Original Article

Impact of imaging modality, age, and gender on craniocervical junction angles in adults without structural pathology

ABSTRACT

Context: Multiple angles of the craniocervical junction (CCJ) are associated with pathological conditions and surgical outcomes, including the clivo-axial angle (CXA), clival slope (CS), and sagittal axis (XS). However, there are varying normative ranges reported and a paucity of data analyzing the effects of imaging modality, age, and gender on these angles.

Setting and Design: A retrospective review of computed tomographic (CT) and magnetic resonance imaging (MRI) scans in fifty adults without CCJ pathology from 2014 to 2019.

Methods: Age, gender, indication, and hours between scans were recorded. Two-blinded observers measured all angles. Analysis between angles from the same patient was performed using the Wilcoxon signed-rank test. Multivariable linear regression was used to test for associations between average angles and age or gender.

Results: Average age and time between scans were 41.3 and 14.3 h, respectively, with 94% performed due to trauma. On CT, average CXA, CS, and XS were 162.1°, 118.4° , and 81.3° , respectively. On MRI, they were 159.8 °, 117.2° , 85.3 °, respectively. There were statistically significant differences between CXA and XS ($P < 0.01$) based on imaging modality. On CT, there was a significant increase in XS by 1.93° and decrease in CS by 1.88 ° and on MRI, there was a significant increase in CXA by 1.93° and decrease in CS by 2.75° corresponding with a 10-year advancement of age. Gender did not have an effect.

Conclusion: There are significant differences in angular measurements of the CCJ between CT and MRI from the same patient, as well as changes in normative values based on age.

Keywords: Clival canal angle, clivo-axial angle, craniocervical, craniovertebral

INTRODUCTION

The craniocervical junction (CCJ) represents a critical anatomic region harboring important neurovascular structures as they traverse the foramen magnum and other skull base foramina. Instability of the CCJ can occur due to multiple etiologies, including congenital anomalies, trauma, degenerative disease, inflammatory processes, infection, and neoplasm. Patients with these conditions may present with occipital neuralgia, cranial neuropathies, myelopathy, and sensorimotor deficits. Defining CCJ pathology through various radiographic parameters has been extensively described in the literature.[1-6] However, interpretation of these parameters is dependent on normative data in healthy

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individuals, which vary widely in terms of imaging modality used and patient demographics in their respective studies.[7-10] Furthermore, in patients who require surgical intervention to address pathology at the CCJ, there are few studies defining what degree of correction of various measurements is required to achieve acceptable clinical outcomes.[11-13]

Among the most frequently used landmarks to define the anatomic structure of the CCJ are the clivus and C2 vertebrae. Angular measurements relative to these structures are influenced by bony orientation, integrity of various ligaments, and paraspinal musculature. In particular, the clivo-axial angle (CXA), also referred to as the clivus-canal or clival-canal angle, has been shown to correlate with clinical symptomatology and response to surgical intervention.[4,11,14-16] This angle is formed by the intersection of lines drawn along the slope of the clivus (Wackenheims line) and posterior spinal line of C2. The CXA can also be defined as 360° minus the sum of the clival slope (CS) and the sagittal axis (XS). The CS is defined as the angle formed by the slope of the clivus relative to a horizontal reference line. Similarly, the XS is defined as the angle formed between the posterior spinal line of C2 and the same horizontal reference line [Figure 1].

In order to better define the utility of these angles in the preoperative assessment of patients with CCJ pathology and potential goals for corrective surgeries through combinations of anterior or posterior decompression/stabilization strategies, we aimed to address the following issues. First, to determine a normative range of values of these angles in individuals with no known preexisting CCJ pathology who underwent imaging of the cervical spine confirming that they were normal. Second, to determine if there are significant differences in these angles based on the imaging modality used (computed tomographic [CT] versus magnetic resonance imaging [MRI]). Third, to determine if there are significant differences in these angles based on gender and age.

