Measurement Techniques for Upper Cervical Spine Injuries: Consensus Statement of the Spine Trauma Study Group

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Abstract and Introduction

Study Design: Literature review.

Objectives: The Spine Trauma Study Group compiled a collection of clinically useful imaging methods used in upper cervical spine trauma and standardized how these measurements are documented.

Summary of Background Data: Imaging of the upper cervical spine is crucial for injury detection, description, and treatment decision making. However, a standard set of imaging measurement techniques for this region does not exist. While most clinicians have developed their own methods of describing radiographic pathology, this variability often leads to confusion in developing an agreed on classification system and in proposing universal treatment recommendations.

Methods: The available literature concerning measurement of injury characteristics after upper cervical trauma was reviewed. Consensus of the most clinically applicable measurement methods among the surgeon members of the Spine Trauma Study Group was achieved.

Results: The techniques include: the basion-dens and basion-posterior axial line intervals (C0-C2); fracture gap and fracture length apposition (a reflection of fragment size) for occipital condyle injuries; lateral articular overhang for C1 ring fractures; the atlanto-dens and posterior atlanto-dens intervals for sagittal C1-C2 instability; odontoid fracture angulation and displacement; and C2-C3 angulation and translation for traumatic spondylolisthesis of the axis.

Conclusions: Only through prospective study using a standardized and uniform set of measurement techniques can the clinical significance of these imaging characteristics be fully appreciated.

Imaging examination of the upper cervical spine following trauma is crucial for injury detection and description, especially in light of the potentially dire neurologic consequences of a missed bone or disco-ligamentous injury. Because of the relatively low incidence of occipital cervical trauma, clinicians are often not well versed in the normal spatial relationships between the occiput, atlas, and axis. While surgical treatment for survivors of occipitocervical dissociation is almost universally accepted, the optimal radiologic method of detecting this often subtle injury is not clear. Further inconsistencies and paradoxes are illustrated by 2 common fractures, in which treatment is dependant on accurate radiographic measurements. The classification of traumatic C2 spondylolisthesis relies on the detection of angulation and translation, with accepted methods of measurement of these parameters described. In contrast, measurement methods of displacement and angulation of odontoid fractures have not been universally established.

Possibly because of familiarity with the techniques, many clinicians have applied commonly recommended measurement tools described for instability in patients with rheumatoid arthritis to the setting of upper cervical spine trauma. These measurements, although accurate in defining relationships between anatomic structures, are often difficult to use in the traumatic setting because of their complexity and difficulty with visualizing pertinent anatomic landmarks.

It is the purpose of this paper to present a systematic review of various radiographic measurements in order to develop universal standards for the assessment (measurement) of traumatic upper cervical spine injuries. Furthermore, it is hoped that standardized radiographic methods will lead to more universal acceptance and use among clinicians, leading to better patient care and improved storage, retrieval, and analysis of relevant data, thus facilitating multicenter studies and/or metaanalysis.

Materials and Methods

The available literature concerning measurement of injury characteristics after upper cervical trauma was reviewed. This included computer-based searches using PubMed as well as available textbooks. Consensus of the most clinically applicable measurement methods among the surgeon members of the Spine Trauma Study Group (STSG) was achieved through discussion, debate, and resolution.

A task-oriented subcommittee that was comprised of the authors of this paper developed a narrative with a pictorial, describing in detail how the measurements should be performed, for each chosen method. These were again presented to
all of the members of the STSG for final discussion, modification, and approval.

The STSG performed the current study. The group was formed in early 2002 and had its first official meeting in October 2002. Its purpose of formation was to plan multicenter studies concerning spinal trauma. The international membership represents many of the busiest spine trauma centers in the world, including those in the United States, Canada, Mexico, Sweden, France, Italy, India, Belgium, and Turkey. All of the nearly 50 members are either an orthopedic surgeon or neurosurgeon that specializes in spine surgery. Participants were selected based on their extensive clinical experience and/or established reputations as spine trauma researchers.

