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Review

Foramen magnum variables for forensic identification among Egyptians using computed tomographic scans: A narrative review

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Abstract

Computed tomography scan analysis via three-dimensional (3D) visualization software can portray bones correctly enough that the technique is currently used for forensic identification and virtual autopsy. Foramen magnum (FM) is the largest skull base foramen with widely used variables in the identification of the sex and stature of the human unidentified bone remains. The current study evaluated the published data for using FM variables for identification among Egyptians using computed tomographic scans. The studies showed the reliability of the variables for sexual dimorphism among Egyptians. However, age identification related data were contradictory. Also, most of the published data was considering adults' scans with limited data regarding earlier age FM variables. Further studies are recommended to study the variables among bigger sized samples from the different Egyptian provinces. Furthermore, combined studies of different skull base variables with FM variables are expected to improve the robustness and accuracy of the collected data.

Keywords

Computed Tomography, Identification, Foramen Magnum, Egyptians

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Introduction

An alternative to conventional caliper-based approaches for gathering anthropological measurements is provided by computed tomography (CT) scans. A CT scan's sequence of two-dimensional (2D) slices can be joined to create three-dimensional (3D) representations of bones that the user can modify and examine. According to Simmons-Ehrhardt et al. (2019) [1], these axes and their metric qualities can be utilized to produce 3D coordinates for landmarks of interest. These coordinates, as well as the distances and/or angles between them, can be used for a variety of morphometric research. There may be more access to osteological data because the 3D models can be saved and retrieved frequently for quantitative or visual analysis. The wide availability of archived CT data has given the opportunity for osteological analysis studies using the data of large samples of living populations [2].

When compared to manual measurements, CT-based measurement data are more accurate and reproducible, particularly when rendered in 3D [2-4]. Using 3D visualization software for the processing of CT scans can portray bones correctly enough that the technique is currently used for virtual autopsy, surgical planning, and the creation of unique surgical implants [5, 6].

In forensic and anthropological investigations of unidentified individuals, measurements of different bones are frequently used to estimate age, gender, stature, and ethnicity [7]. Research using direct measurements of the skull or CT image-based research have established that the cranium is sexually dimorphic [6, 8, 9]. A substantial mass of soft tissue covers the base of the skull, aiding in the foramen magnum's protection. Therefore, an intact foramen magnum morphometry aids in identifying a person and distinguishing their gender in situations involving severe trauma, fire, explosions, and other events. Thus, the foramen magnum's morphometry becomes crucial for human identification [10].

Foramen magnum evaluation for identification of human remains

The largest foramen in the skull is called foramen magnum (FM). It lies in the posterior cranial fossa and is positioned anteromedian. It has oval shape with anteroposterior maximum diameter and broader behind. Meninges, vertebral arteries, the spinal accessory nerve, and the lower end of the medulla oblongata are all located within it [11]. The FM can have several shapes, the most common being oval. Variations in shape are significant because they affect the critical structures that travel through them and because they are useful in different surgical techniques. Due to the possibility of compression on the essential structures passing through it, the dimensions of the FM are clinically significant [12].

Additionally, it has been noted that for condylar resection, a longer anteroposterior dimension of the FM allowed for better contralateral surgical exposure [12]. Numerous publications have focused on the FM's radiologic and anatomical values. While anatomic values obtained by many authors are almost identical, radiologic values range from one another [13]. When utilized in approximation, the morphometry and characteristics

Table 1. List of the published Egyptian studies evaluating the Significance of Foramen Magnum (FM) variables in computed tomography (CT) scans in Forensic identification.

