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A Blinded Assessment of Radiographic Criteria for Atlanto-occipital Dislocation

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Study Design. Blinded comparison of 5 methods to diagnose atlanto-occipital dislocation (AOD) on plain radiographs and computerized tomography (CT) of the cervical spine.

Objective. To determine the best method to diagnose AOD.

Summary of Background Data. Several methods are proposed for the diagnosis of AOD, including the Power's ratio, X-line method, basion-dens interval, condylar gap, and Harris method. No blinded comparison of the results of these methods has been compared to patient outcome, and there is no information available regarding the accuracy of these methods applied to CT scans.

Methods. Plain lateral radiographs and CTs of the cervical spine were reviewed in 104 patients, including 6 with AOD. Images underwent a blinded review by a board certified neurosurgeon (D.K.R.), orthopedist (P.A.A.), radiologist (J.C.), and emergency physician (D.B.B.). Each diagnostic method for AOD was applied for determination of sensitivity, specificity, and positive and negative predictive values. The ability to identify relevant anatomic landmarks was also tabulated.

Results. Average values for sensitivities, specificities, positive and negative predictive values for each method applied to plain radiographs are: 0.4625−1.0, 0.8933−0.9725, 0.2775−0.45, and 0.975−1.0, respectively. These values for each method applied to CT scans are: 0.7075−1.0, 0.8725−0.9775, 0.3175−1, and 0.98−1.0, respectively. Identification of relevant anatomic landmarks occurred 99.75% of the time when these methods were applied to CT scans compared to 39% to 84% of the time on plain radiographs.

Conclusions. Sensitivity, specificity, positive and negative predictive values of these methods improve when applied to CT scans because of better visualization of anatomic landmarks. This result suggests CT scans of the cervical spine may be warranted in all trauma patients suspected of having cervical spine injury.

Key words: atlanto-occipital dislocation, Power's ratio, X-line method, basion-dens interval, condylar gap, Harris method, cervical spine injury. **Spine 2005;30:1427–1432**

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Historically, atlanto-occipital dislocation (AOD) has been a difficult injury to identify on plain lateral cervical radiographs because the anatomic structures involved are poorly visualized on the film. This poor visualization may lead to missed injuries. *The Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries* (*Neurosurgery* supplement, 2002) recommends applying the basion-axial interval-basion-dens interval (Harris method) to a plain lateral cervical radiograph. In the event of a nondiagnostic film in the presence of prevertebral soft tissue swelling or clinical suspicion, additional imaging with computerized tomography (CT) or magnetic resonance is recommended. These recommendations are based on only class III evidence. Because there is widespread variation among reported sensitivities of techniques to diagnose AOD,[1–3] we performed a blinded review of plain lateral radiographs and CT scans of the cervical spine to compare the diagnostic accuracy of the Power's ratio, X-line method, basion-dens interval, and basion-axial interval-basion-dens interval (BDI). This study was conducted to determine the best diagnostic method combined with imaging modality to identify AOD.

Materials and Methods

This is a blinded review of the plain lateral radiographs and CT scans of the cervical spine in 104 patients. Six patients had clinically confirmed AOD, and 98 were found not to have AOD based on imaging studies and subsequent clinical follow-up. Pediatric (children younger than 12 years) and adult patients were included in the review. All patients were evaluated in the emergency department of a major university hospital that is also a level one trauma center.

A board certified neurosurgeon (D.K.R.), orthopedic surgeon (P.A.A.), radiologist (J.C.), and emergency physician (D.B.B.) reviewed each image and applied the Power's ratio, X-line method, basion-dens interval, condylar gap, and basion-axial basion-dens interval (Harris method), and recorded their results (Figures 1−3). Instructions of how to apply each method was provided to the reviewers. The Power's ratio is the ratio of the basion-posterior atlas arch to the opisthion-anterior atlas arch and is abnormal at values more than one (Figures 1A, 2A, 3A).[4] The X-line method is considered abnormal if the line from the basion to the axis spinolaminar junction does not intersect C2, and a line from the opisthion to the posterior inferior corner of the body of the axis does not intersect C1 (Figures 1B, 2B, 3B).[3] The basion-dens interval is considered abnormal in the presence of a displacement >10 (12 mm in pediatrics) mm between these 2 structures (Figures 1C, 2C, 3C).[5] A distance >2 (5 mm in pediatrics) mm between the

