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Neuroanatomical study

# Quantitative analysis of the effect of brainstem shift on surgical approaches to anterolateral tumors at the craniovertebral junction

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A B S T R A C T

Many anterolateral craniovertebral junction (CVJ) tumors can safely be resected using a simple posterolateral approach given the surgical corridor provided by brainstem shift. We sought to study how increasing anterolateral CVJ lesion size affects exposure in the posterolateral and far lateral approaches. Six cadaveric heads were used. A posterolateral approach was performed on one side and a far lateral with one-third condyle resection on the other side. Clival and brainstem exposure and surgical freedom were measured. A balloon catheter was used to simulate 10, 15, and 20 mm anterolateral mass lesions. Mean clival exposure was significantly greater with the far lateral approach (197.4 *versus [vs]* 135.0 $mm^2$, $p = 0.03$) with no balloon, but this difference disappeared with lesion sizes of 10 mm (246.8 *vs* 237.9 $mm^2$, $p = 0.79$), 15 mm (306.7 *vs* 262.4 $mm^2$, $p = 0.25$), and 20 mm (360.0 *vs* 332.7 $mm^2$, $p = 0.64$). Mean brainstem exposure was significantly greater with the far lateral approach for 0 mm (127.8 *vs* 65.8 $mm^2$, $p < 0.01$), 10 mm (129.5 *vs* 87.5 $mm^2$, $p = 0.045$), and 15 mm (140.1 *vs* 97.8 $mm^2$, $p = 0.01$) lesions. There was no difference at 20 mm (146.7 *vs* 147.8 $mm^2$, $p = 0.97$). Medial-lateral surgical freedom was greater with the far lateral approach for all sizes. The results of this study provide insight on one important variable in the decision-making process to select the optimal approach for anterolateral CVJ tumors.



## 1. Introduction

Anterior and anterolateral tumors at the craniovertebral junction (CVJ) pose a surgical challenge given the close relation to critical neurovascular structures. Initial attempts using a midline posterior suboccipital approach resulted in high morbidity and mortality [1–8]. Numerous surgical approaches have been developed to address these lesions more safely. From posterior to anterior, these include the posterolateral [9–15], far lateral [16–23], extreme lateral [24–27], anterolateral [28–32], transoral [33–35] and endoscopic endonasal transclival approach [36–39]. There is no clear consensus that a given approach yields optimal outcomes with fewest complications for a given pathology type in this location. Based upon the clinical experience of the senior surgeon (M.A.), the majority of these lesions may be successfully treated using the simple posterolateral approach [40]. Several senior authors have reported similar clinical findings [9–12,14]. However, published anatomical reports have demonstrated significantly greater exposure with partial condyle resection [10,41–43]. However, these studies do not account for brainstem shift seen with many tumors, which may open the surgical corridor and obviate the need for more extensive approaches in certain patients. Our hypothesis was that for anterolateral CVJ tumors, at a certain tumor size the far lateral approach does not provide any further advantage in exposure on the clivus and brainstem compared to the simple posterolateral approach.

## 2. Methods

### 2.1. Supplies and approach

Six cadaveric heads (one for proof of concept, five for quantitative measurements) were prepared and injected with silicone. Stereotactic CT scan with bone fiducials was obtained prior to dissection. Using a semi-sitting position with slight head flexion, a posterolateral approach was performed on one side and a far lateral with removal of one-third of the condyle was performed on the other side. Longitudinal length of each condyle was measured on CT scan and one-third of the total distance was calculated. A neuronavigation (Stryker, Kalamazoo, MI, USA) plan was used to guide the extent of condyle resection. A retractor was used to elevate the ispilateral cerebellar tonsil and kept constant between measurements.

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### 2.2. Measurements and calculations

Boundaries for clival exposure included the inferior portion of the jugular foramen (JF) (superolateral limit), medial clivus in line with the JF (superomedial limit), inferior portion of the hypoglossal canal (inferolateral limit), and medial clivus in line with the basion (inferomedial limit) (Fig. 1). Boundaries for brainstem exposure included the retro-olivary line in line with the JF (superolateral limit), medial brainstem in line with the JF (superomedial limit), sensory rootlet line in line with the basion (inferolateral limit), and medial brainstem in line with the basion (inferomedial limit). Cartesian coordinates for data points were obtained using neuronavigation. Data points were only taken if they could be both visualized and easily reached with the tip of the navigation tool without causing any brainstem or cranial nerve retraction. Thus, resulting areas represent exposure in which surgical instruments can be manipulated rather than area solely visualized.

