Endonasal Access to the Upper Cervical Spine, Part One: Radiographic Morphometric Analysis

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Abstract

Objectives To determine the anatomical relationships that may influence endonasal access to the upper cervical spine.

Setting We retrospectively analyzed computed tomography of 100 patients at a single institution.

Participants Participants included adults with imaging of the hard palate, clivus, and cervical spine without evidence of fracture, severe spondylosis, or previous instrumentation.

Main Outcome Measures Morphometric analyses of hard palate length and both distance and angle between the hard palate and odontoid process were based on radiographic measurements. Descriptive zones were assigned to cervical spine levels, and endoscopic visualization was simulated with projected lines at 0, 30, and 45 degrees from the hard palate to the cervical spine.

Results We found an inverse relationship between hard palate length and the lowest zone of the cervical spine potentially visualized by nasal endoscopy. The distance between the posterior tip of the hard palate and the odontoid tip, and the angle formed between the two, directly influenced the lowest possible cervical exposure.

Conclusions Radiographic relationships between hard palate length, distance to the odontoid, and the angle formed between the two predict the limits of endonasal access to the cervical spine. These results are supported by cadaveric data in Part Two of this study.

Keywords

- cervical spine
- endoscopic
- minimally invasive
- morphometric
- odontoidectomy
- transnasal

Introduction

The transoral-transpalatopharyngeal approach and its various modifications have been the traditional means of ventral access for treating extradural lesions from the midclivus to the level of the C3 vertebral body.^{1–11} However, these procedures involve retraction of the tongue and extensive dissection

of the palate and other structures, resulting in associated morbidity, including infection, palatal fistula, dysphagia, dysphonia, velopharyngeal incompetence, and prolonged intubation. More recently, the transnasal endoscopic approach has been introduced with the goal of achieving similar access without the associated morbidity^{12–16} and in anatomic variations in which transoral access is limited (e.g., micrognathia).¹⁷

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Cadaveric studies have suggested feasibility for lower clival and odontoid decompression, with the added potential benefit of preserving the anterior C1 ring and normal anatomy of alar and apical ligaments for later in the resection.¹⁸ Despite these advantages, there have been few reports of clinical application, including cases of infection, rheumatoid arthritis, and os odontoideum.^{12–14,17,19}

The nasopalatine line has been proposed to delineate the lower limits of endonasal exposure with straight instruments, but this relationship does not necessarily apply to the use of angled instruments.²⁰ A limited cadaveric study attempted to further define the limits of endonasal exposure of the upper spine, but this did not take into account possible differences because of individual anatomic variation.¹⁸ The purpose of our study was to evaluate the role of anatomical relationships between the palate and upper cervical spine in determining the potential caudal extent of surgical exposure for a given individual.

Methods

Patient Selection

This study was approved by the Institutional Review Board (IRB) of Thomas Jefferson University Hospital (IRB # 08D.567). We retrospectively reviewed 113 consecutive computed tomography angiograms (CTAs) of the head and neck that were obtained at our institution over a 1-year period. Isolated cervical spine scans were not used because they often excluded adequate imaging of the hard palate, which was integral to our measurements. Therefore, we used the data obtained from CTAs for our study, which frequently included complete imaging of the hard palate and clivus, in addition to the cervical spine.

Exclusion criteria were age less than 18 years, inadequate imaging, previous or current cervical spine fractures, previous cervical spine instrumentation, severe degenerative joint disease or osteopenia, vertebral body collapse, or autofusion across two or more vertebral bodies. Of the 113 CTAs reviewed, six were excluded due to prior instrumentation, two had prior fractures, three had vertebral body collapse and/or autofusion across two levels, and two had inadequate imaging. Of the remainder, 100 scans met criteria for obtaining measurements related to this study.

Measurements

In an attempt to estimate endoscopic endonasal access to the upper cervical spine, we made anatomical measurements and defined several key parameters that may affect access to the cervical spine (►Fig. 1). Measurement 1 (M1) recorded the length of the hard palate in millimeters. Measurement 2 (M2) recorded the distance from the posterior tip of the hard palate to the odontoid tip in millimeters.

For Measurement 3 (M3) a straight line was drawn along the hard palate and extended posteriorly (the palate line). A second straight line was drawn connecting the tip of the odontoid process to the midpoint of the base of the C2 vertebral body and extended both superiorly and inferiorly (the odontoid line). The angle created by where these two

lines transect was measured in degrees and defined as M3. Increasing the angle M3 was akin to neck extension, and decreasing the angle was akin to neck flexion.

