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EVALUATING CHAMBERLAIN'S, McGREGOR'S, AND McRAE'S SKULL-BASE LINES USING MULTI DETECTOR COMPUTERISED TOMOGRAPHY
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ABSTRACT

***Background*: Traditionally the cranio-cervical junction is assessed by lateral cervical spine and base of skull radiographs which however have diagnostic challenges due to the complexity of the anatomy. Modern day Computed Tomography (CT) offers excellent bony detail and its ability to reconstruct the acquired CT data into various imaging planes makes the assessment of the cranio-cervical junction easy and more accurate.**

***Objective*: To evaluate the relationship of the odontoid peg of C2 to the standard skull base lines of Chamberlain's, McGregor's and McRae's on computed tomography.**

***Design*: Descriptive cross-sectional study**

***Setting*: Kenyatta National Hospital, Nairobi, between April and September 2010.**

***Results*: The mean position of the odontoid process was 2.6 mm below Chamberlain's line (median 2.7 mm, SD 2.2 mm), 1.0mm (median 0.9 mm, SD 2.1 mm) below McGregor's line and 4.7 mm (median 4.6 mm, SD 1.3 mm) below McRae's line. There was no statistically significant difference in measurements between male and female patients, the different age groups and between CT and standard plain radiograph measurements ($p > 0.05$).**

***Conclusion*: Anthropometric measurements obtained using CT were lower than those from plain radiographs. There was however no statistical significant difference between the two imaging modalities. CT demonstrated far much superior anatomical detail compared to plain radiographs.**

INTRODUCTION

Anatomical evaluation of the cranio-cervical junction has improved significantly since the advent of multiplanar computerised tomography (CT). The capability to reconstruct transverse cuts into axial, sagittal, coronal, and oblique reformats has enhanced ability to assess cranio-cervical junction deformities. CT imaging also allows accurate measurements of classical lines and angles, transverse and AP diameters of the foramen magnum and spinal canal.

The standard parameters of Chamberlain's, McGregor's and McRae's lines are used in evaluation of the cranio-cervical junction. They help to illustrate the degree of deformity in patients with basilar impression and aid in surgical decisions with regard to decompression, fixation and stabilisation. These measurements are also used as guides in the conservative follow up of patients or those who are surgically managed (1,2).

Skull base lines of Chamberlain's, Mc Gregor's, and Mc Rae's have been used to asses for basilar impression since the 1940s on plain radiographs (2,3). It is because of magnification and limitations in the accuracy of measurements on plain radiographs that these measurements are significantly most often unreliable. Lack of certainty in the identification of the osseous landmarks and patient positioning on plain radiographs are other limiting factors (6).

Measurements done on newer imaging modalities like CT and MRI have been shown to be more reliable and reproducible (2-6). This is crucial for evaluation of basilar invagination and impression, conditions which if missed can lead to brainstem compression and risk of sudden death. CT exquisitely depicts this anatomy and enhances measurement of the odontoid peg above these lines. It is also acceptable that many conditions causing basilar invagination like

rheumatoid arthritis, osteogenesis imperfect, Paget's disease are now routinely evaluated on CT. This is important for treatment planning and subsequent follow up. It is thus important to know the actual normal measurements for our population.

This study evaluated the relationship of the odontoid tip to skull baselines of Chamberlain's, McGregor's and Mc Rae's using CT bone windows in 392 patients.

The Chamberlain line is drawn from the posterior pole of the hard palate to the opisthion (the posterior margin of foramen magnum). In normal cases the odontoid process should not project more than 5 mm above this line.

McGregor's line is drawn from the posterior pole of the hard palate to the lowest point on the midline occipital curve. Usually the tip of the odontoid process should not project more than 4.5 millimetres above this line.

McRae's line is the line drawn from the anterior border (basion) to the posterior border (opisthion) of foramen magnum. The odontoid process should not project above this line.

