AJNR

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AJNR Am J Neuroradiol 1987, 8 (6) 995-999
http://www.ajnr.org/content/8/6/995

Atlantooccipital Junction: Standards for Measurement in Normal Children

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This study describes a simple method for measuring the distance between the occiput and atlas when a distraction-dislocation injury is suspected in a child. Measurements were made at five evenly spaced locations along the atlantooccipital joint on cross-table lateral skull radiographs in 100 normal children. These data were compared with similar measurements in eight patients with proved atlantooccipital dislocation. The mean normal measurement fell between 1.96–2.63 mm for all five points. For boys or girls aged 1–15 years, the normal distance should not exceed 5 mm at any point in the joint. The likelihood that any normal child will have a measurement ≥4.5 mm at any point is between 0.4–5.85% (expected false-positive rate).

When trying to decide if a distraction-dislocation has occurred at the atlantooccipital junction, we found that there are no adequate criteria for deciding whether the distance between the base of the skull and the first cervical vertebra is abnormally increased in the child.

There are a number of methods for measuring the craniocervical junction when there is concern about atlantooccipital dislocation or distraction injury: (1) the dens-basion relationship proposed by Wholey et al. [1] in 1958; (2) the method of Powers et al. [2], which uses a ratio of the basion-posterior atlantic arch distance to anterior arch of atlas-opisthion distance; and (3) the method of Dublin et al. [3], which is dependent upon the relationship of an intact, nonrotated mandible to the dens and/or to the anterior arch of C1. Although useful at times, each of these methods has been criticized as being unreliable [2, 4–6]. While the method of Powers et al. appears to be the most sensitive of these, it was not successful in detecting longitudinal distraction injury in children [5] and may also fail to detect a posterior atlantooccipital dislocation [7].

In 1982, Kaufman et al. [5] discussed the analysis of the atlantooccipital articulation in four children with longitudinal distraction-dislocation injury who survived. These authors recommended that measurements be made directly of the occipital condyle-C1 condylar facet joint, and speculated that this distance in normal children should not exceed 5 mm, regardless of age.

The present study was carried out to test this theory and to develop normal standards for measuring children by direct assessment of the atlantooccipital joints. Our hypothesis is that by careful measurement of this joint space directly from a standard cross-table lateral skull radiograph one can separate the normal from the abnormal.

Materials and Methods

One hundred normal cross-table lateral skull radiographs were reviewed for analysis. All cases that met the following three criteria were entered into the study: the examination was performed between 1980 and 1986; the patient was 1–15 years old at last birthday; and the indication for examination was headache, pain, fever, sinusitis, abnormal growth, adenoid

Received January 13, 1987; accepted after revision April 21, 1987.

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AJNR 8:995–999, November/December 1987
0195–6108/87/0806–0995