In Measurement 4 (M4), regions of the upper cervical spine were divided into several zones (►Fig. 2). The odontoid was divided into three equal zones: Oa, Ob, and Oc. The disc space between C2 and C3 was labeled as D1. The C3 vertebral body was divided into two equal zones: C3a and C3b. The C3–4 disc space was labeled D2. The C4 vertebral body was also divided into two equal zones of C4a and C4b.

Endoscopes are commercially available with optical angles of 0, 30, and 45 degrees. The purpose of the next measurements was to simulate the view of the upper cervical spine obtained if the tip of an endoscope were to rest at the posterior tip of the hard palate without significant obstruction by the soft palate (►Fig. 2 inset). Measurements 4a, 4b, and 4c recorded the specific zone along the odontoid line (e.g., Oa, Ob), where lines drawn from the tip of the hard palate at angles of 0, 30, and 45 degrees (in relation to the palate line), respectively, transect the vertical odontoid line.

Statistical Analysis

Bivariate analysis and multivariate analyses were performed to determine if independent correlations existed between the measurements M1, M2, or M3 using analysis of variance (ANOVA) with Tukey-Kramer HSD post-hoc test for multiple comparisons.

Results

Demographics

Demographic data are shown in ►Fig. 3. Some patients in the cohort lacked demographic data because of incomplete patient records. Height was recorded for 78 patients, with a mean of 168 cm and standard deviation of 10 cm. Age, race, and gender were recorded in 94 patients. The mean age was 59 years, with a standard deviation of 16.5 years. There were 44 males and 49 females. There were 78 Caucasians, 14 African-Americans, and 2 Hispanics. For the following measurements there were no significant trends between the various races (data not shown).

Means and Medians

Mean, median, and standard deviation of data were normally distributed for hard palate length (M1), distance from posterior tip of hard palate to odontoid tip (M2), and the angle between the odontoid line and palate line (M3) (►Fig. 4A–C). All distances were greater in males than females.

Bivariate Analysis of Anatomic Measurements

Bivariate analysis was performed to determine if M1, M2, or M3 independently correlated with the cervical spine zones transected using 30-degree (4b) or 45-degree (4c) projected lines. There was no independent correlation between M1 and level of transection with 4b or 4c. However, there was an independent correlation between M2 and level of transection with 4b and 4c—that is, as the distance M2 between the posterior tip of the hard palate and the odontoid tip

Fig. 1 Schematic of Measurements 1, 2, and 3 (M1, M2, M3).

increased, both the 30-degree ($p = 0.0011$) and 45-degree ($p = 0.0024$) projected lines transected more caudal zones of the cervical spine (►Fig. 5A–B). There was also an independent correlation with M3—as the angle M3 formed by the palate line and the vertical odontoid line increased, both the 30-degree ($p < 0.0001$) and the 45-degree ($p < 0.0001$) lines transected more caudal zones (►Fig. 5C–D).

Frequency of Cervical Spine Level Transection by 30- and 45-degree Lines

The frequency (N) with which each level of the cervical spine was transected using the 30- and 45-degree projected lines was graphically portrayed (►Fig. 6). The levels Ob and Oc (middle and lower third of the odontoid) were most frequently transected using the 30-degree line, whereas the more caudal C3b (lower half of C3 body) was transected by the 45-degree line. The probability of a projected line transecting a particular zone in the cervical spine was also calculated for all corners (►Fig. 7). Using the 30-degree line, there was a 50% likelihood of transecting Oc and less than a 10% chance of

transecting below D1. Similarly, there was a greater than 90% chance of transecting Oa and Ob (blue graph line) with the 30-degree line. The 45-degree line transected at the level of D1 and C3a with 50% probability (red graph line). The zero-degree line (4a) transected the vertical odontoid line above the odontoid process with 64% likelihood and at Oa with 36% likelihood (►Fig. 7 inset).

Multivariate Analysis

On multivariate analysis, all three measured variables (M1, M2, and M3) correlated with the zone at which the 30-degree (4a) and 45-degree (4b) projected lines intersected the cervical spine (►Table 1). An increase in the length of the hard palate (M1) correlated with the 30- and 45-degree lines transecting a higher cervical spine zone ($p = 0.0302$ and $p = 0.0041$, respectively), whereas an increase in the distance of the hard palate to the odontoid (M2) or between the angle of the palate and odontoid lines (M3) correlated with the 30- and 45-degree lines transecting a lower zone ($p < 0.0001$ each).

Fig. 2 Schematic of Measurement 4 (M4) parameters.

