COMPARISON OF OCCIPITO-ATLANTO-AXIAL PARAMETERS ON COMPUTED TOMOGRAPHY IN PEDIATRIC TRAUMA PATIENTS

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ABSTRACT

Background – Spinal cord injury without radiographic abnormality is a prevalent issue within the pediatric population . Subtle findings on computed tomography (CT) may be able to identify trauma patients that have occult cervical spine injury evident on magnetic resonance imaging (MRI).

Objective - To establish normal occipito-atlanto-axial parameters on CT in the pediatric population to identify patients who are at risk for occult cervical spine injury.

Materials and methods - This is a retrospective study of patients under the age of 10 years who received a cervical CT: 200 patients without presenting history of trauma and 29 patients with a presenting history of trauma that also received subsequent MRI (the reference standard). The lateral atlantodens interval (LADI), atlantooccipital interval (AOI), atlantoaxial interval (AAI), and delta lateral atlantodens interval (ΔLADI) were measured. The values of the normal 200 patients were compared to the 29 traumatic patients using Wilcoxon rank sum test and logistic regression.

Results– The normal LADI, AAI, AOI, and ΔLADI values were found to be 5.3, 3.0, 2.7, and 1.1 mm, respectively. An AOI greater than 2.7mm had a sensitivity of 53.8%, specificity of 93.8%, positive predictive value (PPV) of 87.5%, negative predictive value of 71.4%, and an odds ratio of 17.5 for predicting cervical spine injury on MRI on patients.

Conclusion - An AOI greater than 2.7mm in a trauma patient with an otherwise normal CT should be an indication for further imaging with MRI due to the potential for occult cervical spine injury.

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Introduction/Significance

Spinal cord injury without radiographic abnormality (SCIWORA) is a term that describes neurological injury without evidence of bony on plain radiographs and/or computed tomography (CT). This term, which was coined in 1982 by Pang et al, does not include the use of magnetic resonance imaging (MRI).[1,2,3] Incidence of injury in the pediatric population has often been thought to to be up to 4.6 million per year or one percent of all trauma cases.[3] However, the true incidence of SCIWORA is unclear. Given its potentially high incidence, it is important to recognize and accurately diagnose SCIWORA as misdiagnosis can pose great detriment to patients. It is crucial to evaluate the cervical spine as injury commonly occurs in this region in the pediatric population due to the unique nature of pediatric anatomy.

The most prevalent mechanisms for cervical spine injury in the pediatric population are motor vehicle collisions (MVCs) for children under 8 years of age.[7] Approximately 72% of spinal injuries in children under 8 years of age occur in the cervical spine, and these injuries are associated with a 10-50% risk of neurologic damage.[10,7] Children under the age of 10 are prone to sustaining injury at C1 to C4 because their biomechanical fulcrum exists between C2 and C3.[11] Other factors that predispose young children below the age of 8 to cervical spine injuries are their proportionally larger head-to-body ratio, immature musculature, and smaller occipital condyles.[7,11,12] The larger heads facilitate flexion and extension injuries, while smaller occipital condyles predispose children in this group to horizontal movement between C1 and the occiput.[11, 12] The hypermobility in pediatric spines is exacerbated by their relatively shallow and angled facet joints, underdeveloped spinous processes, and physiologic anterior wedging of the vertebral bodies.[9] Additionally, the increased ligamentous and cartilaginous laxity and elasticity facilitate forward vertebral movement, which predisposes pediatric spines to anterior dislocation. [11, 13] Increased laxity of the soft tissue allows the vertebral column to stretch up to 5 cm and revert back into a normal configuration after high energy impact. Unfortunately, the encased spinal cord can only withhold traction up to 5 to 6 mm. Therefore, the vertebral column can have a normal alignment on imaging while concealing a cervical or spinal cord injury, thus, posing a challenge for radiologists to diagnose occult injuries.[11]

With mortality high as 20% in children with spinal cord injuries, it is important to identify and treat SCIWORA timely.[11] We aim to measure various points of the atlantoaxial and atlantooccipital joints in the cervical spine of pediatric patients without injury to detect irregularities on CT. Additionally, an accurate diagnosis will manage the appropriate type and duration of treatment, which can range from conservative treatment with immobilization to surgery.[7,8]

Various studies have already established normal measurements of cervical spine anatomy; however, our focus will be on the distance between the dens process and the lateral masses of C1, also known as the lateral atlantodental interval (LADI)[19, 20]This particular parameter has not been studied extensively in current literature. Therefore, this study endeavors to identify the normal LADI, as discrepancy in this distance can indicate transverse ligament injury amongst many other causes. Additionally, this study also aims to determine the normal atlantoaxial interval (AAI) and atlantooccipital interval (AOI).