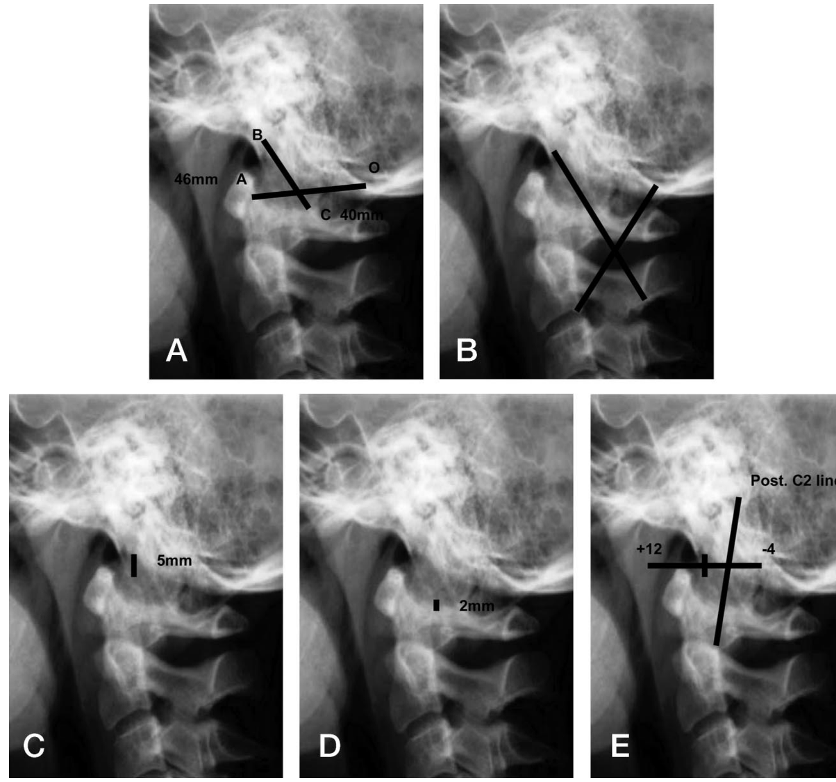

Figure 1. Methods to diagnose AOD shown on plain radiographs of a patient without injury. **A**, Power's ratio-line segments BC/OA, 40/46 mm = 0.87. **B**, X-line method. Posterior-superior aspect of dens and spinolaminar line at C1 are intersected. **C**, Basion-dens interval <10 mm. **D**, Condylar gap, 2 mm with no displacement. **E**, Harris method. Basion-dens interval of 5 mm with no displacement.

occipital condyle and the superior articular facet of the atlas is considered abnormal for the condylar gap method (Figures 1D, 2D, 3D).[6] Finally, anterior displacement >+12 mm or posterior displacement >−4 mm between the basion and posterior C2 line, or displacement >12 mm from the basion to the dens is considered abnormal by the basion-axial basion-dens interval (Harris method) (Figures 1E, 2E, 3E).[2] These methods were applied to a plain lateral radiograph and midsagittal image, or parasagittal image in the case of condylar gap, of a 2-dimensional (2-D) reconstructed CT scans of the cervical spine.

Radiographs were stored as Digital Imaging and Communications in Medicine files on compact discs containing plain