The STSG meets as a whole twice a year. The task-oriented committee in charge of the current study had met on 2 separate occasions. The time line of these meetings was:

1. An initial STSG meeting at which time the study goal was outlined, and 1 of the authors (C.M.B.) was assigned to be principal investigator.

2. A subcommittee meeting that focused on the detailed review of the literature and available measurement techniques. From these techniques, the subcommittee members selected those techniques that had the greatest supporting evidence or perceived clinical relevance.

3. One of the authors (C.M.B.) then prepared a slide presentation of narratives and pictorials of each technique before the next STSG meeting and distributed it to all of the STSG members.

4. At the next STSG meeting, the group as a whole presented, reviewed, and critiqued each measurement technique. During this meeting, individual members had the opportunity to suggest modifications/deletions/additions to the selected measurement techniques. One of the authors (C.M.B.) acted as a mediator for this discussion. A show of hands assessed consensus.

5. The members of the subcommittee prepared and reviewed a manuscript with illustrations at a subsequent meeting. With its approval, the manuscript was forwarded to all members of the STSG.

6. At the latest STSG meeting, slides of the narratives and pictorials of the selected measurement techniques were presented. One of the authors (C.M.B.) arbitrated final suggestions of modifications to these techniques. A show of hands assessed consensus. These modifications were then incorporated into a final manuscript text and figures.

Results

There are several methods to describe the spatial relationship between the occiput, atlas, and axis. The most popular in the setting of trauma are the basion-dental interval (BDI) and the basion-posterior axial line interval (BAI). Originally described by Harris et al., the BDI and BAI have been carefully examined (Figure 1). In the first of 2 companion studies, Harris et al. measured the BAI and BDI on lateral radiographs of 400 normal adults. The BAI and BDI did not exceed 12 mm in 98% and 95% of adults, respectively. The BDI and BAI have come to be known as Harris Measurements, and more descriptively as the Rule of Twelve. Deliganis et al. recommended use of the BDI and the BAI to help detect occipitocervical dissociations. Likewise, Fisher et al. found these to be the most useful radiographic parameters for these injuries.
Measurement technique for the BDI and BAI.

In their second study, the investigators retrospectively reassessed lateral radiographs of 37 patients in whom occipitoatlantal dissociation had been previously diagnosed at the time of admission.\[^9\] They found the BDI and BAI to be greater than 12 mm in 23 patients (group 1) with frank occipitoatlantal dislocation and 8 (group 2) with occipitoatlantal subluxation/dissociation. Measurements were less than 12 mm for 6 patients who initially had suspected instability but did not have supportive clinical findings. In the same patients, the Power ratio (Figure 2) and Lee X line method (Figure 3) could not be measured in 17 of 37 cases because either the opisthion could not be seen or the posterior C1 arch had a developmental anomaly (i.e., not fused). In the remaining patients, these methods enabled detection of only 60% and 20% of injuries, respectively. While these data strongly suggest that BDI/BAI are superior to the Power ratio and Lee X lines, the interobserver and intraobserver reproducibility of these measurements has not been assessed to the authors’ knowledge.
Measurement technique for the Power ratio.

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Source: Spine © 2007 Lippincott Williams & Wilkins
Measurement of Lee's lines.

Other lines and measurements have also been described for the craniocervical junction. The Power ratio (Figure 2) describes the relationship between the occiput and C1 through a ratio of the distance between the basion and C1 posterior arch divided by the distance between the opisthion and anterior C1 arch. Ahuja et al.\(^1\) found lower Power ratios in 5 surviving patients compared to a higher ratio seen in 1 fatal case of occipitocervical dislocation.

Most other descriptive measurements of the occipitocervical junction were originally developed to assess rheumatoid patients with basilar invagination (cranial settling). Thus, the critical pathologic values are usually seen in the lower, rather than upper limits of normal due to the process of settling rather than distraction. These measurements, although possibly useful for some injuries, were not intended to detect widening or translation of the occipitocervical junction. They include: (1) the Chamberlain line, drawn from the hard palate to the tip of the opisthion (Figure 4); and (2) McCrae's line, drawn from the basion to the opisthion, representing the anteroposterior width of the foramen magnum (Figure 5).