Material and Methods

In this retrospective study, 200 non-traumatic and 29 trauma CT exams were reviewed from 2012 to 2017 at a Level 1 trauma center after obtaining appropriate Institutional Review Board approval. For the normal/non-traumatic group (Group I), patients were selected if they were between the ages of 0 to 10 years old and had undergone a cervical CT exam for evaluation of soft tissue infection or had experienced a low impact trauma (such as a dog bite) or penetrating injury. Trauma patients (Group II) were selected if they met the age criteria, experienced a high impact incident such as a motor vehicle accident or fall from a height of six feet or greater, received a cervical CT exam, and underwent a subsequent magnetic resonance imaging (MRI) of the cervical spine.

LADI, AAI, and AOI values were measured bilaterally in each patient. Group I was subdivided into 6 groups (0-12 months, 13-23 months, 2 years, 3-4 years, 5-6 years, 7-10 years) to account for various stages of ossification. Younger children were divided into multiple, shorter time-frames due to rapidly changing cervical ossification centers. Unlike Group I, Group II was not subdivided by age due to small sample size.

LADI

First, the center of the dens was identified on coronal and axial planes. Then, the LADI was measured perpendicularly on the coronal plane from the cortex of the C1 lateral mass to the cortex of the dens process at the level of the dental center (Figure 1). This measurement was obtained bilaterally; therefore, there were a total of 400 LADI values.

AAI

Center of the atlantoaxial joint space was identified . Then the joint space was measured perpendicularly from one cortex to another in coronal and sagittal planes bilaterally (Figures 1 and 2). An average measurement of coronal and sagittal lengths was obtained bilaterally; therefore, there were a total of 400 AAI values as well.

AOI

Center of the joint space between the occipital condyle and the lateral mass was identified in coronal and sagittal planes (Figure 2). Similar to AAI, the joint space was measured perpendicularly from cortex to cortex in coronal and sagittal planes and then averaged. If an occipital notch was present, joint space was measured just adjacent to the notch.

Asymmetry between right and left LADI (Δ LADI)

Due to rotation at C1-C2, patients in non-trauma group who did not have a cervical spine collar demonstrated varying degrees of LADI asymmetry. The LADI was measured bilaterally on the coronal images, which are 2D images of a 3D structure; therefore, when there is even slight rotation of C2 on C1, there is some pseudo-asymmetry. However, marked asymmetry in LADI is a marker for cervical spinal cord injury. Therefore, we aimed to quantify a range of normal asymmetry of LADI. The difference between right and left LADI (Δ LADI) was measured for each patient in both groups.

Comparing Non-Trauma and Trauma groups

Since Group II was not subdivided by age, the overall mean LADI, AAI, and AOI from the Group I were used to compare with the overall means in Group II. Overall mean values and upper limits of normal from the calculated 95% confidence interval from Group I were used as cut-off values for predicting cervical spinal cord injury in Group II, using MRI imaging as the gold standard. Using these cut-off values, sensitivity, specificity, negative predictive value (NPV), positive predictive value (PPV), and odds ratio with p-value were calculated for each parameter.

