Estimation of odontoid process posterior inclination, odontoid height, and pB–C2 line in the adult population

Clinical article

Ziyad L. Khaleel, M.B.Ch.B., David A. Beschio, D.O., Erica F. Bisson, M.D., and Lubha M. Shah, M.D.

1Division of Neuroradiology, Department of Radiology, and 2Department of Neurosurgery, University of Utah Health Sciences Center, Salt Lake City, Utah

Object. Posterior odontoid process inclination has been associated with Chiari malformation Type I in the pediatric population. There are varying reports to support a reliable range of odontoid inclination angles in control adults. The purpose of this study is to estimate the normal measurements in adults for odontoid retroflexion, retroversion, height, and the pB–C2 line (a line drawn through the odontoid tip from the ventral dura perpendicular to a second line drawn from the basion to the inferoposterior aspect of C-2 vertebral body) to establish a normative reference in this population.

Methods. After obtaining institutional review board approval, the authors performed a retrospective analysis of non–contrast enhanced cervical spine CT scans obtained in 150 consecutive control adults. Three neuroradiologists measured odontoid retroflexion, odontoid retroversion, odontoid height, and the pB–C2 line. The cohort was divided into sex and two age groups. Comparisons of the means with unpaired 2-tailed t-test were performed.

Results. A total of 125 subjects met the inclusion criteria: 80 were men and 45 were women (mean age 52 years, range 18–89 years). The odontoid retroflexion angle ranged from 70° to 89° (mean 79.3° ± 4.9°), and the odontoid retroversion angle ranged from 57° to 87° (mean 71.9° ± 5.3°). The range and mean of odontoid height were 17–27 mm and 22 ± 1.8 mm, respectively. The mean pB–C2 line was 6.5 ± 2.1 mm with a range of 0–11.2 mm. The results were also compared with previously published pediatric data.

Conclusions. The current study demonstrates that the odontoid process in adults is anatomically different from that in children: it is longer, more posteriorly inclined, and has a greater pB–C2 line. Therefore, utilization of these parameters with previously published cutoffs in the pediatric population is not appropriate for surgical planning in adults.

Key Words • Chiari malformation Type I • ventral brainstem compression • odontoid retroflexion • odontoid retroversion • pB–C2 line • cervical spine

Posterior angulation of the odontoid process has been associated with Chiari malformation Type I (CM-I) in adults and in children. The ranges of the odontoid process height, posterior inclination, the pB–C2 line (a line drawn through the odontoid tip from the ventral dura perpendicular to a second line drawn from the basion to the inferoposterior aspect of the C-2 vertebral body), a surrogate for ventral brainstem compression (VBSC), in healthy children and in children with CM-I have been previously reported. There are varying literature reports to support a reliable range of odontoid inclination angles in control adults, and, more importantly, there is a lack of research addressing what implications such angles have on the surgical planning in adults with CM-I. The purpose of this study is to estimate the normal odontoid angles in adults to establish a normative reference database.

Methods

After obtaining institutional review board approval,
we performed a retrospective review of non–contrast enhanced cervical CT scans in patients who had been referred to the University of Utah Health Sciences Center over a period of 1 month. Computed tomography scans were performed using a Somatom Definition 128-channel, single tube scanner (Siemens). The review yielded a sample size of 150 subjects and consisted of adults (age ≥ 18 years) who underwent cervical spine imaging for indications other than CM-I. The methodology of measurements by Tubbs et al. was reviewed by 3 neuroradiologists, and a consensus of implementation of the technique was performed at the start of the study. Standard linear caliper method was used to perform the measurements on an institutional picture archiving and communication software system (Philips). The 3 neuroradiologists performed 4 measurements, and each reader examined a set of 50 subjects. The following parameters were assessed: odontoid retroflexion angle, odontoid retroversion angle, odontoid process height, and pB–C2 line (Figs. 1–4). Subjects who presented with osseous injury, osseous mass, extensive arthropathy, or congenital anomaly of the craniovertebral junction were excluded from the analysis. The cohort was dichotomized into female and male groups and into 2 age groups (18–50 years old and > 50 years old). The results were compared with previously published data of the measured parameters in healthy (control) children. Comparisons of the means among the study groups were performed using unpaired 2-tailed t-test. Statistical significance was assigned to p values < 0.05. A concordance correlation coefficient for inter-reader variability was calculated for retroflexion angle (coefficient value of > 0.8 considered as substantial, 0.65–0.8 as moderate, and < 0.65 as poor).