MATERIALS AND METHODS

A descriptive cross-sectional study was undertaken in the X ray department of Kenyatta National Hospital from April to September 2010. This included patients aged 15 years and above undergoing head CT scans that satisfied the inclusion criteria. Patients' consent was obtained before clinical summary was entered into the data collection form.

CT head images were taken using a 16 slice Multidetector CT scanner, Brilliance Model, Serial No.729, manufactured by Phillips in January 2007. Patients were positioned supine with the orbitalmeatal line perpendicular to the horizontal axis of the table. The head was placed in a cephalstat and secured with forehead band to minimise motion and rotational movements. Three to four millimetres slice thickness non contrast axial scans of the skull base and upper part of the cervical vertebrae were obtained (18). Appropriate collimation was done to reduce radiation dose.

Measurements were made in accordance with the standard skull-base line definition. The skull-base line points (posterior end of the hard palate, anterior and posterior margin of the foramen magnum) were easily and accurately identified on bone windows CT. The shortest perpendicular distance from each skull-base line to the tip of the odontoid process was then measured.

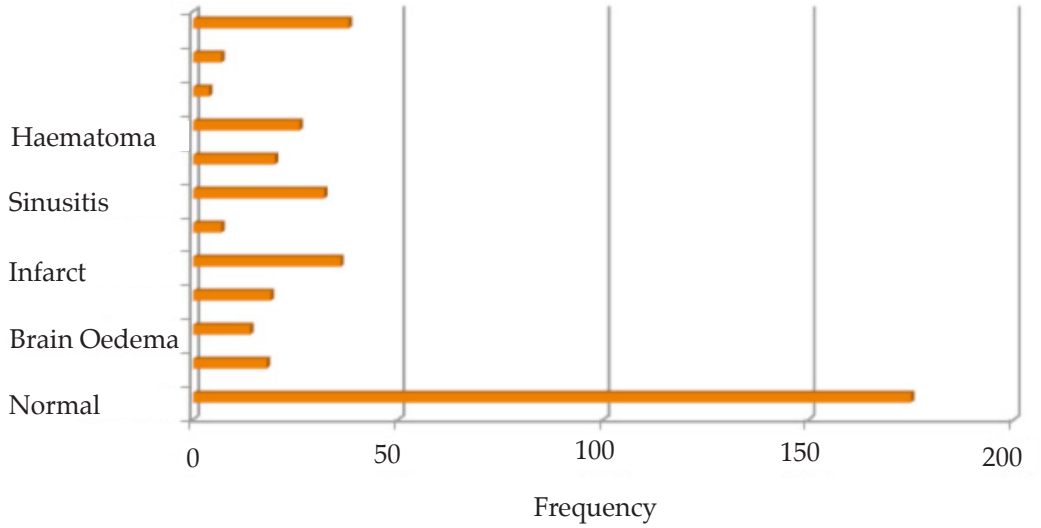
Patients with previous traumatic injury of the cranio-cervical junction, clinical symptoms and signs of basilar impression, congenital structural abnormality of the cranio-cervical junction such as Klippel-Feil syndrome, odontoid anomalies, or hypoplasia of the atlas, acquired deformity of the skull suggestive of basilar impression development, such as Paget's disease, osteomalacia, rickets, osteogenesis imperfecta, rheumatoid arthritis, neurofibromatosis, and ankylosing spondylitis; and brain tumour or metastatic lesion were excluded from the study.

RESULTS

The mean age of the study patients was 40.8 years; median was 39.0 years, the age ranged between 16 and 88 years. Majority of the patients were in the 30-39 age group (n=103, 26.3%) followed by the 40-49 age group (n= 85, 21.7%). There were 17(4.3%) patients who were below 20 years. Fifty four (13.8%) of the patients were above 60 years of age.

Slightly more than half of the patients were males (n=222) representing 56.6%. The rest were females (n=170) representing 43.4% of the sample. Female patients were relatively younger compared to the male patients in all the age groups. Simple head trauma was the most common clinical presentation followed by chronic headache. The most common radiological diagnosis was that of normal CT examination of the head.