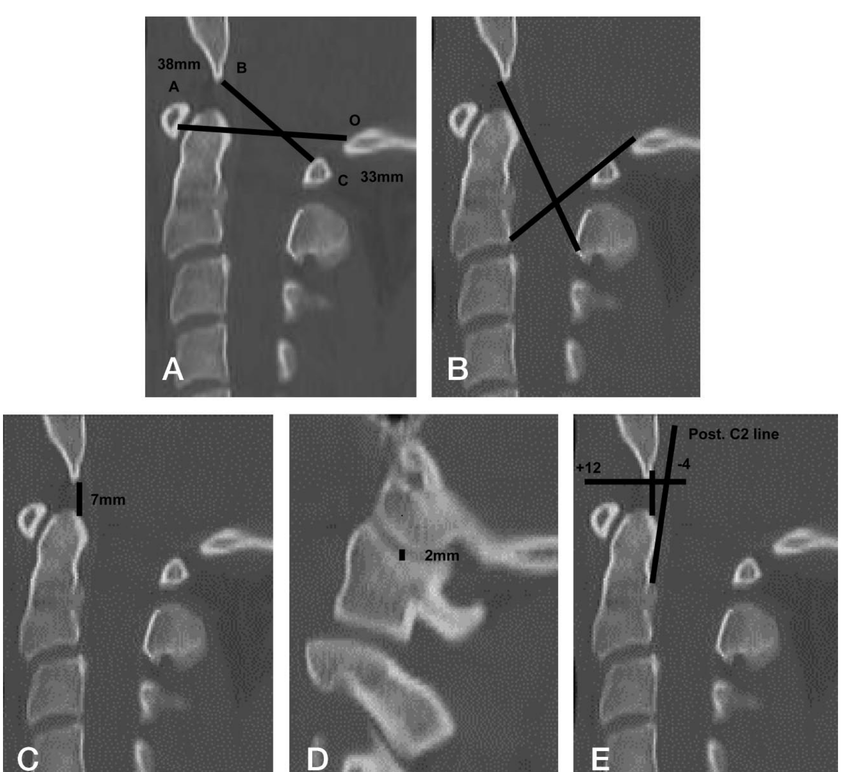

Figure 2. Methods to diagnose AOD shown on CT scans of a patient without injury. **A**, Power's ratio-line segments BC/OA, 33/38 mm = 0.87. **B**, X-line method. Posterior-superior aspect of dens and spinolaminar line at C1 are intersected. **C**, Basion-dens interval, <10 mm. **D**, Condylar gap, 2 mm with no displacement. **E**, Harris method. Basion-dens interval of 7 mm with no displacement.

