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Research Paper

Sexual dimorphism of foramen magnum using Cone Beam Computed Tomography

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ABSTRACT

Objectives: The aim of this study was to evaluate whether the foramen magnum (FM) dimensions could be used for sex determination using the Cone Beam Computed Tomography (CBCT).
Methods: Two hundred and sixty six CBCT full Field Of View (FOV) scans (111 males and 115 female subjects) of the skull were retrospectively selected and the FM length, width measured on reconstructed axial cross section by two observers using the CS 3D imaging software at a slice thickness of 300 μm and the FM area subsequently calculated using two established formulae by Routal and Teixeira. All data were subjected to descriptive and discriminant functional analysis to validate the expression of sexual dimorphism in the metric parameters of FM.
Results: Using the FM dimensions the overall accuracy rate of sex determination was 66.4%. Out of these, 70.3% of males and 62.6% of females were sexed correctly. The best parameter for sex determination was the Area of the FM. In addition, the accuracy rate of sex prediction using the Area dimensions (Teixeira's formula) was 66.4%, same as that of all the four FM parameters used together.
Conclusion: This study validates that there is statistically significant expression of sexual differences in the foramen magnum region, which may prove useful and reliable in predicting sex in partial skull remains by discriminant function analysis when other methods tend to be inconclusive. It suggests the reliability, usability and accuracy of CBCT in forensic identification.

1. Introduction

Establishing the positive identity of an individual is one of the principal objectives of forensic science. This procedure is further complicated in mutilated cadavers in high velocity crashes, fires, explosions or decomposed skeletonized remains. One of the principal biological indicators of identity is the sex of the individual.[1] Thus sex determination plays a crucial role in the identification of human remains as it narrows the possibility for identification by 50%.[2] The most reliable sexually dimorphic bones of the human skeleton are the innominate bones. Depending on the completeness of the specimen, sex can also be determined from the skull, long bone dimensions, discrete features, general size criteria, and several discriminant function tests that compare bone dimensions to their means within databases populated by individuals of known sex.[3] As fragmentary, dispersed and commingled remains make sex determination more challenging and difficult; every part of the human skeleton should be analysed, evaluated and documented to determine its value for identification purposes. Due to the thickness of the cranial base and its relatively protected anatomical position, this area of the skull tends to withstand both physical insults and inhumation somewhat more successfully than many other areas of the cranium.[4]

The Foramen Magnum (FM) is an important landmark of the skull base and is of particular interest in anthropology, anatomy, forensic medicine and other medical fields.[5] The traditional methods of recording measurements of the cranial base include the use of spreading callipers and calibrated paper strips.[6] Radiography can also assist in giving accurate dimensions for which certain formulae can be applied to determine sex.[7]

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In a study on an Iraqi population, Uthman et al.[5] studied the foramen magnum of 88 patients using helical Computed Tomography (CT) where the foramen magnum sagittal diameter, transverse diameter, area and circumference were measured and data were subjected to discriminant analysis for sex using multiple regression analysis which concluded that the circumference and area were the best discriminant parameters that could be used to study sexual dimorphism with an overall accuracy of 67% and 69.3%, respectively. Catalina-Herrera indicated that the sagittal and transverse dimensions of the FM were significantly higher in Spanish human male than in human female skulls.[8]

Cone beam computed tomography (CBCT) is a relatively recently-developed technology that is currently used primarily in a variety of maxillofacial applications such as implantology, oral and maxillofacial surgeries, temporomandibular joint assessment, endodontics, orthodontics, periodontics, sinus imaging, temporal bone/lateral skull and skull base studies and forensics.[9] In some forensic contexts, CBCT offers several advantages for postmortem forensic imaging including good resolution for skeletal imaging, relatively low cost, portability, metal artifact reduction and simplicity.[10] Unlimited virtual dissections of the specimen without incurring any further physical damage are possible through the multiplanar sectioning of the reconstructed data set. Also a single scan of the specimen can later be compared to any possible variety of submitted pre mortem plain film images.[3] CBCT has its use in both pre mortem and postmortem forensic applications and has been earlier used in person identification,[11] age estimation,[12,13] sex determination,[14,15] 3D reconstruction[16] and bite-mark analysis.[17] To date only one study has explored the use of measurements of the foramen magnum to determine sex from CBCT scans.[18] Thus there is limited literature to validate the full potential of CBCT to be used as an alternative to CT in the field of forensics.