The Chamberlain line.
McCrae's line.

Considering the available data, the current authors' feel that Harris measurements (BDI/BAI or the Rule of Twelve) are probably the most useful, sensitive, and reproducible radiographic parameters for detecting and characterizing occipitocervical dissociation and dislocations.

Midsagittal computed tomography (CT) reconstruction is recommended, although a lateral cervical plain radiograph may be used if it is centered on the occipitocervical junction and is targeted from 6 ft with appropriate magnification correction.

The most inferior and posterior aspect of the basion is marked. The superior tip of the odontoid process is also marked. The distance between these 2 points (BDI) is measured in millimeters. A value greater than 12 mm is highly suggestive of occipitoatlantal dissociation (Figure 1).

A vertical line is drawn along the posterior vertebral border of the C2 body. This line should extend superiorly, just past the level of the foramen magnum. A perpendicular line is drawn from this line to the basion mark. This distance is then measured in millimeters (BAI). A value more than 12 mm should be considered abnormal and indicative of an anterior occipitoatlantal dissociation.

Anderson and Montesano\cite{17} described a classification system for occipital condyle fractures. In essence, it distinguishes injuries that are primarily bony versus those that are primarily ligamentous with only small bony flecks. Tuli et al\cite{18} distinguished fractures based on displacement and on the presence of ligamentous instability. Others have noted that condyle injuries with larger bony fragments have a greater likelihood of stable healing with nonoperative treatment, such as a halo fixator.\cite{19,20} From these findings, it appears that the size of the occipital condyle fragment is an important determinant of treatment and outcome; however, there is currently no standard method to measure the size of occipital condyle fragments or the magnitude of fracture fragment displacement. An analysis of the influence of fragment size and displacement on stability and outcome has not been performed.

Axial CT, parasagittal, and coronal reconstructions.

The occipital condyles are often not well visualized on plain radiographs.\cite{21} Better bony detail is afforded by CT images through the occipitocervical junction.\cite{20,22} While axial CT images are useful in assessing the presence of occipital condyle
fractures, they do not usually enable visualization of the entire condyle in 1 image. For these reasons, the authors suggest
that a parasagittal and coronal CT reconstruction through the approximate midaspect of the condyle be used. As principles
of fracture healing dictate, the area of apposed fracture surfaces can influence the potential for fracture healing. Thus, a
similar quantification of the apposed contacting surfaces of occipital condyle fracture fragments is proposed. In regards to
displacement, greater amounts imply greater concomitant soft tissue disruption and instability. The ability to reduce the
fractured fragments would also influence healing potential.

Because actual detailed quantitative measurements would be exceedingly difficult, the length of the fracture line is
measured in millimeters on the midsagittal and coronal condyle images (Figure 6). The coronal and sagittal measurements
are added to derive a total amount of bony apposition for each condyle. For shell-type avulsion fractures that leave a rim of
subarticular cortical bone juxtaposed to the upper C1 articular process, the length of apposed fracture surface would be
essentially complete. This would suggest that the fracture would have a high likelihood of healing. The same would be true
for a fracture through the junction of the condyle and occiput, with minimal displacement. In contrast, a primarily
ligamentous injury with a small bony fleck would have a short measured distance of apposed bone and a presumed lower
rate of healing. Future prospective evaluations using this measurement technique and its relationship to stability and
healing rates need to be performed to support or disqualify the current belief that fragment size is a prognostically
important factor.

Technique for measuring displacement (gap) and apposition of occipital condyle fracture fragments. It is suggested that
injuries with small fracture fragments (flecks) are primarily ligamentous that may have less healing potential than broad
fracture surfaces that are well aligned and minimally gapped.