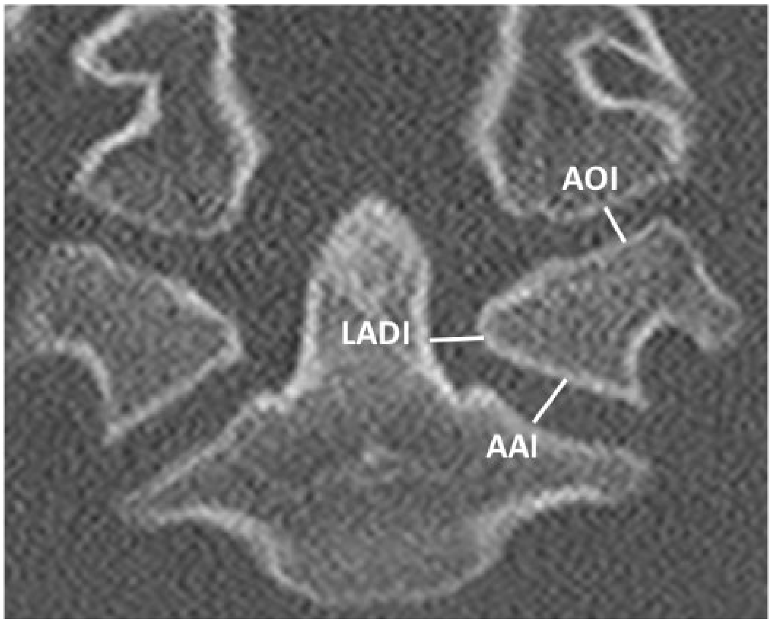

Figure 1: Coronal cervical spine CT image demonstrating LADI, AAI, and AOI measurements

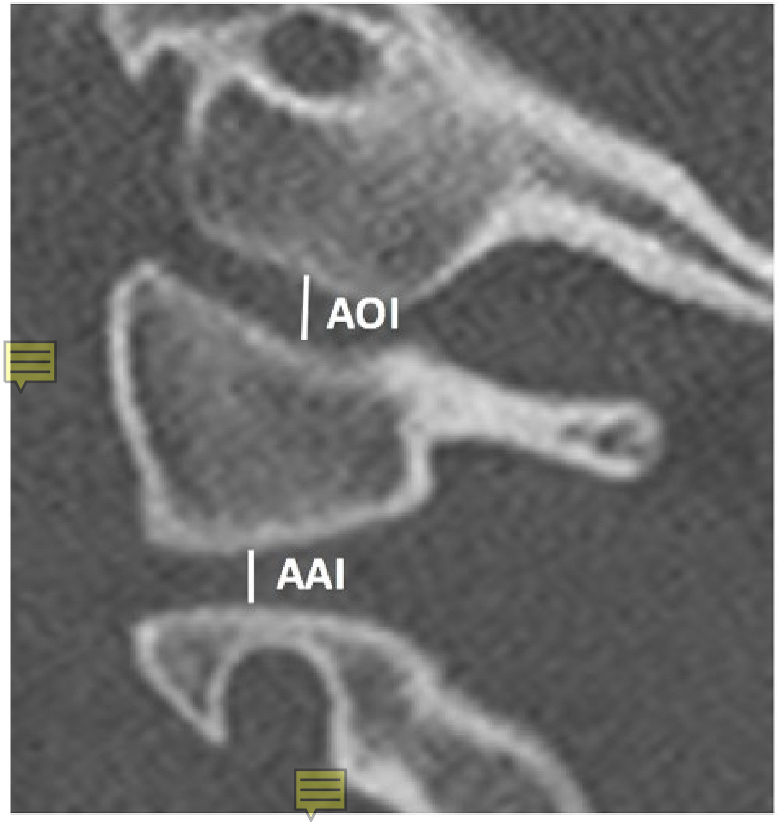

Figure 2: Sagittal cervical spine CT image demonstrating AOI and AAI measurements

Interobserver Reliability

Throughout the duration of this study, multiple raters collected data. To account for interobserver variability, the primary rater and another individual measured joint spaces in the same 10 patients selected randomly. Intraclass Correlation Coefficient (ICC) was calculated to assess inter-rater reliability.

Statistics

Demographic and clinical characteristics were assessed using means, 95% confidence intervals for continuous variables. Simple linear regression was used to determine trends for the normal parameters in Group I. The Wilcoxon Rank Sum was utilized to compare continuous variables for 2-sample comparisons for LADI, AAI, and AOI between Groups I and II. Furthermore, different thresholds of LADI, AAI, and AOI were created to ascertain whether different thresholds modified the effect sizes. Finally, diagnostic characteristics were ascertained using the Receiver Operating Characteristic Analysis using spinal cord injury on MRI as the gold standard. Then, univariate logistic regression ascertained associations between LADI, AAI, and AOI measurements and spinal cord injury among the Group II. All p-values were 2-sided and $p<0.05$ was considered statistically significant. All data analyses were conducted using STATA version 14 (STATAcorp, College Station, TX).