METHODS

Study design

A retrospective review of fifty adult patients that had both CT and MRI scans of the cervical spine that were interpreted as "normal" or "no acute pathology" by a board-certified neuroradiologist from 2014 to 2019 at a single institution was performed. Patients that had >5 days difference between scans, prior suboccipital or cervical spine surgery, known preexisting posterior fossa or cervical spine pathology, and those with imaging that did not include the majority of the clivus and opisthion were excluded from the study. Demographic and clinical data, including age, gender, indications for scans, and the time difference between scans (in hours), were recorded [Table 1].

Radiographic measurements

The CXA, CS, and XS were measured from each scan for each patient. Two different, trained medical professionals measured angles from which an average was obtained. Each observer was blinded to the other's results as well as all clinical and demographic information. Mid-sagittal cut of CT scans using the "bone window" and T2-weighted MRIs were used. To ensure this, we cross-referenced each cut with the corresponding axial scan and also confirmed that the cut contained the maximal height of the odontoid and diameter of the foramen magnum. Multiple straight lines were drawn first, then those used to determine specific angles. The CXA was measured by the angle determined from the intersection of a line along the slope of the clivus (Wackenheims line) and a line drawn from the posteroinferior point of the C2 vertebral body up along the odontoid (posterior spinal line). An approximate "best-fit" of the slope was used in cases where there was mild curvature to either structure.

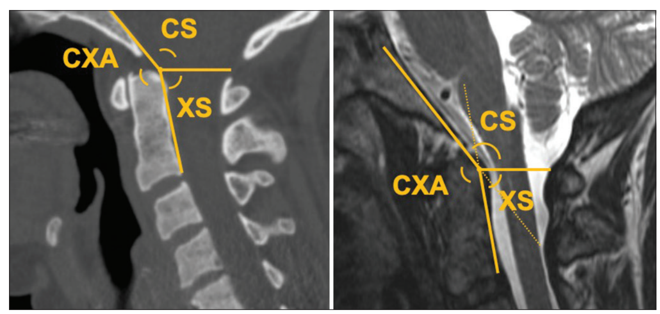

Figure 1: Clivo-axial angle angular measurements based on computed tomographic (left) and T2 magnetic resonance imaging (right). The clivo-axial angle was measured by the angle determined from the intersection of a line along the slope of the clivus (Wackenheims line) and a line drawn from the posteroinferior point of the C2 vertebral body up along the odontoid (posterior spinal line). An approximate "best-fit" of the slope was used in cases where there was curvature to either structure. The angle between the slope of the clivus and a horizontal line was the clival slope, and the angle from the posterior spinal line of C2 and the horizontal line was the sagittal axis

Table 1: Patient demographics and clinical information

Variable	*N* (% or range)
Total patients (*n*=50), *n* (%)	
Male	21 (42)
Female	29 (58)
Mean age (years)	41.3 (21-89)
Time between CT and MRI (h)	14.31 (1.1-105.2)
Indication for scans, *n* (%)	
Trauma	47 (94)
Atraumatic neck pain	2 (4)
Neurologic deficit	1 (2)

CT - Computed tomographic, MRI - Magnetic resonance imaging

A horizontal reference line was drawn from the intersection elbow of the CXA. The angle between the slope of the clivus and this line was the CS, and the angle from the posterior spinal line of C2 and the horizontal reference line was the sagittal axis (XS) [Figure 1].

Statistical analysis

Due to the small sample size and repeated measures, the Wilcoxon signed-rank test was used to evaluate if there were differences between MRI and CT values among the three angle measurements. Hypothesis tests were conducted using the average measurement of the two observers and the separate observer measurements. Multivariable linear regression was used to test for an association between the average rater CT/MRI angle measurements and age. Measurements were modeled as a function of age in years, angle (CS, CXA, and XS), and an interaction between age and angle. Multivariable linear regression was also used to test for an association between the average observer CT/MRI angle measurements and patient gender. Measurement was modeled as a function of patient gender, angle, and interaction between gender and angle. Separate models were constructed for CT and MRI measurements for both analyses.

