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RESEARCH ARTICLE

Radiological measurements of the skull and its use in sex estimation: A study in Sri Lanka

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ABSTRACT

Introduction: In identification of an individual, the forensic pathologists and the anthropologists examine skeletal material. The aim of this study was to determine the cranio-facial structures which can be used to estimate sex in the adult Sri Lankan population.

Methods: The study sample consisted of 166 patients (77 males and 89 females), who underwent computed tomography (CT) brain examinations. The volumes of the maxillary, and frontal sinuses, and the measurements of angular forehead, skull, and facial structures were taken by two observers on axial, sagittal, and coronal planes of CT images. The age and sex of the patient were recorded along with the measurements. Data were analyzed using the statistical tests including independent sample t-test and Mann-Whitney U test, available in the SPSS version 25 software with $P<0.05$ indicating level of significance.

Results: The left maxillary sinus volume (ML), right maxillary sinus volume (MR), skull length (SL), prostio-bregmatic height (PBH), and maximum skull width (MSW), frontal sinus volume (F), angle of deviation of actual from ideal forehead slope (ANB), angle of inclination of actual forehead slope (BNV), and nasofrontal angle (BNC) had a statistically significant differences between males and females ($P<0.05$). There was no statistically significant difference in the angle of inclination of ideal forehead slope (ANV) in the two sexes ($P>0.05$).

Conclusion: Left maxillary sinus volume (ML), right maxillary sinus volume (MR), frontal sinus volume (F), nasofrontal angle (BNC), angle of inclination of ideal forehead slope (ANV), angle of deviation of actual from ideal forehead slope (ANB), skull length (SL), prostio-bregmatic height (PBH), maximum skull width (MSW) can help estimate the sex of a Sri Lankan person.

Left maxillary sinus volume (ML), right maxillary sinus volume (MR), frontal sinus volume (F), skull length (SL), prostio-bregmatic height (PBH), maximum skull width (MSW), nasofrontal angle (BNC), angle of deviation of actual from ideal forehead slope (ANB) and the angle of inclination of actual forehead slope (BNV).

Keywords: computed tomography, estimation, measurements, sex, skull

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INTRODUCTION

The biological identification methods have always been of utmost importance for society, not only living individual identity authentication purposes but also for forensic anthropology as well. The identification of human beings has evolved since ancient times. The dactylography, forensic dentistry, deoxyribonucleic acid (DNA) profile, and skeletal analysis facilitate precise individualized recognition of human beings. The skeletal analysis has to be done even in the events where DNA analysis is

feasible because it helps to narrow down the possibilities and reduces the number of DNA analyses to be done[1].

The skeletal analysis estimates the sex of the deceased by utilizing the skeletal traits such as skull, pelvis, and long bones. Estimation of sex is more precise if the whole skeleton is available, so that the identity can be estimated with 100% accuracy by using the whole skeleton. Among skeletal components pelvis has 95% followed by cranium with 92%[2]. The skeletal analysis gives more attention to the skull to estimate the sex since it bears more information of age, sex and ancestry. It is therefore important to find means to correctly estimate the sex, age, and ancestry of deceased through craniometric analysis.

The frontal sinuses are lobulated air-filled cavities which are located posterior to the superciliary arches in the frontal bone and each of the sinus drains into corresponding middle meatus through an infundibulum. The frontal sinuses are often bilateral, divided by a septum. Each of these sinuses is further divided by incomplete accessory septa and results in several recesses that are communicating with each other. The frontal sinuses are not present at the neonatal stage and start to develop at the age of 2 years and it could be visualized radiographically at the age of 05 years. Throughout the life frontal sinus remains stable unless pneumatization occurs due to atrophy in geriatric period. Total ossification terminates at the age of 20 years[4]. As an alteration of the frontal sinus, unilateral or bilateral agenasia may be present. Even monozygotic twins have indicated unique characteristics when analyzing the frontal sinus[4]. The unique features of the frontal sinus can be used as a substitute for fingerprints[4]. Specific features of frontal sinus are used for verification of age and sex identity.

Apart from the uniqueness of frontal sinus, maxillary sinuses also contribute for sex and age detection. It is a triangular pyramid shape sinus which consists of three recesses called alveolar recess, zygomatic recess and intra orbital recess. The volume of maxillary sinus is unique from person to person, even each side of the sinus differs from the other side in everyone[5]. The maxillary sinus terminates its final configuration at age of 15 years[5].