Results

The mean values for LADI, AAI, and AOI in each age range for Group I (n=200) were measured (Table 1). Additionally, the trends with age for mean LADI, AAI, and AOI were evaluated (Figures 3-5). Overall, mean LADI values decreased with increasing age with a p-trend of <0.001 with the average being stable from birth through 36 months and then steadily decreasing (Figure 3). Conversely, overall mean AAI values increased with increasing age with a p-trend of <0.001 with the average increasing from birth through age 36 months and then remaining stable (Figure 4). Mean AOI values did not show an overall trend as the values increased through age 36 months and then steadily decreased (Figure 5).

Additionally, the study found that the overall mean (age 0-10 yrs) for the LADI, AAI, AOI, and Δ LADI were 5.3 mm (95% CI 5.2-5.5 mm), 3.0 mm (95% CI 2.9-3.1 mm), 2.7 mm (95% CI 2.6-2.8 mm), and 1.1 (95% CI 0.94-1.22 mm) respectively (Table 2). Group II (n=29) demonstrated overall means of LADI, AAI, AOI, and Δ LADI to be 4.6mm (95% CI 4.3-5.0 mm), 3.3 mm (95% CI 3.0-3.6 mm), 2.5 mm (95% CI 2.3-2.7 mm) and 1.5 mm (95% CI 1.0-2.0 mm) respectively (Table 2). Overall mean values from Group I for LADI, AAI, AOI, and Δ LADI were compared to Group II (Table 2).

Overall mean values and the upper limits of the 95% confidence intervals for LADI, AAI, AOI, and Δ LADI from Group I were used as the threshold values for predicting occult injury evidenced on MRI in Group II (Table 3). The threshold that demonstrated a statistically significant difference between Groups I and II was the overall mean value for AOI of 2.7 mm. An AOI greater than 2.7 mm had a sensitivity of 53.8%, specificity of 93.8%, PPV of 87.5%, NPV of 71.4%, and an odds ratio of 17.5 (p-value 0.015); therefore, a patient with an AOI greater than 2.7 mm is 17.5 times more likely to have an occult cervical spine injury on MRI. The mean and upper limit of normal cutoff values for LADI, AAI, and ΔLADI also showed odds ratios of 2.1/4.5, 2.3/2.7, and 3.8/3.8 respectively; however, these values were not statistically significant with a p-value greater than 0.05 (Table 3).

Table 1: Normal LADI, AAI, and AOI parameters obtained from Group I, stratified by age

Age		LADI Mean (mm) [95% CI]	AAI Mean (mm) [95% CI]	AOI Mean (mm) [95% CI]
0-12mo	(n=19)	5.7 [5.2, 5.5]	2.3 [2.1, 2.6]	2.4 [2.1, 2.7]
13-23mo	(n=20)	5.9 [5.6, 6.2]	2.6 [2.4, 2.9]	2.8 [2.5, 3.0]
24-35 mo	(n=25)	5.9 [5.4, 6.3]	3.1 [2.9, 3.4]	2.9 [2.6, 3.2]
36-59 mo	(n=44)	5.6 [5.2, 6.0]	3.2 [3.0, 3.3]	2.8 [2.6, 2.9]
60-83 mo	(n=42)	5.1 [4.8, 5.3]	3.4 [3.2, 3.6]	2.8 [2.6, 3.0]
84-131 mo	(n=50)	4.7 [4.4, 5.0]	3.0 [2.8, 3.2]	2.6 [2.4, 2.8]
Overall	(n=200)	5.3 [5.2, 5.5]	3.0 [2.9, 3.1]	2.7 [2.6, 2.8]
P-trend		<0.001	<0.001	0.85