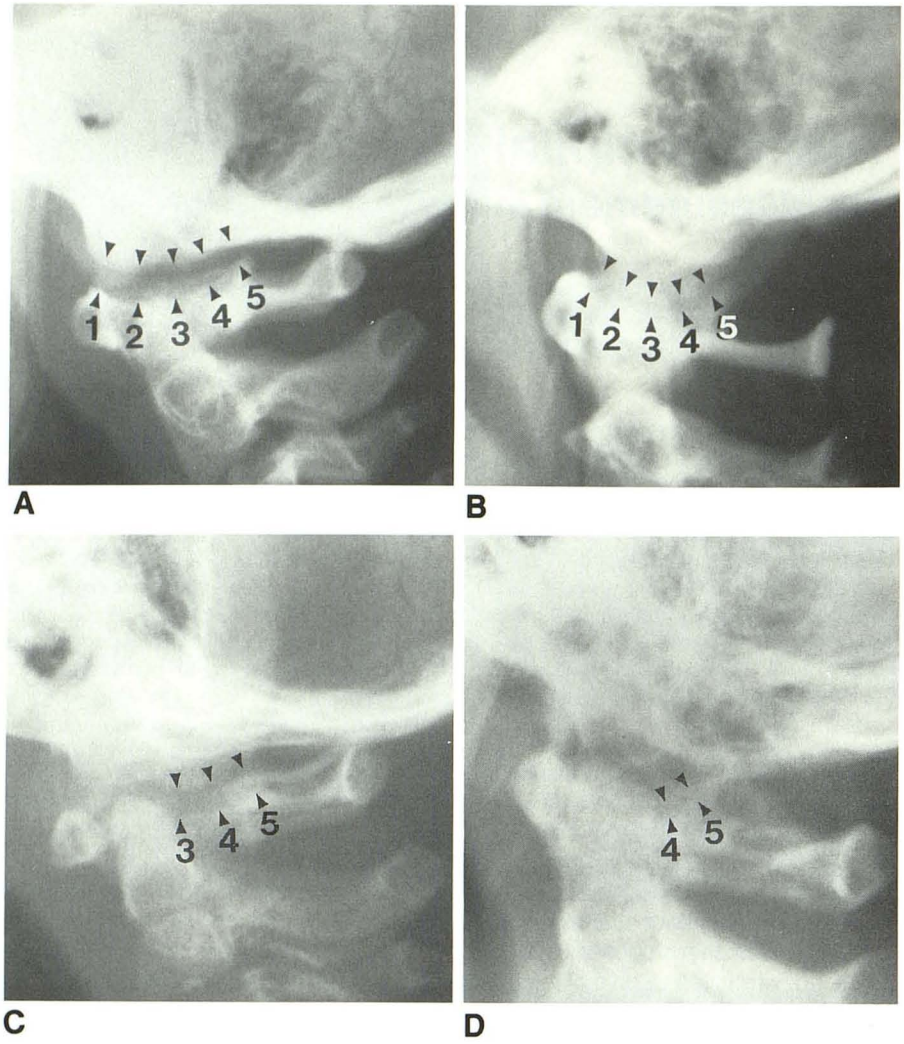

Fig. 1.—Atlantooccipital joint measurement points 1–5 (*arrowheads*) demonstrated on normal cross-table lateral skull radiograph in an 8 year old (*A*) and in a 14 year old (*B*). Note that atlantooccipital joint is commonly more horizontal in younger children than in adolescents.

***C*, Example of atlantooccipital joint in which confident measurement could only be made at three points.**

***D*, Example of atlantooccipital joint in which measurement could only be made at two points.**

problems, or *minor* trauma. No child with significant trauma, skull fracture, loss of consciousness, neurologic abnormality, or malformation syndrome was included. The age and sex of each child were recorded, but information on race was unavailable.

All radiographs were made with a 40-in focal spot-film distance and an 8:1 grid.

Cases were analyzed in groups of 10–20. The atlantooccipital joint was traced directly onto a plastic film by one of us. Measurements were made with a hand lens micrometer* at five evenly spaced points (measurement points 1–5) along the joint surface (Fig. 1). Each case was reviewed and the results agreed upon by two examiners. Eight cases of proved atlantooccipital distraction or dislocation injury were also analyzed in the same manner (Fig. 2). Four of these cases were previously reported [5].

Results

Of the 100 patients analyzed, 63 were boys and 37 were girls. Cases were divided into three age groups for analysis: 1–5 years, 6–10 years, and 11–15 years, with 51, 26, and 23 patients in the groups, respectively.

* Edmund Scientific, Barrington, NJ.

Age and Sex Differences

There was no statistically significant difference between boys and girls at each of the five measured points. Thus, we combined data from boys and girls for analysis.

There was no significant difference at measurement points 1, 2, 3, and 5 among the age groups. For measurement point 4 there was a borderline difference ($p = .0465$) among the age groups, but it was not consistent with age $\bar{X}_{(1-5\text{ years})} = 2.1$ mm, $\bar{X}_{(6-10\text{ years})} = 2.5$ mm, $\bar{X}_{(11-15\text{ years})} = 1.9$ mm, and therefore of doubtful significance.

Independence of Measurements

The measurement points 1–5 are not independent. Points that are closer together have a higher coefficient of correlation; e.g., 1, 2 or 4, 5, and all of these correlations are statistically significant ($p = .0001$ to $<.02$).

Measurement Values at Points 1–5 in Normal Children

Mean, minimum, and maximum value; standard deviation; coefficient of variation; and sample size for each measurement