Several studies have proven that there is an innovative approach provides for sex estimation by angular measurements of frontal bone and linear measurements of skull. On the other hand, identification can also be achieved by assessing these cranium components by using their unique features. These features include bizygomatic breadth, fronto-nasal angle, mastoid process height and width, cranial index, foramen magnum length, and orbital height. By combined analysis of all the prominent features of the skull, a conclusion can be drawn regarding sex[3].

Computed tomography (CT) is utilized to supplement autopsy. A synergistic effect is evident between conventional autopsy findings and CT based forensic findings which tend to improve the medico-legal investigations. On the other hand, forensic data in CT can be utilized as an auxiliary tool for assessment of facial reconstruction[6]. Much research has been conducted on image guided virtual autopsy which enhance the reliability of the conventional autopsy techniques, and these methods can be used for development of medico – legal investigations in Sri Lankan context[6].

It is known that there is volume variation of Maxillary sinus with ethnic group and sex[7]. Therefore, medico-legal practitioners in Sri Lanka are unable to use the guidelines given through similar studies done in other countries.

OBJECTIVE

To determine the cranio-facial measurements which can be used to estimate the sex in the adult Sri Lankan population.

METHODS

Patients over 20 and below 90 years of age, who underwent non-contrast CT brain examination with details of their CT brain scans in machine storage from 1st of October to 31st of December 2020 at the Department of Radiology, University Hospital, Kotelawala Defense University (UHKDU) were considered. Patients who had traumatic or any other pathological conditions associated with the frontal and maxillary sinuses and skull bones, patients who had anatomical variation that might affect the volume of frontal or maxillary sinuses, patients who had craniofacial anomaly or condition affecting mid facial development, those CT scans with artifacts and images that did not contain required anatomical reference points were excluded from the study.

The study sample consisted of 166 individuals including 77 males and 89 females.

A multi-detector computed tomography (MDCT) scanner (Philips, Brilliance iCT family, 256 slices, the Netherlands) located in the radiography department

at UHKDU was used to do the CT examinations. All the measurements were taken using a commercial interactive volumetric-assist software (Volume Tracing in Advanced Vessel Analysis, Philips Healthcare, Cleveland, Ohio, USA) with the guidance of an experienced radiologist. The CT machine was operated at 120 kVp, 80 mA, and with the scan time of 60 seconds with 1mm slice thickness for each scan.

The research proposal was approved by the Internal Research Screening and Monitoring Committee (IRMSC) of Faculty of Allied Health Sciences, General Sir John Kotelawala Defence University. The ethical clearance for the study was obtained from the Ethical Review Committee (ERC) of Faculty of Medicine, General Sir John Kotelawala Defence University. The collected data were handled and stored with highest degree of confidentiality, which has limited access protected by password. Permission for data collection was obtained from the institutional review board of UHKDU.

All the CT brain examinations were done by radiological technologists, who are qualified with a basic degree of radiography, and registered in Sri Lanka Medical Council (SLMC), using the same standard head protocol. All the measurements were taken using axial, sagittal, and coronal planes by two observers separately under the supervision of a board certified radiologist, without any inconvenience to the hospital setup. The age and sex of the patient were recorded along with the measurements.

The volume of frontal sinus, and right and left maxillary sinuses were calculated using a commercial interactive volumetric-assist software (Volume Tracing in Advanced Vessel Analysis, Philips Healthcare, Cleveland, Ohio, USA) available in Philips CT scanner after creating the 3D image of each sinus by marking the lumen of sinuses manually in each of the axial image using bone window, and by erasing the excessive marked areas and remarking unmarked areas on sagittal and coronal images.

The angle of inclination of ideal forehead slope (ANV), the angle of inclination of actual forehead slope (BNV), the angle of deviation of actual from ideal forehead slope (ANB), and the nasofrontal angle (BNC) were taken as the measurements of angular forehead. These measurements were taken in the bone window of middle slice of sagittal reconstructed image selected using a viewing workstation (Extended Brilliance Workspace, Philips Healthcare, Cleveland, Ohio, USA). The line H (the anterior base of the skull which is defined as the reference horizontal plane), line V (the line which is, perpendicular to line H, defined as the reference vertical plane using the sagittal view), line A (ideal slope/line drawn from the nasion (Point N) to the point immediately superior to the supraorbital ridge, at the junction where supraorbital bossing ends and the softer curvature of the forehead begins), line B (actual slope/line drawn from the point N to the most anterior point of the supraorbital ridge), and line C (nasal slope/line drawn from the point N to the most anterior/inferior point of the nasal bone) were used as horizontal, and vertical reference planes for obtaining angular forehead measurements **(Fig.1)**.