Authors	Sample size	Aim	Outcomes
Kholeif and Radwan, 2023 [18]	120 Egyptians aged from 1 year to 65 years.	To determine the age from the FM variables using 3D-CT.	- FM length (FML) decrease and FM width (FMW) increase with aging. Subsequently, FM index (FMI) tends to decrease with age. - There was a weak positive correlation between age and LFM, WFM and FM area (FMA) and there was a negative correlation between age and FMI.
Kenawy and Mousa, 2022 [19]	One hundred and twenty of adult Egyptian (sixty males and sixty females).	To evaluate the role of FM variables in sexual dimorphism among Egyptians using cone beam computed tomography (CBCT).	- All the FM variables were higher in males than that in females with statistical significance difference, except for the FMI which was higher in males, but the difference didn't reach the statistical significance level. - Discriminant function analysis showed that FM length and FM area have the best sex discriminative values.
Abo El-Atta et al. 2020 [14]	367 subjects (204 females and 163 males) aged between 18-75 years	To evaluate the accuracy of FM variables and occipital condyles in determination of sex using CT.	- All the studied FM parameters showed significantly higher values among males except the left occipital condylar width. - Length of the RT occipital condyle and FM width are highly significant discriminating variables predicting sex.
Slima and Abdou 2020 [20]	300 cranial CT scans of 168 males and 132 females, aged from 18 to 65 years	To demonstrate the sexual dimorphism of the orbit and the foramen magnum (FM) in a sample of Egyptian population	- The orbital height, width and index differences between males and females were statistically significant. - Significant difference was also observed in FM transverse diameter, FM anteroposterior diameter and FM area. - Tetragonal shape of FM was the most common in both sexes of the study sample.
Lashin et al. (2019) [21]	200 adult Egyptian individuals (100 male and 100 female)	To investigate FM measurements and shape as a forensic tool for sex identification among Egyptians using CT scans	- All FM measurements except FM index were significantly higher in males compared to females. - There was no statistical correlation between FM measurements and age. - The best overall sex prediction was reported for FM circumference and area, then FM transverse and sagittal diameters.
Saleh et al. 2019 [22]	100 CT images of the skull of adults (50 males and 50 females).	To document and analyze the FM reliability in sex prediction at CT scans of adult Egyptians.	- There is significant difference between the length and breadth of FM in males and females. - There is no significant difference between different ages in FM variables after puberty.

of the FM and occipital bone are strong indications for the diagnosis of sex from both a qualitative and quantitative perspective [14, 15].

However, from a quantitative standpoint, measurements of the FM have been used to develop age estimation indices [16]. The FM reaches adult size rather early in development, in comparison to other skeletal sections, and its dimensions and contour are not affected by any musculature. The size of the FM does not vary markedly with ageing as a result of the nervous system's early maturity compared to other bodily systems. The occipital bone's portions are completely united as early as a child reaches the age of five to seven years old with expected non-significant changes in the bone size and FM dimensions in older ages [17].

Egyptian studies of foramen magnum variables for identification

Different studies have been published from Egypt discussing the application of the skull variables in computed tomography scans for personal identification and estimation of sex, age and stature using different parts of the skull. According to available data on Pubmed, Scopus, Web of Science and Google Scholars, Six Egyptian articles have been published regarding the application of FM for Forensic identification among Egyptians (Table. 1).

The maximum length (sagittal diameter) and maximum breadth (transverse diameter) of the FM were the primary characteristics measured in the reported Egyptian studies. The FM's maximum length was measured along the foramen's major axis in anteroposterior direction. While FM width was estimated based on the widest transverse diameter of the FM in a perpendicular plane to the maximum length. For measurements of data robustness, measurements of length and width were taken on at least three consecutive axial cross section views that were parallel to the foramen's plane. Then, using mathematical formulas, the FM area and the FM index (FMI) were determined. The FM area was estimated using two different formulas (Routal and Teixeira formulas), which are based on the estimated FM width and length [Routal et al. (Area 1 = ¼ x π x length x width) and Teixeira formula (Area 2= π x [(length + width)/4]2)] [23, 24]. While FMI was estimated as follows: FM width / FM length x 100 [25].