This study was therefore undertaken to potentiate the further use of CBCT imaging technology in forensics, as well as to further validate the usefulness of foramen magnum in forensic sex determination. This study also assessed whether sexual dimorphism of the metric measurements of foramen magnum could be determined using the CBCT imaging modality.

2. Methods

A total of 280 CBCT full Field Of View (FOV) scans of the skull were retrospectively retrieved from the database of the Oral Radiology unit of a Nair Hospital Dental College, Mumbai located in western part of India for a period of September 2014 to July 2015. Only high quality reconstructed images were selected and all low quality images with blurring or artifacts caused by metallic objects were excluded. Scans that were not covering the entire extent of the foramen magnum were excluded. Also, scans of subjects with history of trauma, surgery or any other pathological lesion (congenital/acquired) in the region of skull base were excluded. After initial screening for adaptability to the inclusion and exclusion criteria, 266 CBCT scans with 111 males and 115 female subjects with an age range of 18–70 years were selected. All the scans belonged to the western Indian population. The scans were made using a Kodak 9000 C 3D unit (Carestream Health Inc., 150 Veronal Street, Rochester, NY 14608, USA), with variable field of view, voxel size – 76.5 × 76.5 × 76.5 μm, x-ray pulse time of 30 ms, kVp – 60–90 kV (max), mA – 2 to 15 Ma, exposure time of 10.8 s. Images were reconstructed using a high spatial frequency reconstruction algorithm.

Two independent observers (both experienced radiologists) blind to the details of age and sex of the subjects, used the Digital Image Communication in Medicine (DICOM) compatible CS 3 D Imaging software (version 3.2.9, copyright Carestream Health Inc.) to independently analyze the reconstructed image sections. All the CBCT images obtained in the DICOM format were transferred to a separate workstation and the measurements taken in a quiet windowless room with dimmed lighting. The images were viewed on HP Envy Spectre XT Ultrabook 13–2015tu, 13.3″ diagonal HD Bright View LED-backlit Display (Hewlett Packard Company, 71004 Boeblingen, Germany) at a 1366 × 768 resolution and measurements were done in axial cross section view. Observers were allowed to use two – fold magnification and modify screen brightness as well as scroll through the axial cross section with slice thickness standardized at 300 μm. The metric parameters of the foramen magnum measured in this study were the maximum length, the maximum width and the area. The length and width of the foramen magnum were measured on the axial cross sections parallel to the plane of the foramen in order to select the best image of the foramen where the maximum distances could be measured.

- Maximum length of the foramen magnum (LFM) measured in an Anteroposterior direction along the principal axis of the foramen (Fig. 1A).
- Maximum width of the foramen magnum (WFM) measured approximately perpendicular to the LFM and recorded at the widest transverse diameter of the foramen[1] (Fig. 1B).

The measured length and width were then inserted into two different formulae to estimate the area of the foramen magnum.

- The first method used a formula proposed by Routal et al.[6]

$$\text{Area} = ¼ \times \pi \times \text{length} \times \text{width}$$

- The second method used a formula derived by Teixeira.[19]

$$\text{Area} = \pi \times [(\text{length} + \text{width})/4]^2$$

Throughout this communication, the two different formulae are referred to as Area 1 (calculated by Routal's formula) and Area 2 (calculated by Teixeira's formula).

2.1. Analysis

All data were first subjected to descriptive analysis where comparison between the male and females groups was done with the help of unpaired t – test with p – value less than 0.05 taken as significant level. Correlation was done with Pearson's Correlation coefficient with significance at the 0.01 level (2-tailed). A discriminant functional analysis was then performed to predict the sex based on the value of the measurements of the foramen magnum. The data analysis was done using the software, SPSS version 16.

3. Results

A total of 266 scans were assessed (111 males and 115 females with an age range of 18–70 years) using four metric parameters of the foramen magnum. The interexaminer reliability test (Average Measure) for all the four parameters showed no significant statistical differences ($p < 0.05$) using intra-class correlation coefficient indicating significant agreement between the two observers. In this study the overall values of the parameters were significantly greater in males as compared to the females. Table 1 shows the descriptive analysis of the parameters of the foramen magnum according to sex. Significant mean differences were observed amongst all the four parameters i.e. the length, the width, the area 1