Figure 1
Distribution of radiological diagnoses



Chamberlain's line was found to be, on average, 2.7 millimetres in men and 2.5 millimetres in women above the tip of the odontoid process. McGregor's line was, on average, 0.9 millimetres in women and 1.1 millimetres in men above the tip of the odontoid process. The tip of the odontoid process was 4.6 millimetres in women and 4.8 millimetres in men below Mc Rae's line. Using independent Student's t-test no significant difference was found between the male and female odontoid processes to skull-base line CT measurements for any of the skull base lines. (Tables 1 and 2).

Table 1
Compares distance from odontoid tip to skull base lines of Chamberlains, Mc Gregor's and Mc Rae's on CT and Plain radiograph.

	CT	Plain Radiograph
Chamberlain's(mm)	2.6	0.94
SD	2.2	3.6
Range		
Minimum(tip above the line)	4.8	< 5
Maximum(tip below the line)	8.9	
Mc Gregor's(mm)	1.0	0.8
SD	2.1	2.4
Range		
Minimum(tip above the line)	5.5	< 4.5
Maximum(tip below the line)		
Mc Rae's(mm)	4.7	5
SD	1.3	1.8
Range		
Minimum(tip above the line)	1.0	Tip never above the lines
Maximum(tip below the line)		

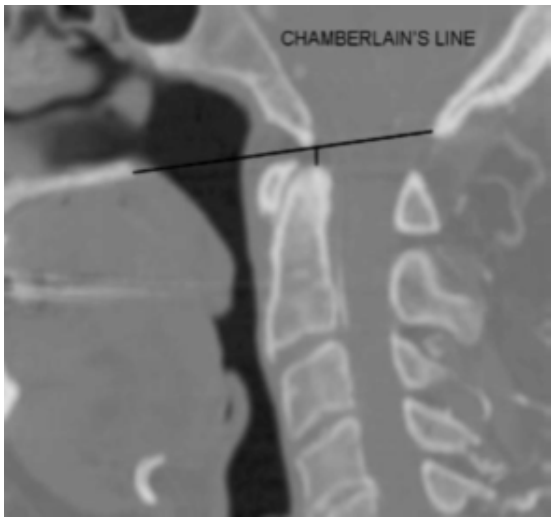
Table 2
Mean distance (mm) from the odontoid tip to Chamberlain's, Mc Gregor's, and Mc Rae's lines

	Distance from odontoid tip		
	Chamberlain	McGregor's	McRae's
Mean	2.6	1.0	4.7
Median	2.7	0.9	4.6
Std. Deviation	2.2	2.1	1.3
Range	13.7	12.5	8.0
Minimum	-4.8	-5.5	1.0
Maximum	8.9	7.0	9.0

* -4.8 and -5.5mm means that the tip of the odontoid was above the lines of Chamberlain's, Mc Gregor's and Mc Rae's.

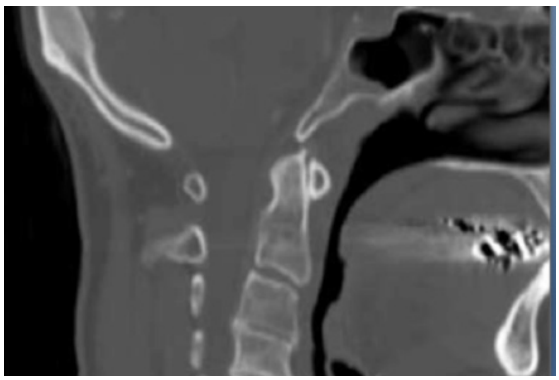
Representative images A to E below:

A



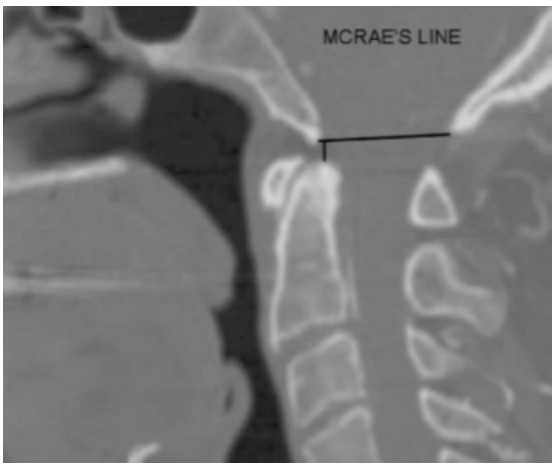
Method and measurement of Chamberlain's line on sagittal CT brain image.

B



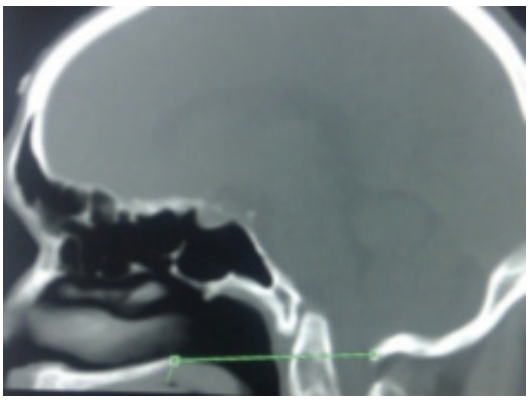
Method and measurement of McGregor's line on sagittal CT brain image.

C



Method and measurement of McRae's line on sagittal CT brain image.

D



The tip of odontoid process above the Chamberlain's line in asymptomatic elderly patient.
*Note generalised bone osteopaenia and deformed opisthion.

DISCUSSION

The study findings showed that the mean (sample) distance from the odontoid tip to Chamberlain's line was 2.6 millimetres with a standard deviation of ±2.2 millimetres and Mc Gregor's line was 1.0 millimetres with a standard deviation of ± 2.1mm) while the mean distance to Mc Rae's line was 4.7mm with a standard deviation of ±1.3 millimetres. These findings concur with those from a study done by Cronin *et al* in Ireland who evaluated the relationship of the odontoid tip to the skull baselines in 150 asymptomatic Caucasian adults (4). In this study Cronin demonstrated that the mean distance from the odontoid tip to Chamberlain's line was 1.4 millimetres with a standard deviation of ±2.4 millimetres, 0.8 millimetres with a standard deviation of ±2.4 millimetres to Mc Gregor's line and then finally to Mc Rae's line the distance was five with a standard deviation of ±1.8 millimetres. The minor differences observed between the two studies could be due to use of different models and generation of CT equipment, differences in physical characteristic of participants and possible variation in study methods used (2).

Evaluating variations between sexes, the findings from this descriptive study and associated literature review provided some useful insights regarding the differences in the relationship of the odontoid tip and skull baselines. The study findings revealed that in males the mean distance from the odontoid tip to Chamberlain's line was 2.7 millimetres (SD2.2 millimetres), to Mc Gregor's 1.1 millimetres (SD 2.1 millimetres) and Mc Rae's 4.8 millimetres (SD 1.3 millimetres). In female patients the mean distance from the odontoid tip to Chamberlain's line was 2.5 millimetres, to Mc Gregor's 0.9 millimetres and Mc Rae's line was 4.6 millimetres. Using student's t-test there was no significant difference in the distances demonstrated between the two sexes. There were cases in both sexes where the tip of the odontoid was above the lines of Chamberlain's and Mc Gregor's but with no clinical symptoms. This was mostly observed in elderly patients. The maximum asymptomatic distance at which the tip of the odontoid process was above both Chamberlain's and Mc Gregor's lines was approximately 5.4 millimetres in males and 5.5 millimetres in females. The odontoid tip was never above the Mc Rae's line. This finding has also been documented on plain radiograph studies in which there were asymptomatic elderly patients whose tip of the odontoid process was less than five millimetres above the Chamberlain's line and less than four point five millimetres above Mc Gregor's line. Cronin *et al* in their study of 2009 also showed that there was no significant difference between male and female adult Caucasians (1).