P-trend calculated using Simple Linear Regression

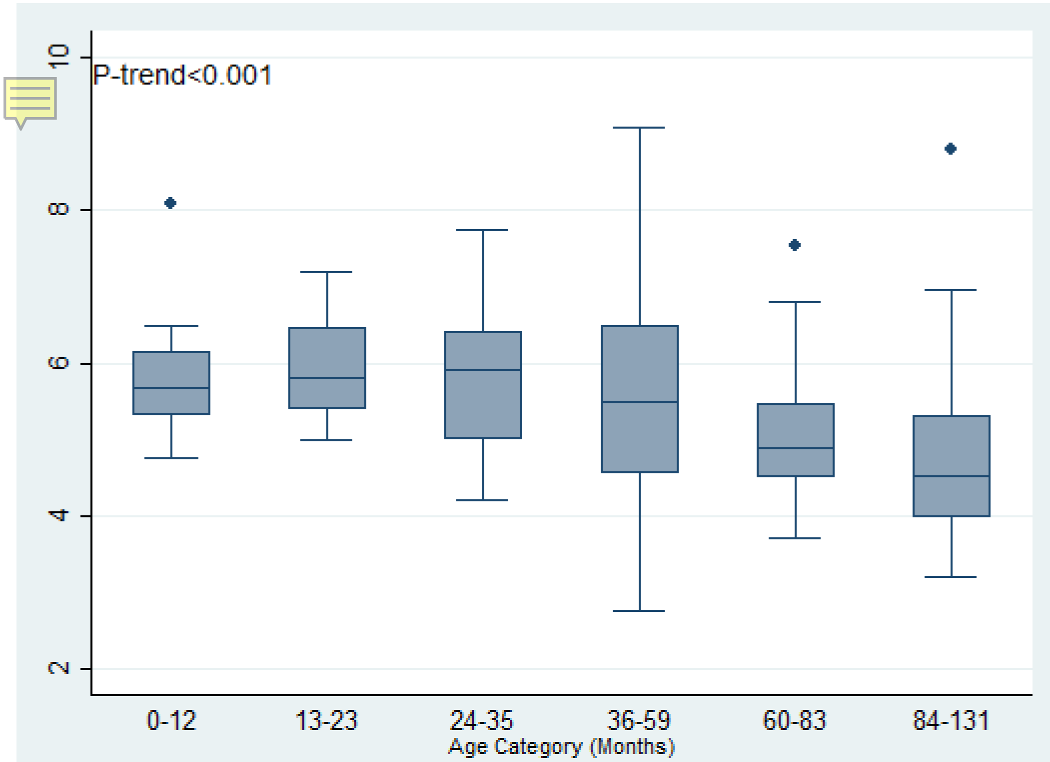

Figure 3: Scatter plot of LADI measurements in each age category demonstrating a downward trend with age