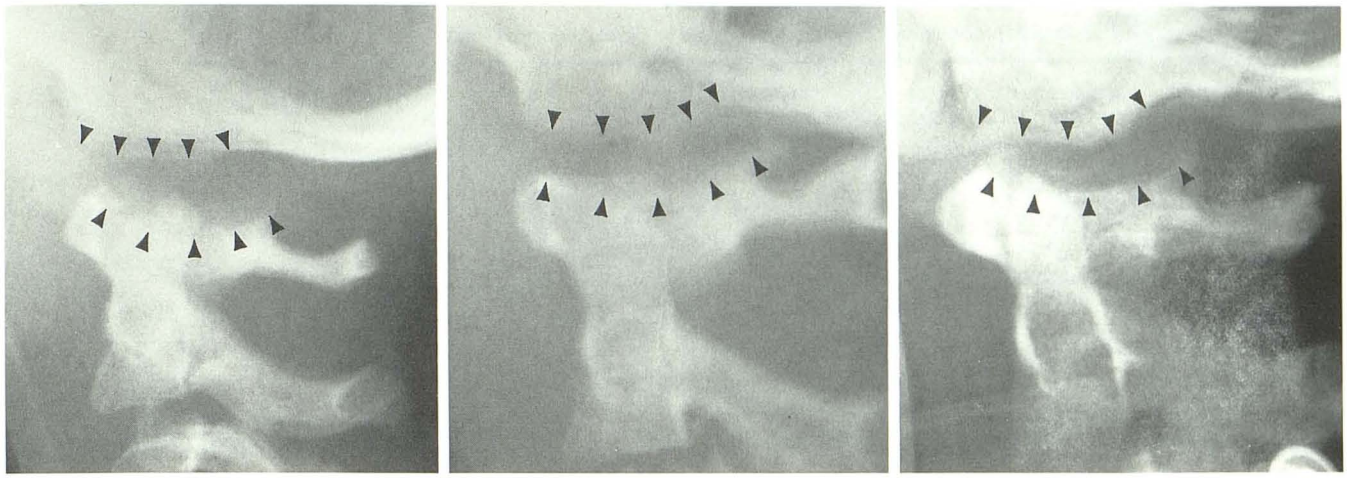

Fig. 2.—Atlantooccipital distraction-dislocation injuries.
***A*, 5½-year-old girl with a mean distraction distance of 7.9 mm (range, 6.0–9.0 mm).**
***B*, 7-year-old boy with a mean distraction distance of 6.6 mm (range, 6.0–8.0 mm).**
***C*, 12-year-old boy with a mean distraction distance of 5.5 mm (range, 4.5–6.0 mm). This patient, who represented the most subtle example, died of retroperitoneal and mediastinal hemorrhage and, at autopsy, had nearly complete disruption of both the intraspinal and extraspinal supporting atlantooccipital ligaments. Reprinted with permission from Kaufman et al. [5]. Using the ratio of Powers et al. [2], we determined that cases 2B and 2C were within normal limits, and case 2A was barely abnormal.**

TABLE 1: Atlantooccipital Joint Measurements in 100 Normal Patients (in mm)

Measurement No.	Sample Size	Minimum Value	Maximum Value	Mean	Standard Deviation	Coefficient of Variation	% Able to Measure (n = 84[a])
1	65	1.0	3.5	2.22	0.70	31.4	77.4
2	64	1.0	5.0	2.63	1.02	38.8	76.2
3	58	1.0	5.0	2.52	0.95	37.6	69.0
4	63	1.0	4.0	2.13	0.70	32.9	75.0
5	60	1.0	4.0	1.96	0.65	33.3	71.4

[a] 84 of 100 cases reviewed had measurable points; 16 of 100 had no measurable points.

point are shown in Table 1. The mean atlantooccipital joint measurement fell between 1.96–2.63 mm for all five points. The highest measurement values were found at points 2 and 3, both for means and maximum values. No measurement (points 1–5) exceeded 5 mm.

Measurability of Points 1–5

Sixteen cases (16%) could not be measured at any point. Only one point could be measured in one case, and at least two points could be measured in 83 cases. Most of the 84 cases that could be measured had more than three measurement points available. There was no statistically significant difference in success of measurement among the five points (Table 1). Among the 100 cases reviewed, each point (1–5) was measurable about 58–65% of the time. Among the 84 cases that were measurable, each measurement was obtainable about 75% of the time.

Measurement Values at Points 1–5 in Atlantooccipital Dislocation Patients

Similar data from eight patients with proved atlantooccipital dislocation-distraction injuries are given in Table 2. The mean atlantooccipital joint measurement in these cases fell between 6.33–8.12 mm for all five points. The minimum measurement values were all found in a single patient. Minimum values in the other seven patients were higher.

Relationship of Normal to Abnormal Patients

At measurement point 1, normals (maximum, 3.5 mm) are separate from abnormals (minimum, 4.5 mm). At measurement point 3, normals (maximum, 5.0 mm) are separate from abnormals (minimum, 5.5 mm). At point 4, normals (maximum, 4.0 mm) are separate from abnormals (minimum, 5.0 mm).