The best image for the FM scans was selected to be from continuous 5 mm thick slices and parallel to the orbitomeatal line. The shape of the FM was evaluated by the direct visual examination and the shapes were classified into main three types which were; regular shape (including oval, egg, round, tetragonal, pentagonal, hexagonal), irregular A (formed by combination of two different semicircles for the former types), and irregular B which cannot be categorized to the previously mentioned types.

Foramen magnum for sexual dimorphism among Egyptians

Sex estimation data were considered in five studies which concluded that all FM variables were significantly higher in Egyptian males than females to variable extents. There was a conflict regarding the variable with the best sex discriminative value. However, FM area was shown to be the best sex discriminant measurement. Tetragonal shape of FM was the most common in both sexes of the study sample.

The FM index was found to be non-significantly higher in males than in females in Kenawy and Mousa study, which is in accordance with Vinutha et al. Indian study. However, the difference in FMI showed significance between both sexes in other Egyptian studies reported by Slima et al. and Abo El-Atta et al.

According to the published Egyptian data, the range of means FM length and FM width were in males (36.71-36.8, 31.1-31.83mm) and (32.18-35.7, 27.2-30.26mm) in females respectively. These mean range values for both males and females were higher than reported values among Indian [26], English [27], and Turkish populations [28]. However, The Egyptian values were lower than the values reported in Swiss population by Edwards et al. study. The differences among populations can be explained by the anatomical variations of the studied populations due to genetics as well as habits and customs. Moreover, the Egyptian studies showed sex discrimination value for the area of FM, which is in accordance with previously published data by Tambawala et al. [26], Tellioglu et al. [29], and Edwards et al. [30] on different populations.

By discriminant function analysis, Egyptian studies reported overall accuracy of sex prediction value by FM length to range from 59.5 to 65% and for FM (Area 2) to range from 64.2 to 65%. While the estimated overall accuracy for FM width was 61.7-64.5%, the overall accuracy of sex prediction for FM (Area 1) and FMI was 62.5% and 14.2% respectively. These values were higher than those reported by Lopez et al. [31] study for Brazilian population, which showed prediction values of 59.6%, 57.4%, 51.1% and 44.7% for Area2, Area1, FM length and the FM width, respectively. However, Uthman et al. [32] study showed a higher sex prediction value for FM area (69.3%) among Iraqi population.

Foramen magnum for age estimation among Egyptians

Regarding age estimation from FM variables, the studies of Lashin et al. [21] and Saleh et al. [22] that included a total of 300 adults who underwent CT scans reported that there was no statistical correlation between FM measurements and age. However, the study of Kholeif and Radwan [18], with 120 scans with ages ranging from one to 65 years, showed that FM length (FML) decrease and FM width (FMW) increase with aging after the age group of 10-19 years. Subsequently, FM index (FMI) tends to decrease with age with a negative correlation between age and FMI. These studies show that mostly no significance of skull variables diameters on age estimation after the ages of puberty. This can be attributed to the ossification of the occipital bone with increasing age [33]. This coincides with the studies done by Wilk et al. [34], Samara et al. [35] and Moodley et al. [36]. In contrast to the Egyptian study data, Meral et al. [37] reported a larger foramen magnum area among Turkish adults. These contradictory FM data regarding age estimation highlight the role of nutritional and sociodemographic factors on the studies outcomes and revealed the limited role of the FM variables in the estimation of age in the human remains.

Concluding remarks

The current studies showed the importance of FM variables in computed tomography scans as reliable tools for sexual dimorphism among Egyptians. The data regarding the benefit of FM variables in age estimation was contradictory and mostly showed a limited role of FM variables regarding age estimation.

Also, most of the published data was considering adult scans with limited data regarding earlier age FM variables. Further studies are recommended to study the variables among bigger sized samples of Egyptian populations from the different provinces of the countries. Aso combined studies of different skull base variables with FM variables are expected to improve the robustness and accuracy of the collected data.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or compareable ethical standards.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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