Illustrative Case Presentation

We present an example where the above model was prospectively used to predict access to the cervical spine through the endonasal route. A 51-year-old presented with neck pain and myelopathy from a cervical chordoma (►Fig. 8A). Using morphometric analysis, we predicted how much of the tumor could be removed through the transnasal approach. Our analysis predicted that the 30-degree line would transect the lower third of the odontoid (Oc). Images before and after resection are shown in ►Fig. 8B, demonstrating how accurately the morphometric analysis predicted the actual extent of surgical resection in this case. Based upon the C1–C2 resection, the patient required an instrumented occipital-cervical autograft fusion.

Discussion

There are several pathological processes that affect the craniocervical junction and upper cervical spine, including but not limited to C1–2 pannus associated with rheumatoid

arthritis, tumors (e.g., chordomas, metastases), traumatic fractures of C1–2 causing dense displacement, basilar invagination, and os odontoideum.¹² Traditionally, surgical approaches to this region of the upper cervical spine have been performed through a transoral-transpalatal route and, more recently, an endoscopic transcervical approach with tubular retractors has also been described.^{18,21}

Complications associated with the transoral-transpalatal approach may include velopharyngeal incompetence (VPI), hypernasal speech and nasal reflux, dental injury, edema or tongue necrosis, upper airway obstruction from retropharyngeal edema, posterior pharyngeal wound dehiscence, dysphagia, odynophagia, pharyngeal cellulitis, meningitis (from cerebrospinal fluid leaks), and temporomandibular joint syndrome.^{3,5–7,9,11,22–26} The transcervical approach has the advantage of preserving the nasopharynx and a purported lower risk of postoperative meningitis, with the caveat of limited working angles, inaccessibility of the clivus, and possibly increased likelihood of inadvertent durotomy.^{18,21}

Fig. 3 Demographics: age, ethnicity, gender, and height.

The endonasal approach offers several advantages to the traditional open transoral approach, including improved lateral visualization, decreased airway and swallowing morbidity, preservation of palatal function, decreased postoperative pain, and reduced frequency of tracheostomy.¹² These findings may be related to the fact that the incision used for the transnasal approach is more superior in the nasopharynx than that used for the transoral approach. Keeping the nasopharyngeal incision above the level of the soft palate may spare more of the posterior pharyngeal musculature and mucosa, resulting in less tissue volume loss and retraction in the retropharynx from scarring. The preservation of the posterior pharyngeal function and the avoidance of soft palatal splitting may contribute to fewer pharyngeal complications and less VPI with the endonasal approach. Although the endonasal and transoral approaches have not been compared in a prospective study, the theoretical advantage of keeping the incision above the level of the soft palate with the endonasal approach may offer a better chance for healing with less postoperative morbidity. In our experience, patients have a low incidence of dysphagia and start oral feeds immediately after surgery without a requirement for a nasogastric tube.

When compared with the endoscopic transcervical approach, the transnasal route has the advantage of accessing the lower clivus if needed, whereas both the transcervical and transnasal approaches are equally superior to the transoral approach in preservation of the anterior C1 ring.^{18,21} On the

Fig. 4 (A) Length of hard palate in mm: Measurement 1 (M1). (B) Distance from posterior tip of hard palate to odontoid tip in mm: Measurement 2 (M2). (C) Angle between palate line and odontoid line in degrees: Measurement 3 (M3).

Fig. 5 (A, B) Measurement 2 (M2) plotted against Measurement 4b and 4c, respectively. (C, D) Measurement 3 (M3) plotted against Measurement 4b and 4c, respectively.

other hand, the main advantage of the transcervical approach above the other two is a sterile field with a theoretically lower likelihood of meningitis, should durotomy occur.^{18,21}

The nasopalatine line has been proposed to delineate the lower limits of endonasal exposure with straight instruments, but it does not appear to apply to the use of angled instruments.²⁰ Using radiographic morphometric analysis, we attempted to estimate the extent of access to the upper cervical spine via the endonasal approach with angled instruments, based on individual anatomic variation. Bivariate analysis demonstrates that, with increasing distance between the posterior tip of the hard palate and the odontoid tip (M2), the 30- and 45-degree projection lines reach a more caudal zone of the cervical spine. With the 45-degree line, the relationship was significant down to the second disk space,

after which the normal lordotic curvature brings the more caudal cervical spine away from the odontoid line. A similar result is obtained for the angle between the hard palate and odontoid lines (M3).