RESULTS

Fifty patients (29 females) with an average age was 41.3 years old (21–89) met inclusion criteria. About 92% of patients had both scans within 1 day, with an average time difference between scans of 14.31 h (range 1.1–105.2 h). Forty-seven patients had scans performed in the setting of acute trauma. MRI was performed in these patients when they demonstrated persistent pain on clinical assessment. Two patients had scans performed in the setting of acute nontraumatic neck pain and radiculopathy, and one patient had scans performed in the setting of acute painless neurologic deficit of the upper extremity [Table 1].

On CT, the average CXA, CS, and XS were 162.1°, 118.4°, and 81.3°, respectively. On MRI, the average CXA, CS, and XS were 159.8°, 117.2°, 85.3°, respectively. Results were consistent across the average measurement and the observer-specific measurements. Statistically significant differences between CT and MRI measurements were observed for the CXA and XS angles ($P < 0.01$) [Table 2 and Figure 2].

In regard to age, statistically significant interactions were observed in both models (CT: $F2, 144 = 5.01$, $P < 0.01$, MRI: $F2, 144 = 8.3$, $P < 0.001$). Using multivariable linear regression, the estimated measurement difference corresponding to a 10-year increase in age for CXA, CS, XS as measured on CT was −0.05, −1.88, and 1.93, respectively [Figure 3]. On MRI, these values were 2.04, −2.75, and 0.71, respectively [Table 3 and Figure 4]. There was insufficient evidence to conclude an association exists between patient sex and CT/MRI measurement for any angle based on CT or MRI [Table 4].

Table 2: Wilcoxon signed-rank test results for difference between magnetic resonance imaging and computed tomographic measurements

Observer	Median (IQR)		*P*
	MRI	CT	
CXA			
Average	159.8 (149.5-164)	162.1 (153.5-170.3)	<0.01
Observer 1	156.6 (147.8-161.2)	160.7 (152.7-168.6)	<0.01
Observer 2	160.2 (151.3-166.3)	161.2 (154.2-171.4)	0.03
CS			
Average	117.2 (110.4-124.4)	118.4 (109-126.1)	0.91
Observer 1	119.7 (110.1-124.2)	117.3 (108.2-125.3)	0.93
Observer 2	116.8 (109.6-125.5)	119.2 (110.1-126.5)	0.98
XS			
Average	85.3 (79.5-90.6)	81.3 (74.5-86.1)	<0.01
Observer 1	87.8 (80.3-92.1)	81.2 (74.8-87.8)	<0.01
Observer 2	82.3 (75.2-89.4)	77.5 (73.4-85.1)	0.04

IQR - Interquartile range, CT - Computed tomographic, MRI - Magnetic resonance imaging, CXA - Clivo-axial angle, CS - Clival slope, XS - Sagittal axis

Table 3: Estimated change in computed tomographic/magnetic resonance imaging angle measurements with age

Angle	Measurement difference	95% CI
CT		
CXA	−0.05	−1.73-1.64
CS	−1.88	−3.56-−0.2
XS	1.93	0.24-3.61
MRI		
CXA	2.04	0.34-3.74
CS	−2.75	−4.45-−1.05
XS	0.71	−0.98-2.41

CT - Computed tomographic, MRI - Magnetic resonance imaging, CXA - Clivo-axial angle, CS - Clival slope, XS - Sagittal axis, CI - Confidence interval

Table 4: Estimated differences in female versus male computed tomographic/magnetic resonance imaging angle measurements