At measurement point 2, there is some overlap between normals (maximum, 5.0 mm) and abnormals (minimum, 4.5

TABLE 2: Atlantooccipital Joint Measurements in Eight Abnormal Patients (in mm)

Measurement No.	Sample Size	Minimum Value	Maximum Value	Mean	Standard Deviation	Coefficient of Variation	% Able to Measure ($n = 8$)
1	8	4.5	8.0	6.44	1.43	22.1	100.0
2	8	5.5	11.0	8.12	2.20	27.1	100.0
3	6	5.0	9.5	7.50	1.70	22.7	75.0
4	6	5.0	10.0	7.67	2.09	27.3	75.0
5	3	3.5	9.5	6.33	3.01	47.6	37.5

mm). At measurement point 5, normals (maximum, 4.0 mm) slightly overlap abnormals (minimum, 3.5 mm).

Using a 4.5-mm distance as an arbitrary discriminator, there were five normal children with one of the five measurement points ≥4.5 mm, one normal child with two of the five measurement points ≥4.5 mm, and no normal children with more than two measurement points ≥4.5 mm. The maximum distance among the normal children at any point (1–5) was 5.0 mm.

On the basis of this series it was determined that the likelihood that a normal child will have a measurement ≥4.5 mm at any point (1–5) is 7% (6/84); the likelihood that a normal child will have a measurement ≥4.5 mm at two points is 1.2% (1/84). The single abnormal patient with a borderline measurement had clearly larger (abnormal) measurements at all other measurement points; the few normal patients with borderline values at one or (in one instance) two points had clearly normal values at all other measurement points.

Prediction of False Positives from This Method

A model for the distribution of the measurements obtained in this study can be combined with the data set to give an expectation of the rate of future false-positive cases. A Gossett's (Student's) t-distribution with 6 degrees of freedom fits the data well. One can use the number of standard deviations from the mean that corresponds to the value of 4.5 mm in each of the distributions to give an expected rate of false-positive cases. The results of this statistical model indicate that one can expect a 0.4–5.85% false-positive rate for measurement points 1–5, with the greatest number of false positives occurring at points 2 and 3.

Discussion

Most normal children have an atlantooccipital junction measurement of less than 4.5 mm, regardless of age or sex, and at any single point measured. A small percentage of normal children have a joint measurement of 4.5–5.0 mm, but none was observed in excess of 5 mm.

When one encounters a borderline measurement of 4.5–5.0 mm, the entire joint should be measured at all five reference points if possible. A normal child should not have more than one additional measurement in the same range; most normal children measure ≤4.0 mm throughout the remainder of the joint. Similarly, the abnormal patient with atlantooccipital distraction who falls within the borderline range (4.5–5.0 mm) should have the same or greater measurement throughout the remainder of the atlantooccipital joint. We expect that most children with radiographically detectable atlantooccipital distraction injuries well exceed the borderline range (Fig. 2).

The occurrence of the widest measurements in the normal atlantooccipital joint at reference points 2 and 3 (Table 1) and the greater likelihood of encountering a false-positive case at these two points can be explained by the normal development and shape variations of the occipital condyle in the infant and child. Two factors influence this: the condylar "notch" and the normal occipital synchondrosis. The condyle varies slightly in most children from anterior to posterior, as well as from medial to lateral. Often the condyle is not smoothly rounded, but may have a central groove or notch [5] (Fig. 3). This notch may persist into adulthood. In addition, the rostral basioccipital part of the condyle is separated from the caudal exoccipital portion by the radiolucent synchondrosis intraoccipitalis anterior (SIA) [8] present in infants and young children. This synchondrosis begins to ossify at age 6, first laterally then medially, and closes between the ages of 7–8 years [8].

According to Tillmann and Lorenz [8], the notch of the bilobed condyle and the SIA are not related. The notch occurs approximately in the middle of the condyle (reference point 3) and the SIA at the rostral fifth of the condyle (reference point 2). The cartilage covering the occipital condyle is thickened in these locations. Thus, there is a greater likelihood of a larger measurement at reference points 2 and 3 than at points 1, 4, and 5. Most of the atlantooccipital "joint space" evaluated by this method actually represents cartilage covering both the condyle and facet of C1, lying between the ossified margins of each.

When our data were divided into two age groups, 1–7 and 8–15 years, respectively, the mean measurements in the 1–7 age group at points 2 and 3 (2.72 and 2.59 cm, respectively) were slightly higher than in the 8–15 age group (2.50 and 2.42 cm, respectively), but these small differences were not statistically significant and were not of importance in this study. Nonetheless, it is our impression that the normal widening that occurs at points 2 and 3 may make it more difficult to measure the center of the joint in some patients.