A total of 125 of the 150 adults met the inclusion criteria for the analysis. The study population consisted of 80 men and 45 women ranging in age from 18 to 89 years (mean age 52 years). Odontoid retroflexion and retroversion angles ranged from 70° to 89° (mean 79.3° ± 4.9°) and from 57° to 87° (mean 71.9° ± 5.3°), respectively. The range of the odontoid process height was 17–27 mm (mean 22 ± 1.8 mm). The mean pB–C2 line was 6.5 ± 2.1 mm with a range of 0–11.2 mm; the measured parameters for the cohort are shown in Table 1. Comparisons of the measurements to those from 50 healthy children (age 3–18 years) in Tubbs et al. are summarized in Table 2. The results of the sex and age groups are presented in Tables 3 and 4, respectively.

The concordance correlation coefficient for retroflexion angle between Readers 1 and 2 was 0.7, between Readers 1 and 3 was 0.69, and between Readers 2 and 3 was 0.69. The difference between measurements for any pair of readers did not reach statistical significance (> 0.05, paired 2-tailed t-test).

**Discussion**

By comparing the results obtained in this retrospective analysis with previously published parameters in children, the current study revealed morphological differences in the odontoid process between control adults and control children. When compared with the normal pediatric population, the odontoid process in control adults is longer, more posteriorly inclined, and associated with a greater pB–C2 line. Furthermore, normal women have a
significantly shorter and more posteriorly oriented odontoid process than control men. Unlike sex, age did not have any effect on the odontoid height and angles without a statistically significant difference in any of the measured metrics between the age groups.

Previous investigators have attempted to estimate the odontoid process inclination by examining dried cadaveric specimens, cervical spine radiographs, a combination thereof, and MRI scans utilizing various methodologies. Consequently, different ranges of odontoid inclination have been reported for both adults and children. We agree with the assumption of Tubbs et al. that other measurement techniques relied either on a relatively variable anatomical structure such as the base of the C-2 vertebral body or a difficult to identify landmark such as the midbody of the C-2 vertebra. Tubbs et al. introduced the odontoid retroflexion angle based on the dentocentral synchondrosis of C-2, a readily identifiable and extremely consistent finding on both CT and MRI scans that serves as an embryological landmark of the inferior boundary of the odontoid process base. Accordingly, we measured the retroflexion angle as a true representation of the dens inclination. We were able to identify the dentocentral synchondrosis as a hyperdense line in all cases. The retroflexion angle measurements were reproducible by the 3 readers in this study. We also estimated the retroversion angle, using the base of the C-2 vertebral body, as a comparative measure to prior published data. The mean retroversion angle was 71.9°, more acute than the mean retroflexion angle, but closer to previously published values of 64.1° from Xu et al. and 53.6° from Gosavi and Swamy, where both applied the same measurement method. To our knowledge, this study is the first to report the dens retroflexion angle measurements in healthy adults based on the dentocentral synchondrosis.

In this investigation, the finding of the dens in control adults being more posteriorly oriented than that in control children can be explained by the functional adaptation of C-2 curvature in response to the changing skull base angulation during normal development. Krmpotić-Nemanić and Keros described that at birth, the kyphosis of both the skull base and the odontoid process is compensated by the lordosis of the cervical spine below C-2. During normal growth, and particularly in the first 5 years of life, the cranial base becomes more kyphotic and the odontoid process becomes increasingly lordotic to compensate for the cranial deformity. Supporting the adaptive alteration in the odontoid axis, Koebke and Satemus found steady increase in the posterior inclination of the dens with advancing age in the axes of 55 children from birth until 37 months of age. The adaptive phenomenon probably continues into late adolescence and early adulthood and ceases when the skull base angle stabilizes. This may explain the lack of a statistically significant difference in the dens angulation measurements between the 2 age groups (18–50 years old vs > 50 years old).

**TABLE 1: Measured odontoid parameters for the study population (n = 125)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>odontoid retroflexion (°)</td>
<td>79.3 ± 4.9</td>
<td>70–89</td>
</tr>
<tr>
<td>odontoid retroversion (°)</td>
<td>71.9 ± 5.3</td>
<td>57–87</td>
</tr>
<tr>
<td>odontoid height (mm)</td>
<td>22 ± 1.8</td>
<td>17–27</td>
</tr>
<tr>
<td>pB–C2 line (mm)</td>
<td>6.5 ± 2.1</td>
<td>0–11.2</td>
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</table>
Estimation of odontoid process posterior inclination