On coronal and parasagittal reconstructed images, the maximal gap between the fractured fragments are measured in
millimeters (Figure 6).

Lee et al[23] used an open-mouth view to measure displacement of C1 lateral mass fractures. Most authors seem to agree
on this method of assessment. Spence determined that 6.9 mm is the critical amount of total displacement necessary to
disrupt the transverse ligament. This measurement was derived by direct cadaveric measurements, however. Heller et al[24]
warned of overestimating the amount of displacement based on plain films. They determined that the transverse ligament
should be considered intact in patients with less than 8.1-mm total displacement as measured on a plain open-mouth
radiograph. This consideration may be obviated using calibrated axial and coronally reconstructed CT images.

Coronal CT-reformatted images through the center of the lateral masses of the atlas.

Vertical lines are drawn along the most lateral aspect of the bone of the C1 and C2 articular processes (Figure 7). The
transverse distance between them is then measured in millimeters. These are then added to calculate the total lateral mass
displacement.

Measurement technique for lateral mass overhang.

While the atlanto-dens interval (ADI) and posterior atlanto-dens interval (PADI) are widely used to detect traumatic cervical instability, the authors could find no article assessing their reliability in the setting of acute injury. Studying the flexion-extension radiographs of 72 patients with Down syndrome, Wellborn et al.\(^{[13]}\) found ADI to have statistically significant intraobserver agreement in 2 of 3 observers. Although the interobserver agreement was considered fair, it was statistically better than measurements using the Power ratio. Supportively, Cremers et al.\(^{[25]}\) found the ADI to be reliable in detecting instability in 279 children with Down syndrome. Intraobserver and interobserver agreement was better using flexion versus the neutral radiograph. The PADI represents the anteroposterior diameter of the spinal canal at this level. It has been shown to be a more useful prognosticator in rheumatoid arthritis patients than the ADI. However, it has not been validated in the same manner for traumatic atlantoaxial instability. With traumatic atlantoaxial instability being relatively uncommon and the aforementioned measurements having undergone significant epidemiological rigor for other pathology, the authors propose the use of the ADI and PADI as described below.

Lateral cervical radiograph or midsagittal CT reconstruction.

The craniocaudal midpoint of the anterior ring of C1 is marked. A line parallel to the ring of C1 is drawn from this point toward the odontoid process. The distance between the C1 mark and intersection with the anterior aspect of the odontoid process is measured in millimeters (Figure 8).
The ADI and PADI.

Rotation between the C1 and C2 rings can occur by itself or in combination with a sagittal translational deformity. Most reports of atlantoaxial rotational instability are in children, commonly associated with nontraumatic upper pharyngeal infections. Most recommendations concerning optimal measurement of atlantoaxial rotation are derived from this body of literature. Most authors agree that CT is the imaging modality of choice for detection and quantification of rotational deformity, though its reliability and accuracy for detecting dynamically unstable joints has been questioned. In the authors’ experience, dynamic CT is rarely indicated (and can be dangerous) in the adult patient with traumatic instability.

Transaxial CT images through mid body of C2 and mid body of C1.

For optimal measuring, the CT gantry angle should be aligned along the transverse plane of the upper cervical vertebrae. An axial CT slice at the level of the C2 body and C1 ring are then obtained. An anteroposterior line is drawn from the midpoint of the C2 body to the center of the spinous process. A perpendicular to this line is drawn along the posterior C2 vertebral body. On the best axial slice of C1, the midpoints of the transverse (vertebral artery) foramens are marked, and a line is drawn between them. The angulation between these 2 lines represents the degree of static atlantoaxial rotatory deformity (subluxation) (Figure 9). By convention, the side (right or left) toward which the atlas (head) points is considered the side of the rotation.
Measurement of right (R) (A) and left (L) (B) atlantoaxial rotation.
Odontoid fracture displacement and angulation are known to be important prognostic factors of fracture healing. However, in the authors' review of the literature, there are no assessments of the optimal method for measuring these parameters. Carlson et al.[15] measured displacement by drawing lines along the anterior aspect of the dens fragment and the intact caudal body of C2. The angle subtended by these lines would be the degree of fracture angulation. The location of the apex of fracture angulation would be described as anterior or posterior.