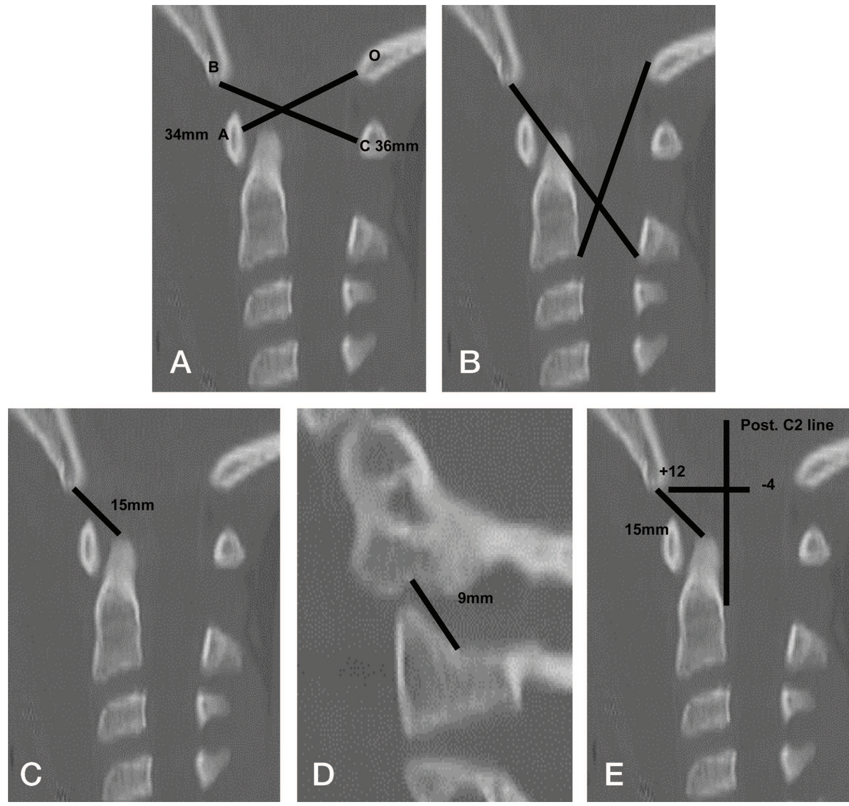

Figure 3. AOD shown on the CT scans of a pediatric patient. **A**, Power's ratio-line segments BC/OA, 36/34 mm = 1.1. **B**, X-line method. Posterior-superior aspect of dens and spinolaminar line at C1 are not intersected. **C**, Basion-dens interval, 15 mm. **D**, Condylar gap is 9 mm, 4 mm higher than the maximum 5 mm allowed in pediatric patients. It is anteriorly displaced. **E**, Harris method. Basion-dens interval of 15 mm, higher than 12 mm allowed for this method and anteriorly displaced.

radiographic and CT images of the cervical spine. CT images included axial, sagittal, and coronal reconstructions. Because every image was digitized, we were able to remove all patient identifying data and dates while generating discs. Each compact disc contained a software program, eFilm™ Lite™ (eFilm Medical Inc., Milwaukee, WI), that read the images and would automatically load onto a reviewer's computer. Although a reviewer could control image quality and magnification with built-in commands on the image-reading program, resolution was limited to that of a standard personal computer. On 3 occasions, an original film with patient identifiers removed was provided to the reviewers because of software problems reading the digitized image.

Discs were distributed to reviewers along with instructions of how to apply each method and datasheets to record their results. Data collected included calculated values for the Power's ratio, basion-dens interval, condylar gap, and yes/no answers to appropriate points of intersection for the X-line and Harris methods. Additionally, we collected data regarding how often reviewers were able to identify anatomic landmarks.

For each technique we calculated the sensitivity, specificity, positive and negative predictive values, interobserver variability, and percentage of time landmarks were visualized on films. The results were averaged for all reviewers. Data were analyzed using the Student *t* test with a value of 0.05 used to establish statistical significance. SAS statistical software (version 6.12, SAS Institute Inc., Cary, NC) was used to calculate these values. This study was approved by the University of Wisconsin-Madison Health Sciences Human Subjects Committee.

■ Results

Sensitivity, specificity, positive and negative predictive values were calculated for each method. These values were tabulated independently for each reviewer per radiographic modality and then averaged together, grouped by modality (Figures 4–7). The percentage of time reviewers were able to identify relevant landmarks on the images is presented in Figure 8. These results are presented here because of their effect on the calculation of sensitivities, specificities, positive and negative predictive values. If landmarks could not be identified on the image, the method being reviewed could not be applied. Hence, there were no results for that image to include in the calculation. Using the midsagittal view, or parasagittal for the condylar gap, on a 2-D reconstructed CT scans, relevant anatomic landmarks were identified 99.75% to 100% of the time (Figure 8).

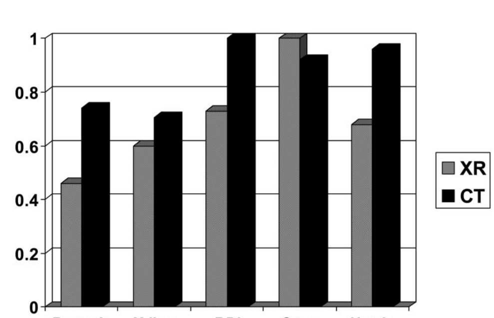

Figure 4. Average sensitivities for the 5 methods studied. Power's ratio x-ray (XR) (0.46), X-line XR (0.60), basion-dens interval (BDI) XR (0.73), condylar gap (Cgap) XR (1.0), and Harris method XR (0.68). Power's ratio CT scans (0.74), X-line CT scans (0.71), BDI CT scans (1.0), Cgap CT scans (0.92), and Harris method CT scans (0.96).

