams only.\textsuperscript{35,40} A proper surgical indica-
tion is of vital importance to guarantee the best results. Odontoidectomy is indicated only for irreducible ventral compression; otherwise, reducible lesions should be treated only by posterior fixation.\textsuperscript{35,38,40}

We feel that each patient should be studied preopera-
tively in an individual manner, because anatomy and pa-
thology vary enormously, and the most suitable and cus-
tomized approach should be chosen.

A virtual surgical simulator could also be helpful during the preoperative planning of endoscopic appro-
aches to the CVJ.\textsuperscript{14,15,29} The strength of the RPL as a predictor of the caudal exposure of the EEA to the upper cervical spine resides not only in its reliability, efficacy, and ease of application but also in its accounting for the anatomical variability. Because individual anatomy and surgical pathologies vary enormously among different patients, es-
pecially with congenital skull base abnormalities, the RPL constitutes an instrument of general estimation of the in-
ferior extent of endonasal odontoidectomy and should not be applied as a hard-and-fast rule. The main anatomical limits of the EEA to the CVJ are the soft and osseous tissues of the nose and palate superiorly and inferiorly, re-
spectively. The RPL considers these anatomical limits in its construction and represents the surgical trajectory to the CVJ; thus, it seems to be more appropriate and reliable than the palatine line and other palatal lines.\textsuperscript{5,12,13,46}

**Conclusions**

The RPL predicts the actual inferior limit of the EEA to the CVJ more accurately than previously described lines. The use of the RPL may assist surgeons in choosing suitable candidates for the EEA and in selecting those for whom a transoral or extended approach would work best.
References
21. Menezes AH: Craniovertebral junction database analysis:

Author Contributions
Conception and design: Schwartz, La Corte. Acquisition of data: Schwartz, La Corte, Greenfield, Härtl, Anand. Analysis and interpretation of data: Schwartz, La Corte, Aldana, Ferroli. Drafting the article: Schwartz, La Corte. Critically revising the article: Schwartz, La Corte, Aldana, Ferroli. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Schwartz. Statistical analysis: Schwartz, La Corte. Administrative/technical/material support: Schwartz. Study supervision: Schwartz.

Correspondence
Theodore H. Schwartz, Department of Neurosurgery, Weill Cornell Medical College, NewYork-Presbyterian Hospital, 525 E. 68th St., Box 99, New York, NY 10065. email: schwartz@med.cornell.edu.