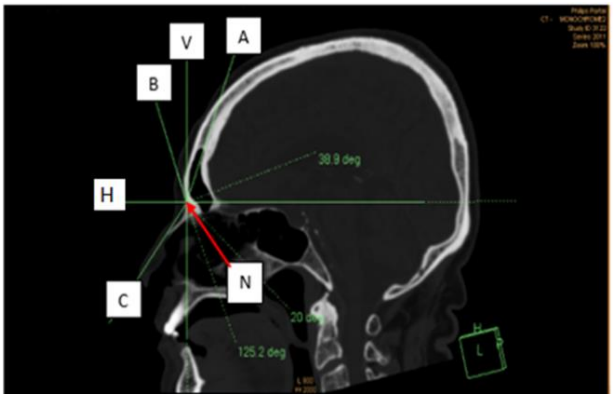

Figure 1: CT image showing the measurements of angular forehead

The glabella, external occipital protuberance, prosthion, bregma, and euryon were considered as the reference points to take the skull and facial measurements of each study participant. The skull length (SL) was measured from the glabella to the external occipital protuberance. The prostio-bregmatic height (PBH) was measured from the prosthion to the bregma. The maximum skull width (MSW) was measured from right euryon to left euryon. The SL, and PBH were taken using sagittal images while MSW was taken using coronal images (Fig.2). All these measurements were also taken in bone window by using a viewing workstation (Extended Brilliance Workspace, Philips Healthcare, Cleveland, Ohio, USA).