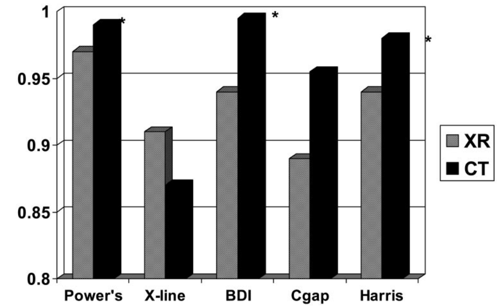

Figure 5. Average specificities for the 5 methods studied. Power's ratio x-ray (XR) (0.97), X-line XR (0.91), basion-dens interval (BDI) XR (0.94), condylar gap (Cgap) XR (0.89), and Harris method XR (0.94). Power's ratio CT scans (0.99), X-line CT scans (0.87), BDI CT scans (0.995), Cgap CT scans (0.955), and Harris method CT scans (0.98). The asterisk denotes statistical significance of the difference in specificities between XR and CT scans ($P < 0.05$).

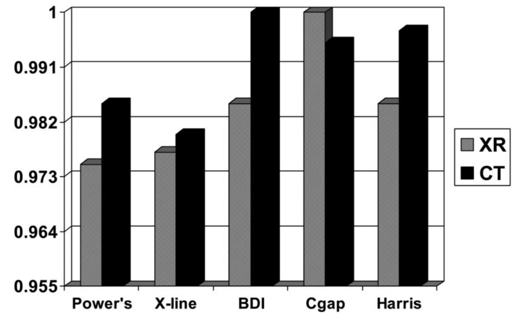

Figure 7. Average negative predictive values for the 5 methods studied. Power's ratio x-ray (XR) (0.975), X-line XR (0.977), basion-dens interval (BDI) XR (0.985), condylar gap (Cgap) XR (1.0), and Harris method XR (0.985). Power's ratio CT scans (0.985), X-line CT scans (0.98), BDI CT scans (1.0), Cgap CT scans (0.995), and Harris method CT scans (0.995).

Power's Ratio

The average sensitivity, specificity, positive and negative predictive values for the Power's ratio applied to lateral radiographs of the cervical spine are 0.46, 0.97, 0.44, and 0.98, respectively. Applied to CT scans, the results for sensitivity, specificity, positive and negative predictive values are 0.74, 0.99, 0.81, and 0.99, respectively. The differences between the values of specificity and positive predictive value between plain radiographs and CT scans were statistically significant ($P < 0.05$). There was a nonsignificant trend for improvement in sensitivity ($P = 0.08$).

X-Line Method

For the X-line method applied to lateral radiographs of the cervical spine, the average sensitivity, specificity, positive and negative predictive values are 0.60, 0.91, 0.28, and 0.98, respectively. Applied to CT scans, the results for sensitivity, specificity, positive and negative predictive values are 0.71, 0.87, 0.32, and 0.98, respectively. There were no statistically significant differences among any of these values between plain radiographs and CT scans.

Basion-Dens Interval

The average sensitivity, specificity, and positive and negative predictive values for the basion-dens interval applied to lateral radiographs of the cervical spine are 0.73, 0.94, 0.37, and 0.99, respectively. Applied to CT scans, the results for sensitivity, specificity, and positive and negative predictive values are 1.0, 0.995, 0.93, and 1.0, respectively. The differences between the values of specificity and positive predictive value between plain radiographs and CT scans were statistically significant ($P < 0.05$).

Condylar Gap Method

For the condylar gap method applied to lateral radiographs of the cervical spine, the average sensitivity, specificity, and positive and negative predictive values are 1.0, 0.89, 0.45, and 1.0, respectively. Applied to CT scans, the results for sensitivity, specificity, and positive

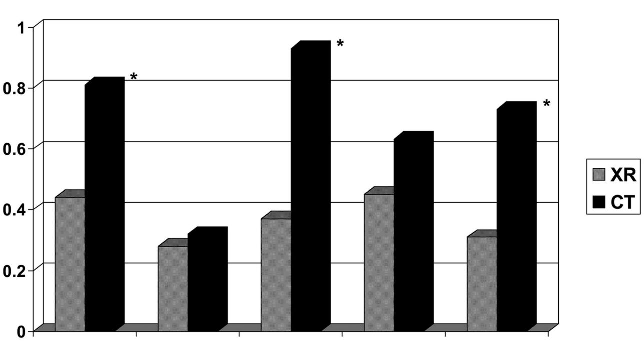

Figure 6. Average positive predictive values for the 5 methods studied. Power's ratio x-ray (XR) (0.44), X-line XR (0.28), basion-dens interval (BDI) XR (0.37), condylar gap (Cgap) XR (0.45), and Harris method XR (0.31). Power's ratio CT scans (0.81), X-line method CT scans (0.32), BDI CT scans (0.93), Cgap CT scans (0.63), and Harris method (0.73). The asterisk denotes statistical significance of the difference in positive predictive values between XR and CT scans ($P < 0.05$).