Lateral cervical radiograph or midsagittal CT reconstruction.

A tangent line is drawn along the anterior aspect of the odontoid fragment and the anterior aspect of the C2 body. At the level of the fracture, a transverse line is drawn connecting these 2 lines. This distance is measured in millimeters and represents sagittal fracture displacement (Figure 10).

Odontoid fracture displacement.

A tangent line is drawn along the posterior aspect of the odontoid fragment and the posterior aspect of the C2 body. The angle subtended by these lines would be the degree of fracture angulation. The location of the fracture apex angulation would be used for the descriptor anterior or posterior (Figure 11).
Odontoid fracture angulation.

Levine and Edwards\textsuperscript{[14]} described a method of measuring both angulation and translation of C2 with traumatic spondylolisthesis (Hangman's fractures).

Lateral cervical radiograph or midsagittal CT reconstruction.

Endplate method. As depicted in Figure 12, lines are drawn perpendicular to the inferior endplate of C2 and C3 to measure angulation.
C2-C3 angulation measurement using the endplate method.

Similarly, posterior vertebral body lines are drawn along the posterior aspect of C2 and C2 to enable measurement of angulation (Figure 13) and displacement (Figure 14). Both of these parameters are important in classification and treatment decision making for this injury.
C2-C3 ANGULATION
(POSTERIOR VERTEBRAL BODY LINE METHOD)

C2-C3 angulation measurement using the posterior vertebral body line method.
Measurement of C2-C3 translation.

Discussion

Recommended measurement parameters for upper cervical spine injuries are extremely complicated because of the region's unique anatomy and frequently subtle signs of injury. Radiologic examination is a crucial step in both early injury detection and treatment decision making. Although radiologic images demonstrate spatial relationships of structures to each other, they are also used to quantify injury characteristics, such as vertebral displacement, angulation, and rotation, which are used to classify and prognosticate a particular fracture or ligamentous injury. Despite this importance, there are currently no uniform radiologic measurement guidelines for the upper cervical spine after trauma.

It is generally believed that variables such as fracture displacement, angulation, and fragment size influence outcomes. For example, odontoid fractures displaced more than 5-6 mm are thought to be at higher risk for nonunion. Likewise, distinguishing between type II and IIA Hangman's fractures relies on detecting angulation with or without displacement. In both these situations and other upper cervical injuries, there are no clearly accepted methods of assessing these parameters. While most clinicians have developed their own individual measurement techniques, this variability can limit application of current treatment recommendations. Furthermore, a lack of standardization breeds inconsistencies between published clinical series, which may confound conclusions regarding injury measurements. Optimally, the clinical significance of important injury features would be best determined by prospective study using a standardized and uniform set of measurement techniques.

The authors have developed a set of measurement techniques to assess upper cervical spine injuries through an extensive review of the literature in addition to substantial clinical experience. For further clarity, a rationale for the selection of what is considered an optimal technique(s), the preferred radiographic study, and a detailed description of precisely how the measurement is to be performed are also described. However, several limitations must be noted. The authors highlight that the accuracy and reproducibility of many of these parameters have not been reported. This would be an important step in validating the proposed measurement methods. Also, though the selections are representative of those that are most commonly used by spine trauma practitioners, it should not be inferred that other useful measurements do not exist or should not be employed.
Sidebar: Key Points

- Measurements of upper cervical spine injury characteristics are often used to determine optimal treatment.

- A comprehensive set of radiographic measurement techniques for upper cervical spine injuries has been presented in the hope of standardizing the methods by which injuries are described and evaluated.

- Only through prospective study using a standardized and uniform set of measurement techniques can the clinical significance of these imaging characteristics be fully appreciated.

References


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