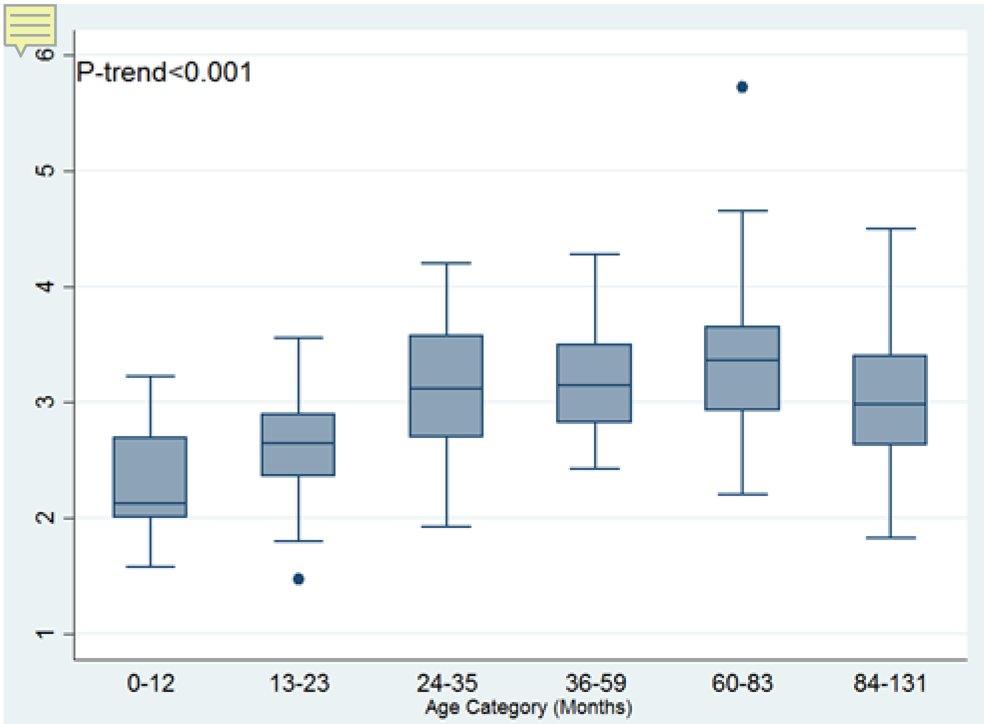

Figure 4: Scatter plot of AAI measurements in each age category demonstrating the upward trend with age

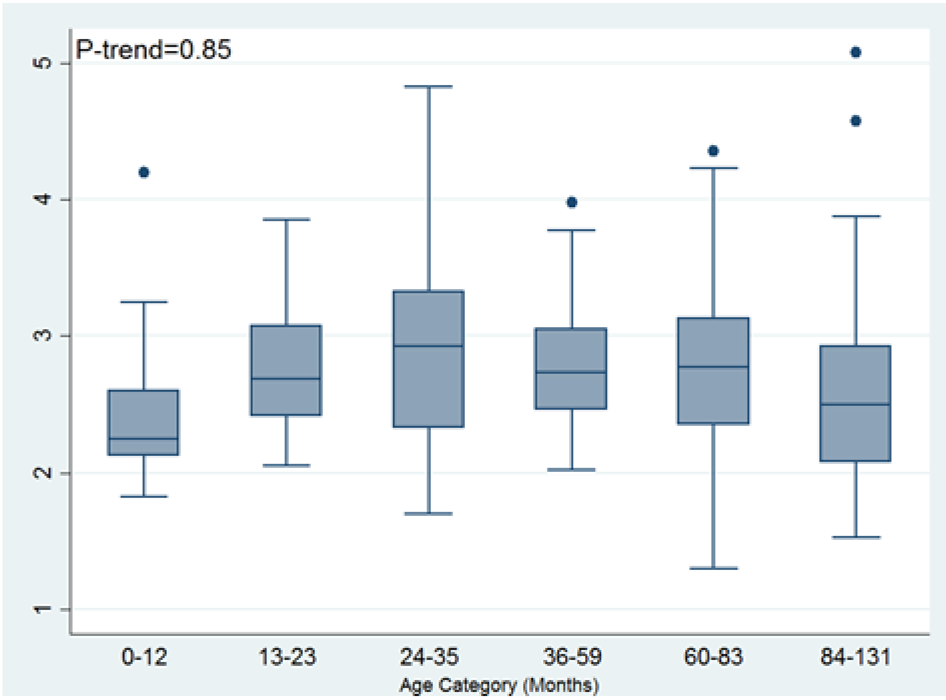

Figure 5: Scatter plot of AOI measurements in each age category demonstrating no change with age

Table 2: Comparison of the mean LADI, AAI, AOI, and ΔLADI values between nontrauma and trauma patients

	Group I Mean (mm) [95% CI]	**Group II Mean (mm) [95% CI]**	**P-value**
	(n=200)	(n=29)	
LADI	5.3 [5.2, 5.5]	4.6 [4.3, 5.0]	**<0.001**
AAI	3.0 [2.9, 3.1]	3.3 [3.0, 3.6]	0.18
AOI	2.7 [2.6, 2.8]	2.5 [2.3, 2.7]	0.067
Δ LADI	1.1 [0.94, 1.22]	1.5 [1.0, 2.0]	0.075

The Wilcoxon Rank Sum was used to compare between groups.