Many studies have evaluated differences in the anatomical variability of the C-2 vertebra by age, sex, race, and body dimensions. There are reports of sex difference in odontoid inclination. Koller et al. assessed 100 radiographs (54 females and 46 males; age range 15–94 years) and showed the mean angle between the anterior odontoid line and a line along the base of the C-2 vertebral body to be 59.1° in females compared with 63.1° in males (statistically significant difference). Likewise, our results revealed that healthy females had a statistically more dorsally inclined odontoid process than their male counterparts. We did not specifically look at body height in our patients as previous studies found that neither body height nor weight was significantly correlated with dens dimensions, and that these measurements were, therefore, poor predictors of the size of the dens. In a study determining sex variation in cervical vertebrae, Wescott found no significant sexual dimorphism between black individuals and white individuals but did find that the C-2 dimensions were greater in whites than in blacks. Although Wescott reported racial differences in the C-2 vertebral body, we could not evaluate this finding. As of the 2012 population, 91.8% of Utah residents were white (US Census Bureau); therefore, our population was predominantly white.

The C-2 vertebra is composed of 5 ossification centers: 2 posterolateral centers that form the neural arches, a basal central center, and 2 median cranial centers. The latter two are the dentate and the apical centers. The dentate ossification center forms the neck and base of the dens while the tip of the odontoid process is formed by the apical center. The ossification centers are separated by cartilaginous synchondroses; the neurocentral synchondroses are among the neural arches and C-2 body, and the dentocentral synchondrosis is between the dentate center and C-2 body. The synchondroses fuse at 3–6 years of age. The longitudinal growth of the odontoid process is composed of bone formation at the dentocentral synchondrosis inferiorly and at the tip superiorly. The tip fuses with the remainder of the odontoid process by 12 years of age. It is intuitive to expect a linear relationship between the odontoid process height and increasing age. Cokluk et al. demonstrated the odontoid process to be statistically longer in control adults than in control children. Similarly, this is observed when our results are compared with published pediatric measurements. The mean height of the dens in our cohort was 22 mm. Some authors have described nearly similar results. Others have reported the odontoid height to be shorter. We believe this discrepancy in the dens height is attributed to the difference in measuring techniques. We identified the dentocentral synchondrosis as the inferior boundary of the odontoid process rather than the more cranial superior border of the C-2 superior articular processes implemented by other investigators, since the former represents the lower border of the dens embryologically. Our finding of statistically shorter dens in control females than in males concurs with prior reports. Interestingly, no statistical difference in odontoid height has been previously reported when comparing control male and female children, suggesting that the sex effect may become more evident with skeletal maturity.

The pB–C2 line was first introduced by Grabb et al. as an objective measurement of VBSC by the odontoid process and any investing tissues into foramen magnum or the rostral spinal canal in patients with CM-I. The authors examined the MRI scans of 40 subjects and found the mean pB–C2 line to be 7 mm in patients with CM-I compared with 3.7 mm in 12 control children (no statistical significance provided). They found that the majority of VBSC was caused seemingly by a posteriorly oriented odontoid. It is intuitive that a more dorsally angulated odontoid tends to cause greater cervicomедullary encroachment and is associated with a longer pB–C2 line. In accordance with this notion, we found the mean pB–C2 line in normal adults to be longer (6.5 mm) than that in control children (2.9 mm) from the study by Tubbs et al.

### TABLE 2: Odontoid measurements obtained in healthy adults versus pediatric control measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>p Value*</th>
<th>t-test.</th>
</tr>
</thead>
<tbody>
<tr>
<td>odontoid retroflexion (°)</td>
<td>79.3 ± 4.9</td>
<td>97 ± 5.1</td>
<td></td>
</tr>
<tr>
<td>odontoid retroversion (°)</td>
<td>71.9 ± 5.3</td>
<td>95 ± 6.6</td>
<td></td>
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<tr>
<td>odontoid height (mm)</td>
<td>22 ± 1.8</td>
<td>15.8 ± 4</td>
<td></td>
</tr>
<tr>
<td>pB–C2 line (mm)</td>
<td>6.5 ± 2.1</td>
<td>2.9</td>
<td></td>
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</tbody>
</table>

* In the current cohort there were 125 subjects ranging in age from 18 to 89 years. In the control cohort (from the study by Tubbs et al.) there were 50 children ranging in age from 3 to 18 years.

### TABLE 3: Comparison of the odontoid measurements between sex groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>p Value*</th>
<th>t-test.</th>
</tr>
</thead>
<tbody>
<tr>
<td>odontoid retroflexion (°)</td>
<td>79.3 ± 4.9</td>
<td>78 ± 4.8</td>
<td>0.042</td>
</tr>
<tr>
<td>odontoid retroversion (°)</td>
<td>72.9 ± 5.7</td>
<td>70 ± 4</td>
<td>0.002</td>
</tr>
<tr>
<td>odontoid height (mm)</td>
<td>22.1 ± 1.7</td>
<td>21.2 ± 1.5</td>
<td>0.0004</td>
</tr>
<tr>
<td>pB–C2 line (mm)</td>
<td>6.7 ± 2.2</td>
<td>6 ± 2</td>
<td>0.066</td>
</tr>
</tbody>
</table>

* In the current cohort there were 125 subjects ranging in age from 18 to 89 years. In the control cohort (from the study by Tubbs et al.) there were 50 children ranging in age from 3 to 18 years.