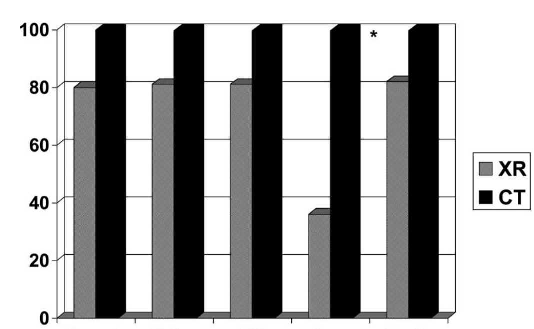

Figure 8. Average rates of readability. Percentage of the time reviewers were able to identify relevant anatomic landmarks on x-ray (XR) and CT scans. Power's ratio XR (80%), X-line XR (81%), basion-dens interval (BDI) XR (81%), condylar gap (Cgap) XR (36%), and Harris method XR (82%). Power's ratio CT scans (100%) and X-line, BDI, Cgap, Harris (99.75%). The asterisk denotes statistical significance in the difference between readability of XR and CT scans ($P < 0.05$).

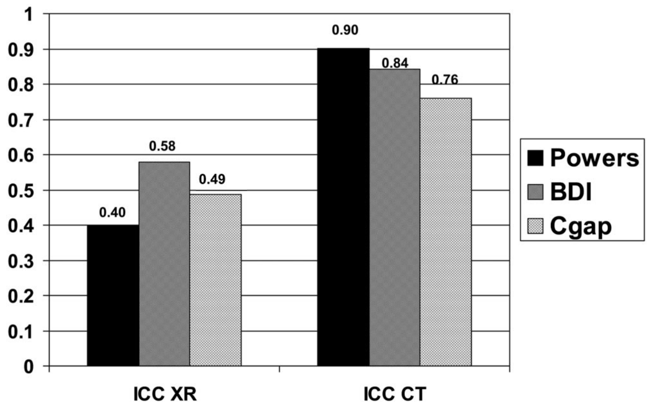

Figure 9. The intra-class correlation coefficient (ICC) is an index of reliability that can measure interobserver variability. Values closer to one represent decreased variability. Here, for the Power's ratio, basion-dens interval (BDI) and condylar gap (Cgap) applied to CT scans the values are closer to one when compared to x-ray (XR). This shows there is more variability among reviewers when these methods are applied to x-rays.

and negative predictive values are 0.92, 0.955, 0.63, and 0.995, respectively. There were no statistically significant differences among any of these values between plain radiographs and CT scans.

Basion-Axial Interval-Basion-Dens-Interval (Harris method)

The average sensitivity, specificity, positive and negative predictive values for the basion-axial interval-basion-dens-interval (Harris method) applied to lateral radiographs of the cervical spine are 0.68, 0.94, 0.31, and 0.99, respectively. Applied to CT scans, the results for sensitivity, specificity, and positive and negative predictive values are 0.96, 0.98, 0.73, and 0.998, respectively. The differences between the values of specificity and positive predictive value between plain radiographs and CT scans were statistically significant ($P < 0.05$).

Except for the sensitivity of the condylar gap and specificity of the X-line method, sensitivity, specificity, and positive and negative predictive values increased when applied to the midsagittal reconstructed view on a 2-D reconstructed CT scans.