All distances were calculated using the three-dimensional distance formula in which the distance between points ($X_1$, $Y_1$, $Z_1$) and ($X_1$, $Y_1$, $Z_1$) can be defined as:

$$d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}$$

For area calculations, the four collected points were plotted in three dimensions (3D) to determine the shape of an irregular quadrilateral in 3D. This shape was divided along a diagonal to produce two planar triangles. The sum of these two triangles was defined as the area of the original quadrilateral. The length of each side was determined by using the 3D distance formula with the vertices being the four points that were plotted. After all side lengths were determined, the area of the two triangles was calculated separately. For a triangle with side lengths defined as $a$, $b$, $c$, the semiperimeter was calculated as $s = \frac{1}{2}(a + b + c)$. The final area of the triangle was found by Heron's Formula: $A = \sqrt{s(s-a)(s-b)(s-c)}$. The areas of both triangles were added to give the total area of the original shape. Of note, if medial clival limits were beyond midline thus creating a curvilinear area, superior and inferior midpoints were registered and used to calculate clival exposure as two separate planar quadrilateral areas.

**Fig. 1.** Boundaries for clival exposure. Lateral limits (stars) included inferior portion of the jugular foramen (JF) and inferior portion of the hypoglossal canal. Medial limits (dotted lines) were in line with the JF superiorly and in line with the basion inferiorly.

Surgical freedom was defined as medial to lateral degrees of microdissector rotation about the basion. In the semi-sitting position, we found there was virtually unlimited inferior surgical freedom. Therefore, to capture the change in freedom associated with brainstem shift and condyle resection, we devised a method to capture medial-lateral surgical freedom. The basion was identified using neuronavigation and a microdissector 19.1 cm in length was inserted into the dura at that point and the handle was rotated to four points: laterally against the upper and lower condyle and medially against corresponding points against the brainstem. At each point the handle end of the dissector was registered to obtain coordinates. The resulting quadrilateral area was plotted and transverse condyle-brainstem distances were calculated along the superior and inferior quadrilateral and averaged (Fig. 2). This transverse distance was then converted to degrees using the length of the microdissector.

### 2.3. Simulating brainstem shift

The anterolateral CVJ area was identified using neuronavigation and marked. A 12 F coude catheter with the tip ligated just distal to the balloon was placed in the anterolateral space and filled with a water, coloring dye, and ioxehol solution to a pre-determined volume to simulate 10, 15, and 20 mm mass lesions. Initial specimens underwent post-balloon CT scan to verify size and anterolateral placement (Fig. 3). Specimens were then stored for 48 hours to allow molding of the surrounding neurovascular structures to the balloon. At this point, the balloons were removed and exposure

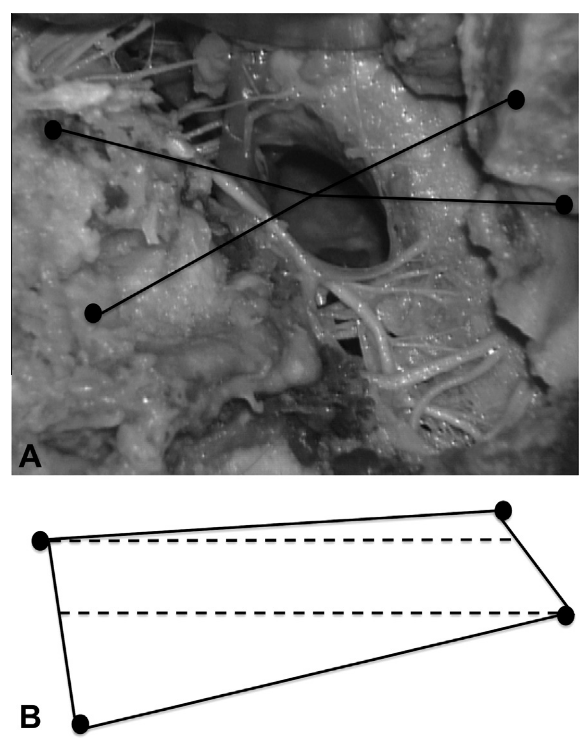


**Fig. 2.** Depiction of the surgical freedom method. Microdissector tip was placed at the basion. (A) The microdissector handle (solid line) was rotated about four points (black dots): upper and lower lateral extent as limited by the upper and lower limits of condyle, upper and lower medial extent as limited by the brainstem roughly in line with the condylar points. (B) The resulting quadrilateral (solid lines) was plotted and superior and inferior transverse distances (dotted lines) were calculated and averaged. Mean transverse distance was then translated into degrees using the length of the microdissector.