The influence of advancing age on the distance from the tip of odontoid to Chamberlain's, Mc Gregor's and Mc Rae's lines was specifically evaluated in this study. The findings of the study demonstrated that there was a decrease in the distance from the tip of the odontoid process to skull base lines of Chamberlain's, Mc Gregor's and Mc Rae's with advancing age and in some cases the odontoid tip was above the skull baselines with no clinical symptoms. A possible explanation to these findings is that with age, bone and adjacent soft tissue undergo involution. Bone demineralisation (osteomalacia) due to age predisposes to bone deformities. Associated ligament laxity may lead to joint sublaxation resulting into upward migration of the odontoid tip. Though there was a notable difference in the distance from the odontoid tip to skull baselines with age in our current study, statistical correlation of the findings demonstrated no significant difference (p-value > 0.05)

Conventional radiographs are commonly used as first line imaging modality by most orthopaedic surgeons to assess bone pathology (7). Low radiation dose, low cost and the easy availability of plain radiographs favours its use compared to newer imaging modalities like MRI and CT. Use of radiographs has however been shown to be less accurate when it comes to assessing subtle bony changes or in evaluating complex anatomical parts unlike cross section imaging (1,4). This was also demonstrated in our study where comparison between skull base measurements obtained using CT to those acquired using conventional plain radiographs was done. It was noted that on plain radiograph the distances from the odontoid tip to skull baselines of Chamberlain's, Mc Gregor's and Mc Rae's as documented in literature are 0.94 millimetres with a standard deviation of ±3.6, 0.8 millimetres with standard deviation of ±2.4, and five millimetres with standard deviation of ±1.8 millimetres respectively. The mean measurements on CT were somewhat higher especially in relation to Chamberlain's and McGregor's unlike McRae's which were lower than those documented on conventional radiographs. In CT bone window the clear separation of bone from adjacent soft tissues and the capabilities to easily obtain a mid sagittal reconstructed image resulted in more accurate measurements. The difference observed between the two imaging modalities was however of no statistical significance. These findings are in keeping with the results obtained by Cronin *et al* in adult Caucasians (1). Excellent bony detail present on CT and advanced measuring techniques were thought to account for the small difference in measurements seen.

In conclusion, the results of our study has demonstrated that, measurements of the normal relationship of the odontoid tip to standard skull base

lines using a CT scan were higher and more accurate in comparison to those measurements obtained by conventional plain radiograph. Statistically the difference in measurements observed was not significant.

The distances of the odontoid tip to the skull baselines of Chamberlain's, Mc Gregor's and Mc Rae's were noted to be higher in males than females. The difference seen was however not statistically significant.

The study revealed that the distance of the odontoid tip to standard skull base lines was reducing with age. Resorptive bone changes of the elderly and laxity of ligaments supporting the odontoid process were possible explanations. The difference observed was not statistically significant. Bony landmarks were clearly identified and the measuring techniques were easily demonstrated in this study using multiplanar CT.

RECOMMENDATIONS

On multiplanar CT a radiologist / orthopedist is able to precisely identify bony land marks. The capabilities to reformat the images in multiple planes makes linear and angular measurements to be easily and accurately obtained. CT measurements are highly reproducible as compared to plain radiograph measurements. Post surgical follow up images are accurately assessed on CT than plain radiographs. It is therefore recommended that multiplanar CT be the imaging modality of choice when assessing the cranio-cervical junction. Conventional plain radiographs should continue to be used in assessing gross bony abnormalities or as first line imaging modality. A study to direct correlate CT and plain radiograph measurements of the same patient should be done in future. This will be a more objective and accurate comparison.

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