Certain technical factors contribute to the difficulty in applying this measurement method. Head rotation and overlying structures, such as ear lobe and mastoid tip, may add some confusion to interpretation until one becomes familiar with the anatomy [5] (Fig. 4). Sixteen percent of the routine cases

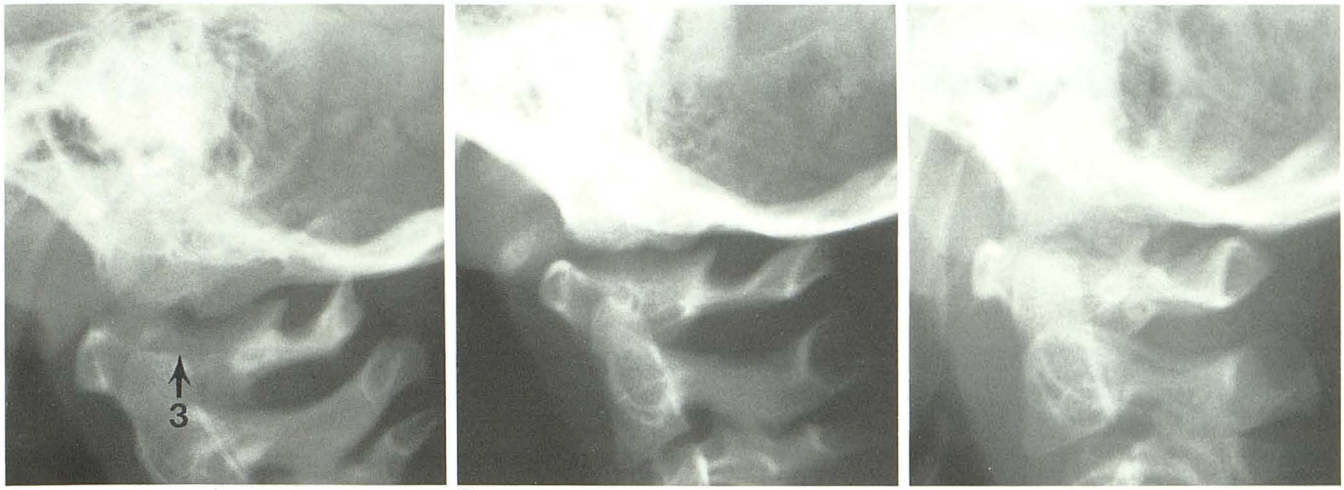

Fig. 3.—*A*, Normal occipital condyles may have deep notch in articular surface opposite measurement point 3 (*arrow*).

***B*, Similar but less deep groove in occipital condyles. Notch is common normal variant and may account for the tendency for slightly greater distances at measurement point 3.**

Fig. 4.—Rotated head increases difficulty of measurement. Ear lobe helices and mastoid tips overlie notched condyles, making analysis more difficult. However, close scrutiny will allow for measurement in most cases. All five points were measured in this case.

reviewed could not be measured; however, if abnormality of the atlantooccipital joint is suspected, a repeat radiograph can be obtained. A well-positioned anteroposterior skull radiograph offers another opportunity to view the atlantooccipital joint directly [5].

The shortcomings of this study include the small number of abnormal cases available for analysis. While craniocervical injuries are common in autopsy series in children [9], survival is still considered rare. Thus, the number of examples available in any one medical center is likely to be small. Another potential shortcoming is the choice of cross-table lateral skull radiograph for analysis rather than the lateral cervical spine radiograph. Since the centering of the X-ray beam for the cross-table lateral view is closer to the craniocervical junction than it is in the cervical spine radiograph, we postulated that careful analysis of the skull radiograph would provide more accurate and less variable data. Finally, the atlantooccipital joints are paired structures, yet we measured only one side in each case. Often, the joints overlapped symmetrically on well-positioned cross-table lateral radiographs, while in other cases it was only possible to measure one side because of overlying structures.

The problem in interpreting the possibly injured craniocervical junction is recognition of the abnormal. A false-positive examination will likely lead to careful neurologic evaluation, immobilization, hospitalization, and further imaging analysis of the craniocervical junction, usually by polytomography, CT, or MR. Such prudent measures should lead to a successful outcome for the patient. The risks of a false-negative examination are potentially disastrous. It is our purpose to avoid the possibility of the error of omission by applying these standards to the analysis of the atlantooccipital junction in children.

In conclusion, we have devised a simple method of directly measuring the distance between the occiput and the atlas in children when distraction-dislocation injury is suspected.

ACKNOWLEDGMENTS

Thanks to J. Scott Dunbar for his advice and encouragement and to Marlena Tyre for preparing the manuscript. Thanks also to Linda Reilman for loaning us one of the abnormal cases.

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