On bivariate analysis the length of the hard palate (M1) did not significantly correlate as the others did, but with multivariate analysis all three variables (M1, M2, and M3) influenced the caudalmost level of visualization. This may be because of an inverse relationship between M1 and M2—that is, a longer hard palate (M1) potentially decreased the distance between the posterior aspect of the hard palate and the odontoid (M2). Multivariate fits can sometimes reveal that one variable dominates the outcome, and a variable that was significant individually drops out of the multivariate fit. However, both M2 and M3 remained significant in this case.

Fig. 6 Frequency (N) with which each zone of the spine is accessed using angles of 30 and 45 degrees.

Fig. 7 Probability with which each zone of the spine is accessed using angles of 30 and 45 degrees.

These findings are perhaps not surprising, similar to the finding that the position of the sternum influences access to the lower cervical spine when performing a ventral approach. However, to our knowledge the anatomic variables affecting endonasal access to the spine have not been studied except in one report describing the nasopalatine line as a defining factor the lower limits of ventral cervical exposure by zero-angle endoscopy.²⁰

Taken together, these data suggest that ways to theoretically improve access are to decrease the length of the hard palate (M1), simultaneously increasing the distance from the posterior hard palate to the odontoid (M2). This could be achieved by back-biting or drilling the hard palate, without disrupting the soft palate, to improve caudal visualization of the cervical spine. Although removal of the posterior aspect of the hard palate would not be routinely advocated by the authors, it could be considered in some circumstances.

Similarly, the angle between the hard palate and the odontoid line (M3) may affect caudal exposure. It could be inferred that one of the ways to increase caudal exposure is through neck extension to tilt the hard palate relative to levels of the subaxial spine, although we did not perform flexion and extension for these images.

Although in all cases zero-degree projection lines can reach the top third of the dens (Oa) or above, it must be

remembered that surgeons may encounter difficulties with rostral visualization in cases of basilar invagination from trauma or degenerative disease. In these cases, the odontoid may be obscured from settling of the clivus, requiring drilling through its caudal portion to access behind the odontoid. Similarly, in cases of rheumatoid pannus surrounding the odontoid, anterior C1 ring and caudal portion of the clivus, exposure of the bony cervical anatomy through the endonasal route is challenging but feasible.

In our model based on computed tomography structures (e.g., bony landmarks) alone, the endoscope rests flush along the hard palate with its tip at the posterior edge of the hard palate, where the length of the palate and its distance from the odontoid are important predictors of theoretical visualization. In actual practice, one way to increase the caudal extent of visualization of the cervical spine is to tilt the tip of the scope down using the posterior aspect of the hard palate as the fulcrum. The factors that limit this motion are the nasal bone and the piriform aperture. However, we chose to make our measurements with a simulated endoscope lying flat across the palate which, in our experience, is more applicable to surgery. In general we keep the endoscope as low as possible so that one can introduce the suction, drill, image guidance wand and other instruments from above for ease of maneuvering and to reduce collisions between the instruments and the endoscope. Other practitioners keep the endoscope at the top of the nostril with all instruments introduced below it, in which case they rest on the hard plate rather than the endoscope. For this technique our model would require modification.

A caveat of this approach is that our ability to project a line between the radiographic limit of the hard palate and a zone of the cervical spine does not guarantee that the area will be properly visualized endoscopically, nor is it equivalent to being able to operate effectively in the area. One may not be able to always maneuver instruments safely at these angles. If an endoscope could provide visualization as depicted by the 30- and 45-degree projection lines, one would likely need angled instruments (such as a 70-degree drill) to work in the visualized area. Thus, it must be remembered that this is a purely theoretical application that must be corroborated with

Table 1 Multivariate Analysis Considering the Joint Effects of Measurements 1, 2, and 3 on Endoscopic Range for Caudal Visualization in the Cervical Spine

30-degree endoscope	
Source	p value
M1: length of the hard palate (mm)	0.0302
M2: posterior tip of hard palate to odontoid tip (mm)	< 0.0001
M3: angle of hard palate and odontoid line (deg)	< 0.0001
45-degree endoscope	
Source	p value
M1: length of the hard palate (mm)	0.0041
M2: posterior tip of hard palate to odontoid tip (mm)	< 0.0001
M3: angle of hard palate and odontoid line (deg)	< 0.0001

Fig. 8 (A) Sagittal computed tomography (CT) and magnetic resonance imaging views of cervical chordoma. (B) Sagittal preoperative CT predicting morphometric extent of resection using 30-degree endoscope; postoperative CT depicting actual resection.

cadaveric dissection and prospective clinical studies. The cadaveric portion of this study is discussed in Part Two of this paper.

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