Angle	Difference	SE	Df*	*t*	*P*
CT					
CXA	−1.58	3.01	144	−0.53	0.60
CS	2.84	3.01	144	0.95	0.35
XS	−1.26	3.01	144	−0.42	0.67
MRI					
CXA	−2.53	3.10	144	−0.81	0.42
CS	0.85	3.10	144	0.28	0.78
XS	1.67	3.10	144	0.54	0.59

*Difference represents the estimated measurement difference for females - males. CT - Computed tomographic, MRI - Magnetic resonance imaging, CXA - Clivoaxial angle, CS - Clival slope, XS - Sagittal axis, SE - Standard error

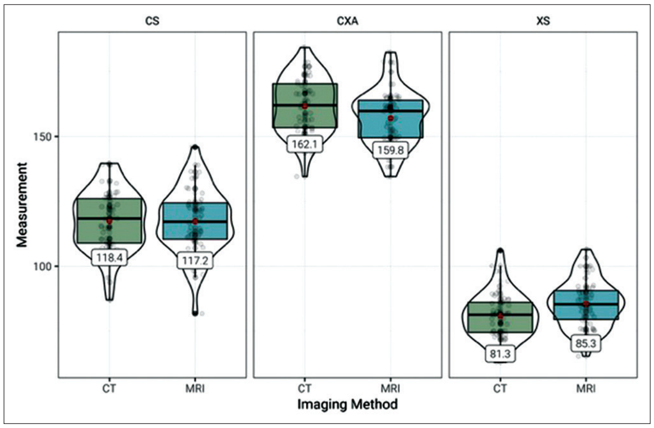

Figure 2: Boxplots of average observer magnetic resonance imaging and computed tomographic measurements by angle. Annotations correspond to median measurements

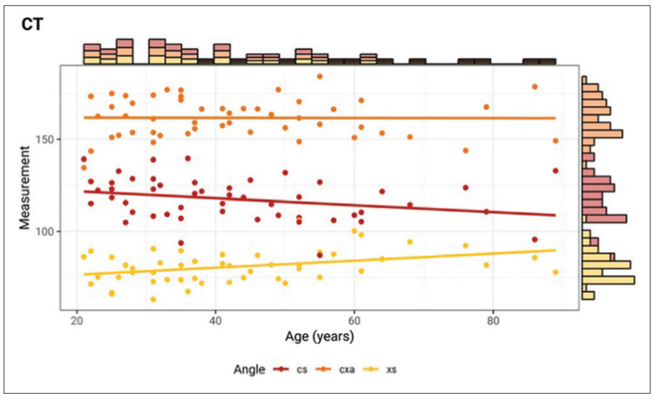

Figure 3: Scatter plot and marginal histogram of angle measurement based on computed tomographic scans

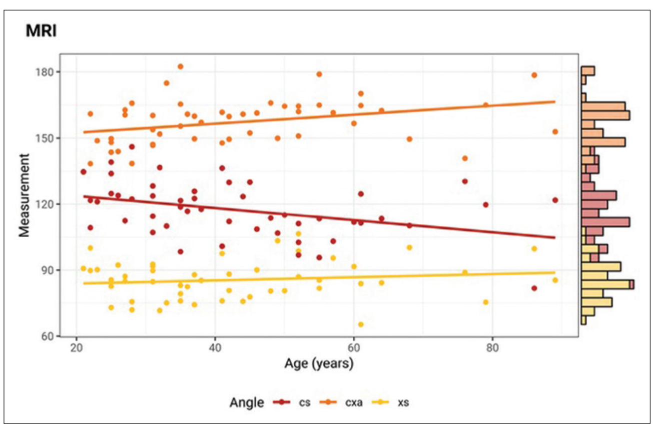

Figure 4: Scatter plot and marginal histogram of angle measurement based on magnetic resonance imaging scans