To quantify the interobserver variability, we used the intra-class correlation coefficient, a ratio of between individual variability to the sum of between individual and between reader variability. Values can range from zero to one, those closer to one represent smaller amounts of variability. This was calculated for the Power's ratio, basion-dens interval, and condylar gap methods (Figure 9). X-line and Harris methods were not included in this calculation because their determination includes nonnumerical assessments, and intra-class correlation coefficient can only be calculated for integer values. The least amount of variability was observed for the Power's ratio applied to CT scans (0.9029). Highest variability was seen in the Power's ratio applied to radiographs (0.3974). There is decreased interobserver variability among values obtained from CT scans.

Discussion

AOD is one of the most devastating injuries of the craniocervical junction. Sequelae include death, quadriplegia, paresis of one or more extremity, and cranial nerve deficits. Head injuries and fractures at other spinal levels are frequent comorbidities, confounding identification of specific pathology responsible for a patient's neurologic deficit. Rapid identification and treatment of this injury is imperative to improve survival and prevent further neurologic decline, especially in patients who present neurologically intact or have limited deficits. Therefore, a reliable, sensitive, and easy-to-apply method for the diagnosis of AOD is required.

The radiographic diagnosis of AOD may be made using plain lateral cervical radiographs by applying the Power's ratio, X-line method, basion-dens interval, condylar gap, and Harris methods. There is widespread variation in the reported accuracies of each. Depending on the study, the sensitivity of the X-line method ranges from 20% to 75%,[2,3] Power's ratio 33% to 60%,[2,3] 50% sensitivity of the basion-dens interval,[3] and 100% sensitivity of the Harris method. It is noteworthy that these statistics only apply to radiographs on which the required landmarks could be identified.

A universal theme underlying the difficulties in diagnosing AOD using plain lateral cervical radiographs is the ability to visualize the anatomic landmarks required for application of these methods. The basion is frequently obscured by other bony anatomy of the skull or can be "cut off" as the radiograph is shot. Both of these problems are alleviated by CT scans with 2-D reconstruction of the cervical spine. Our reviewers indicated that they were able to identify landmarks nearly 100% of the time when using CT scans. Conversely, they could only identify the condylar gap on radiographs an average of 36% of the time and measure the basion-dens-basion-axial interval (Harris method) an average of 82% of the time.

Except for the sensitivity of the condylar gap and specificity of the X-line method, the sensitivity, specificity, and positive and negative predictive values of each method improved with application to a CT scans. Sensitivities increased an average of 23 percentage points for each method when applied to CT scans, and positive predictive values increased an average of 31 percentage points. It should be noted that the condylar gap can also be measured from the open-mouthed odontoid view on a plain film. We did not include this view in our study because this image is frequently not available for patients who are likely to have AOD. Advanced Trauma Life Support guidelines recommend a lateral cervical radiograph only during the primary survey; because many patients at risk for AOD are intubated, the odontoid view is usually not obtained.

In our study, we found the basion-dens interval, defined as abnormal when >10 mm, to have the highest sensitivity (1.0), specificity (0.995), and positive (0.93) and negative predictive values (1.0) when applied to CT scans of the cervical spine. On plain radiographs, the condylar gap method has the highest sensitivity (1.0), positive predictive value (0.45), negative predictive value (1.0), while the Power's ratio has the highest specificity (0.97). These values are superior to those we obtained when we applied the Harris method, as recommended by the Guidelines for the Management of Acute Cervical Spine and Spinal Cord Injuries. Our findings support the use of the basion-dens interval (with 10 mm as the cutoff) as the diagnostic test of choice when applied to CT scans as it is the easiest to apply and appears to be the most accurate method of those evaluated. Furthermore, our findings also support the use of CT imaging of the craniocervical junction because CT scans improves the diagnostic accuracy of these methods tested, largely by improving the ability to identify anatomic landmarks.

■ Key Points

- AOD is a potentially fatal injury that requires rapid identification to prevent further morbidity or mortality.
- Diagnosis of AOD has historically been difficult on plain lateral cervical radiographs because of poor visibility of anatomic structures involved.
- There is better visibility of craniocervical junction anatomy on a 2-D reconstructed CT scans of the cervical spine, improving the identification of AOD.
- Sensitivities, specificities, and positive and negative predictive values of diagnostic methods for AOD improve once applied to CT scans of the cervical spine.

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