### TABLE 4: Comparison of the odontoid measurements between the two age groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean ± SD</th>
<th>p Value†</th>
<th>t-test.</th>
</tr>
</thead>
<tbody>
<tr>
<td>odontoid retroflexion (°)</td>
<td>79.7 ± 4.7</td>
<td>78.9 ± 5</td>
<td>0.358</td>
</tr>
<tr>
<td>odontoid retroversion (°)</td>
<td>72.1 ± 5.5</td>
<td>71.6 ± 5.1</td>
<td>0.624</td>
</tr>
<tr>
<td>odontoid height (mm)</td>
<td>22.2 ± 1.7</td>
<td>22 ± 1.9</td>
<td>0.582</td>
</tr>
<tr>
<td>pB–C2 line (mm)</td>
<td>6.4 ± 1.9</td>
<td>6.5 ± 2.3</td>
<td>0.756</td>
</tr>
</tbody>
</table>

* There were 60 individuals in Group 1 (age range 18–50 years) and 65 individuals in Group 2 (age range 51–89 years).
† t-test.
not find a statistical difference in pB–C2 length between males and females.

It has been demonstrated in children with CM-I that a greater posterior odontoid inclination is correlated with increased incidence of syringomyelia and a more caudally displaced obex.23 Such a configuration has also been implicated in at least amplifying, if not causing, a significant degree of hindbrain herniation in pediatric patients with CM-I.21 Moreover, greater posterior angulation and height of the odontoid process may correlate with greater degrees of VBSC in patients with CM-I.8,15 Expectedly, addressing this finding during surgical decompression has been proposed to improve outcomes with respect to resolution of an associated syrinx and symptoms of VBSC. Grabb et al.8 indicated that patients with a pB–C2 length of 9 mm or greater will probably require not only a posterior fossa decompression but also odontoidectomy. Although the study by Grabb et al.15 is skewed to the pediatric population with 38 children of 40 CM-I patients and lacked an adult control cohort, a pB–C2 line of 9 mm or greater has been used as an objective indicator of VBSC in adults with CM-I.19 Two recent reports used the pB–C2 line as described by Grabb et al. to evaluate adult with CM-I and VBSC. One16 used both anterior and posterior decompression in 2 adult patients using the criteria of a pB–C2 line greater than 9 mm. Despite a mean pB–C2 line of 11 mm, which was quoted exceeding the normal limit of 9 mm, the second study19 performed dorsal decompression alone with only 1 failure. Our study demonstrates that the range of the pB–C2 line in healthy adults is 0–11 mm; therefore, using 9 mm as a threshold and making a suggestion on the efficacy of an anterior-posterior versus a posterior-alone surgical approach may not be appropriate.

This study has limitations. A pediatric control cohort was not examined in the analysis as the results of the pediatric population from Tubbs et al. were felt to be comprehensively documented.21 Also there was a comparatively low number of females in the examined sample.

Conclusions

The current study demonstrates that the adult odontoid process is anatomically different from that in the pediatric counterpart; it is more posteriorly inclined, increased in height, and associated with a greater pB–C2 line. Clinical symptoms as well as imaging evaluation of the brainstem are integral in surgical planning for patients with CM-I; however, given the differences between adult and pediatric measurements, our findings show that surgical planning and stratification of treatment options in adult patients with CM-I should not be based on pediatric odontoid measurements. Further investigation of the aforementioned odontoid parameters in adults with CM-I compared with asymptomatic adults is ongoing at our institution.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Author contributions to the study and manuscript preparation include the following: Conception and design: Khaleel, Besachio, Shah. Acquisition of data: Khaleel, Besachio, Shah. Analysis and interpretation of data: Khaleel, Besachio, Shah. Drafting the article: Khaleel. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Khaleel. Statistical analysis: Khaleel. Study supervision: Shah.

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Address correspondence to: Ziyad L. Khaleel, M.B.Ch.B., Neurological Intervention and Imaging Service Western Australia, 1st Floor G Block, Sir Charles Gairdner Hospital, Hospital Ave., Nedlands, Western Australia 6009, Australia. email: ziyadlk@hotmail.com.