DISCUSSION

The CXA is an important parameter in patients with CCJ pathology to describe the degree of cervicomedullary junction (CMJ) compression. Patients with basilar invagination, Chiari malformation, retroflexion of the odontoid due to congenital reasons or nonhealing fractures, pannus formation in the setting of rheumatoid arthritis, or primary or metastatic tumor involvement of the odontoid may all demonstrate a low CXA. Angles typically <135°–145° result in an increasingly acute angle that causes an abrupt kinking of the CMJ, which most commonly affects ventral brainstem and spinal cord motor fiber tracts vital to swallowing, cardiopulmonary regulatory centers, and extremity motor function.[4,5,12,13] Moreover, excessive reduction in the CXA following occipitocervical fusion is associated with the development of dysphagia, dyspnea, and aspiration risk.[17]

Normative values for the CXA in neutrally-positioned healthy adults vary widely. Furthermore, this value changes based on the degree of flexion or extension the patient is placed in. Nagashima and Kubota evaluated 40 individuals (50% of men/women) with an average age of 41 years old and found a mean CXA of 158.1° as measured by X-ray, ranging from 139° to 172°. On full flexion and extension, average values were 149° and 169°, respectively.[7] Botelho *et al*. measured the CXA in 33 patients and found an of the average value of 148°, ranging from 129 to 175°.[8] Batista *et al*. evaluated 100 patients treated for non-CCJ conditions with CT, finding a mean CXA of 153.6°, ranging from 132.3° to 173°.[9] However, patient sex and age were not taken into account. Besachio *et al*. specifically looked at CXA between men and women, findings average values of 164.8° and 163.7°, respectively, with no statistically significant difference between the two groups.[10] These results based on gender were consistent with our findings.

The CS measured in our study is analogous to other angles defining the CCJ described in the literature, especially in the setting of pathology. Boogard's angle is formed by a line drawn from the dorsum sellae to the basion, and then a line drawn from the basion to the opisthion (McCrae's line), with normative values ranging between 119° and 135°.[8,18,19] Angles greater than this are consistent with basilar invagination.[2,18] However, in patients that have had prior suboccipital decompression with no native opisthion present, there is the limited utility of this angle. Welcher's basal angle is formed by a line drawn from the nasion to the tuberculum sellae, then from the tuberculum sellae to the basion along the clivus, with normative values of 124°–142°.[5,8,9,20-23] Values >145° are associated with platybasia.[2,8,20,24,25] However, many patients who have isolated imaging of the cervical spine do not capture the tuberculum sellae, leaving this angle unmeasurable. Both angles are also limited in frequent situations due to the initial lines described for each not coinciding with Wackenheims line, restricting interpretation of the true angle of the clivus. Our goal in describing the CS and sagittal axis based on a horizontal reference line aim to circumvent the limitations imposed by Boogard's and Welcher's basal angles. By defining these angles in patients without pathology, future studies evaluating the changes in these measurements in pathologic states before and after surgery will have a baseline of normative values to compare to.

To our knowledge, this is the first study of its kind comparing the CXA, CS, XS in individuals without acute pathology of the CCJ based on imaging modality, and the associations of these values relative to age and gender. Being able to understand the relationship between CT and MRI measurements of the CCJ in the same patient is of importance. In some situations, only one type of scan is available preoperatively, with only the other available postoperatively. In an era where health-care costs are being increasingly scrutinized, being able to forego additional imaging when not absolutely mandatory is critical. Furthermore, as we have found in our own practice of patients undergoing surgery for the pathology of the CCJ, patient-specific factors may dictate what is available for review preoperatively and postoperatively. Adolescents and younger adults are less likely to receive CT scans in nonurgent situations with neurological symptoms to save them from unnecessary radiation as well as to best define spinal cord anatomy and pathology. We have found that after the surgery, due to pain, discomfort, or non-MRI compatible devices (e.g., laryngeal monitoring endotracheal tube, and certain types of drain canisters), patients only receive CT scans, which must then be used to compare to preoperative MRIs to assess the extent of correction.