Table 3: Sensitivity, Specificity, PPV, NPV, and Odds Ratio of LADI, AAI, AOI, and ΔLADI for Predicting Occult Cervical Injury in Pediatric Trauma Patients Using Group I Mean Values and upper limit of 95% CI as the Cutoff and MRI evidence as the Gold Standard

	Mean (mm)	**Sensitivity (%)**	**Specificity (%)**	**PPV (%)**	**NPV (%)**	**Odds Ratio [95% CI]**	**P-value**
LADI	>5.3	23.1	87.5	60	58.3	2.1 [0.3, 14.9]	0.45
	>5.5	23.1	93.8	75.0	60.0	4.5 [0.4, 49.6]	0.21
AAI	>3.0	69.2	50	52.9	66.7	2.3 [0.5, 10.4]	0.30
	>3.1	61.5	62.5	57.1	66.7	2.7 [0.6, 12.0]	0.20
AOI	>2.7	53.8	93.8	87.5	71.4	17.5 [1.8, 174.4]	0.015
	>2,8	38.5	93.8	83.3	65.2	9.4 [0.9, 94.7]	0.058
ΔLADI	>1.1	69.2	62.5	60.0	71.4	3.8 [0.79, 17.7]	0.095
	>1.22	69.2	62.5	60.0	71.4	3.8 [0.79, 17.7]	0.095

Diagnostic Characteristics calculated using the Receiver Operating Characteristic Analysis. Odds Ratios and 95% CI calculated using univariate logistic regression.

Table 4: Two Rater Intraclass Correlation Coefficient Representing Interobserver Reliability

	Right Coronal	Left Coronal	Right Axial	Left Axial	Right sagittal	Left sagittal
LADI	0.94 [0.85, 0.98]	0.89 [0.73, 0.97]	0.90 [0.77, 0.97]	0.86 [0.70, 0.95]	N/A	N/A
AAI	0.02 [-0.15, 0.37]	0.66 [0.39, 0.87]	N/A	N/A	0.75 [0.48, 0.93]	0.79 [0.53, 0.94]
AOI	0.48 [0.17, 0.78]	0.34 [0.08, 0.68]	N/A	N/A	0.55 [0.25, 0.82]	0.28 [0.04, 0.63]

Discussion

Calculated normal parameters

The normal LADI values are shown in Table 1. The overall normal LADI 95% CI is 5.2-5.5 mm, but Figure 3 demonstrates that joint space measurements increase with age until 36 months after which they slightly decrease with the overall trend being a joint space narrowing of ADI with age. This can be explained by varying levels of ossification and normal bone maturation.[9]

The normal AAI values are tabulated in Tables 1 and 2, which are different from the values found in literature. Vachhrajani et al., who only took one averaged measurement at the center of the joint similarly to our study, found a 95% CI of 0.7-2.6 mm for AAI that minimally decreased with age. [21] Whereas, our study determined the AAI 95% CI to be 2.9-3.1 mm and an upward trend with age until age 36 months, after which they remain relatively stable (Figure 4). The AAI widening from birth to 36 months is most likely due to varying levels of ossification, and the AAI stability thereafter can be explained by normal bone maturation with age.[21]

The normal overall value for AOI 95% CI was calculated to be 2.6-2.8 mm (Table 1). Figure 5 demonstrates an upward trend through 36 months, again most likely demonstrating varying degrees of ossification and then a slight downward trend thereafter explained by normal bone maturation with age. Smith, P., et al similarly demonstrated that this interval peaks at ages 2-4 with their study yielding a peak of 2.4 mm in the coronal plane and 2.6 mm in the sagittal plane with a gradual decline with age through adolescence. [22]

Data also highlights a normal ΔLADI 95% CI to be 0.94-1.22 mm (Table 2). This parameter was not stratified with age because it was just assessing the absolute difference between the two sides in the same patient. The asymmetry is secondary to head tilt during exam and lack of a cervical spine collar to center the spine, which can lead to pseudo-asymmetry on coronal plane as slices are obtained through a slightly anterior lateral mass which would appear closer to the dens process than the contralateral side.[6]

Interobserver reliability

Most of the data was collected by one primary rater; however, to evaluate the reliability of measurements, 10 patients were chosen at random for each joint space and ICC was calculated. All LADI measurements and the right and left sagittal AAI measurements had an ICC were greater than 0.70 indicating good reliability between reviewers. The left coronal AAI and right sagittal AOI measurements had an ICC between 0.50 and 0.70 indicating moderate reliability between reviewers. The rest of the measurements had an ICC less than 0.50 indicating poor reliability between reviewers (Table 4). When measuring in such miniscule spaces, human subjectivity in measurements can result in significant variability as evidenced by some of the measurements having poor reliability.