Overall, our results for the CXA are concordant with previously described values. Cumulatively between CT and MRI, our values ranged from 149.5° to 170.3°. Statistically significant differences between individual CCJ measurements raise a number of interesting points. First, patients undergoing CT scans of the head and cervical spine will have their neck flexed so that radiation fields are minimized to the eyes. Conversely, in MRI scans, there is no concern for radiation exposure to the eyes and cuts are made in the anatomic axial planes with the head in the neutral position. In this regard, one would expect average CT values of the CXA to be lower than MRI, which was not the case in our study, although only different by what one could consider a margin of error of about 2°. Moreover, changes in the CXA should be inversely proportional to changes in the CS given the contribution of Wackenheims line in both angles. Nonetheless, we failed to find a significant difference between CT and MRI measurements of the CS. A likely explanation for this is because 94% of our patients were scanned for trauma and likely kept in a hard cervical collar for the duration of both scans to exclude unstable cervical spine injuries. The hard collar should theoretically immobilize the neck in the neutral position; however, variability in the placement, fitting, and compliance of the collar from patient to patient may have confounded our results.

Second, statistically significant differences between MRI and CT were observed for the XS. The majority of head flexion/extension range relative to the cervical spine occurs at the C0-C1 joint.[26] The interface between the convex occipital condyles and concave articular surface of C1 allows the anterior or posterior movement to achieve extension and flexion, respectively. The contribution of subaxial straightening or increase in lordosis specifically at the CCJ is ill-defined. As the neck is extended, the posterior spinal line of C2 assumes a more vertical position relative to the horizon. Our finding of higher average XS in the MRI over CT measurements is, therefore, in agreement with this hypothesis.

Our study also demonstrates how aging can influence CCJ angles. The CXA remained relatively stable despite age on CT, however increased by about 2° with every 10-year increase in age on MRI. The CS decreased in older patients in both imaging modalities, and XS increased based on CT as patients aged. We hypothesize that the increase in CXA with decrease is clival slope and increase in XS observed is a function of the natural aging process. It has been well demonstrated that aging causes degenerative kyphosis of the thoracolumbar spine due to dehydration of intervertebral discs and decreasing strength of paraspinal extensor musculature.[27,28] Conversely, cervical lordosis increases in the aging population as a compensatory mechanism to this phenomenon in order for individuals to maintain horizontal gaze.[29,30] The discrepancies for CXA and XS as patients' age between CT and MRI in our study are less clear. Our data set is likely underpowered to detect significant differences, as only 9 (18%) of patients in our cohort were 60 years of age or older.

Limitations

There are a number of additional limitations of this study that must be acknowledged. First, the vast majority of patients presented with a traumatic injury and neck pain. A well-known consequence of neck injury is muscle spasm or stiffening. This protective mechanism may result in the straightening of the normal cervical lordosis and then confound the ability of our study to capture true craniometric values of the CCJ. Second, as mentioned previously, we did not record which patients were wearing cervical hard collars during scans, which affects the degree of head flexion/extension and thus CCJ angles. Third, the relatively small sample size may not be powered enough to detect more subtle differences between angular measures from imaging modality used. Fourth, only two observers were used to quantify angular measurements, which may influence wider variability in values obtained. Finally, MRI imaging is less sensitive in defining bony margins, which may contribute to inaccurate measurements compared with CT since all angles measures were based on bony landmarks.

CONCLUSION

There are significant differences in CCJ angles based on CT and MRI scans of the same patient performed within hours of each other. These angles are also influenced in varying ways based on age, whereas gender did not have any effect. These findings suggest that the same imaging modality should be used preoperatively and postoperatively when possible to evaluate the degree of correction from surgical interventions, and that normative values relative to specific age groups should be considered. Future studies with larger populations, asymptomatic adults, and increased number of observers for obtaining measurements are required to further elucidate relationships of CCJ angles with imaging modality, age, and gender.

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Conflicts of interest

There are no conflicts of interest.

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