Comparing normal parameters in trauma population

Since 2012, our team has routinely utilized MRI for evaluation of cervical spine after trauma. However, this poses a challenge in the overall healthcare movement towards value care. MRIs are expensive and many children require general anesthesia to endure the procedure, which carries its own set of complications. Our goal is to identify the high risk patients who would benefit the most from an MRI in order to lower the overall healthcare cost.

There was a statistically significant difference between the Group I overall mean LADI of 5.3 mm and the Group II overall mean LADI of 4.6 mm with a p-value of <0.001 (Table 2). The values for AAI, AOI, and ΔLADI demonstrated no statistically significant difference between the two groups. The lack of difference for most of the parameters between Groups I and II demonstrates that it is not necessary to perform MRI on all trauma patients. Simply having a trauma does not signify cervical spine or spinal cord injury; therefore, to assess the need for MRI in these patients, certain threshold values for normal cervical spine measurements on CT should be utilized.

In Table 3, different threshold values for normal were used to predict cervical spinal cord injury within the trauma group with MRI used as the gold standard. When the overall mean for LADI of 5.3 mm and AAI of 3.0 mm were used as cut-offs for detecting high risk patients in the trauma group, there was an odds ratio of 2.1 and 2.3 respectively, indicating that any patient with an LADI greater than 5.3 mm and an AAI greater than 3.0 mm was 2.1 and 2.3 times more likely to have evidence of cervical spine or spinal cord injury on MRI. However, note that the results were not statistically significant due to small sample size (n =29). Therefore, further studies need be conducted to evaluate the reliability of these normal cutoff values. On the contrary, using the mean AOI value of greater than 2.7 mm as a threshold has a 93.8% specificity, a PPV of 87.5%, and an odds ratio of 17.5 (p-value 0.015) for predicting spinal cord injury in those with trauma. Based on our data, AOI is the most reliable and specific parameter for detection of cervical spine or spinal cord injury on MRI. This finding is consistent with the higher biomechanical fulcrum between C2 and C3 found in the pediatric population.[9]

As mentioned previously, some asymmetry between right and left LADI is normal; however, excessive distortion can point to a transverse ligament injury amongst other occult injuries. If the ΔLADI is greater than 1.1 mm, then the odds ratio is 3.8 (p= 0.09), indicating that a patient with an ΔLADI of greater than 1.1 mm is 3.8 times more likely to have evidence of cervical spine or spinal cord injury on MRI. In this study, this exaggerated asymmetry pointed to injuries such as atlanto-occipital dislocation and occult fractures particularly to the dens process.

Limitations

One of the biggest limitations in this study was the small sample size for the trauma group. This is partly due to a lack of consistent protocol to assess post-trauma pediatric population for cervical spine injury clearance. Innumerable patients did not meet the inclusion criteria for this study because they either underwent MRI or CT only regardless of the inciting event. Additionally, poor image resolution and/or quality due to artifact or movement greatly affected proper visualization of cortical edges, and hence affected exact cortex-to-cortex measurements. Lastly, when measuring such a minuscule joint space, human subjectivity and judgment regarding exact placement of cursor leads to significant variability in measurements as illustrated by ICC values.

Future Directions

In future studies, the age of the population included in the study could be increased to beyond age 10. This would specifically yield more information on how the different parameters change with age. In addition, with a larger trauma group, the values for each parameter could be stratified with age as was done with the normal group. This would allow for a more appropriate comparison between normal and trauma patients as there is known variability with age for each of these parameters. Furthermore, a trauma group with a larger sample size could be separated into trauma with no evidence of spinal cord injury on MRI and trauma with confirmed spinal cord injury on MRI. With these two groups separated, the LADI, AAI, AOI, and ΔLADI could be compared between trauma not resulting in spinal cord injury and trauma not resulting in spinal cord injury. This information could provide a decisive threshold value in one or more of the parameters with which to determine which trauma patients require further evaluation with an MRI.

Conclusion

In order to decrease health care costs and move to more value based medicine, this study established normal values for LADI, AAI, AOI, and ΔLADI on CT and threshold values with which to predict occult cervical spine and spinal cord injury in pediatric trauma patients. Using a threshold value of AOI greater than 2.7 yielded a statistically significant odds ratio of 17.5 for predicting occult cervical spine and spinal cord injury.

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