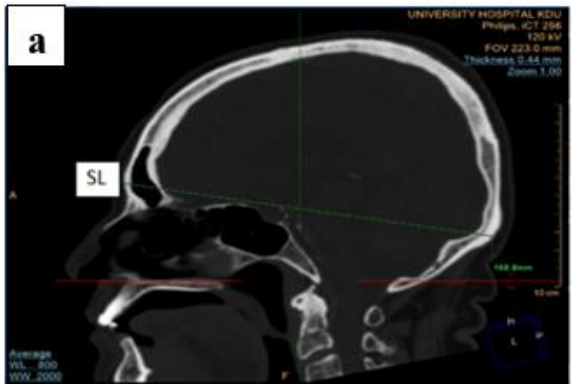

Figure 2a: CT image showing the SL

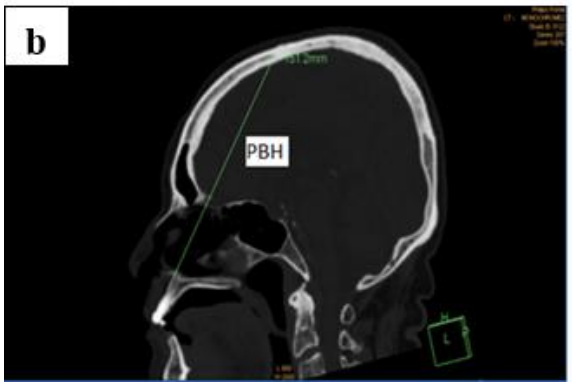

Figure 2b: CT image showing the PBH

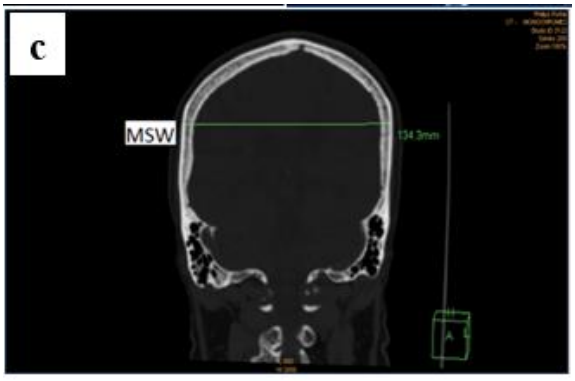

Figure 2c: CT image showing the MSW

All data were recorded in customized Microsoft Excel tables. The data were analyzed using the statistical tests such as independent sample t-test, Mann-Whitney U test, available in the SPSS version 25 software with P<0.05 indicating level of significance. The intraclass correlation coefficient (ICC) estimation was conducted to determine the inter-observer agreement. The independent sample t-test was used to determine if there is a significant difference of the left maxillary sinus volume (ML), right maxillary sinus volume (MR), MSW, PBH, and SL between males and females. The Mann-Whitney U test was used to determine if there is a significant difference of the frontal sinus volume (F), BNC, ANV, ANB, and BNV angles between males and females. The Point-biserial correlation was used to assess the correlation of ML, MR, MSW, PBH, and SL with the sex. The Spearman's correlation was used to determine the correlation of F, BNC, ANV, ANB, and BNV angles with sex.

RESULTS

The results of ICC estimation showed an excellent reliability between the measurements obtained by two observers with the inter-observer agreement greater than 90% (>0.90).

The study sample consists of 77 males (46.4%) and 89 females (53.6%). Study sample according to age groups is illustrated in table 1.

Table 1: Distribution of study sample among age groups

Age Groups	Frequency	Percent
20-29	12	7.2
30-39	8	4.8
40-49	13	7.8
50-59	36	21.7
60-69	36	21.7
70-79	35	21.1
above 80	26	15.7
Total	166	100.0

According to the results of Shapiro-Wilk test, ML, MR, SL, PBH, and MSW were normally distributed (P > 0.05) while F, BNC, ANV, ANB, and BNV angles were not normally distributed (P < 0.05). The descriptive statistics of normally distributed measurements and the descriptive statistics of the rest of the measurements is given in table 2. Furthermore, results of independent sample t-test and Mann-Whitney U test are included in table 2 and table 3 respectively.

Table 2: Comparison of male and female subjects on normally distributed measurements

Measure-ment	Sex	n	Mean	p*
ML	Male	77	14.41±4.49	<0.05
	Female	89	13.01±3.74	
MR	Male	77	14.95±4.68	<0.05
	Female	89	12.95±3.59	
SL	Male	77	174.12±6.31	<0.001
	Female	89	164.72±6.32	
PBH	Male	77	168.27±7.31	<0.001
	Female	89	158.65±7.57	
MSW	Male	77	139.65±5.41	<0.001
	Female	89	136.16±5.38	

***Student's t-test**

According to the results of independent sample t-test, ML, MR, SL, PBH, and MSW in females is lower compared to males and there is a statistically significant difference in measurements between the two groups.

Table 3: Comparison of male and female subjects on measurements which are not normally distributed

Measure-ment	Sex	n	Median	p*
F	Male	77	8.7	P<0.0001
	Female	89	6	
BNC	Male	77	11.3	P<0.0001
	Female	89	122.3	
ANV	Male	77	12.7	P > 0.05
	Female	89	13.3	
ANB	Male	77	43.1	P<0.0001
	Female	89	34.1	
BNV	Male	77	29.9	P<0.0001
	Female	89	19.6	

***Mann-Whiteny U test**

According to the results of Mann-Whitney U test, F, ANB, and BNV of males were significantly higher than those of females while BNC of females was significantly higher than that of males. In contrast, there was no significant difference of ANV between males and females.

DISCUSSION

The results of the present study showed that the males had a statistically significant higher volume in right and left maxillary and frontal sinuses compared to females. Like the present study, a study done in 2004 found that sex can be estimated by using the larger volumes in males' sinuses than in females' sinuses[7]. Further, another study done in 2017 found that the mean volumes of the sinuses were greater in men compared to women[8]. Moreover, a similar study done in 2018revealed that the volumes of right and left maxillary, sphenoid, and frontal sinuses were significantly greater in men compared to women[1]. Therefore it can be concluded that despite the ethnicity, sinus volumes were greater in males than in females.

The results of the present study found that ANB, and BNV of males were significantly higher than those of females while BNC of females was significantly higher than that of males. Further, there was no significant difference of ANV between males and females. In contrast, a study done in 2010 revealed that the angular forehead measurements such as BNC, ANV, ANB, and BNV were significantly larger in men compared to women[9]. The reasons for the discrepancy of the results might be due to the large number of study participant involved in their study compared to the present study, and the ethnic differences between studies.

Similar to the present study, a study done in 2010 found that all skull and facial structure measurements such as SL, PBH, and MSW were significantly different between males and females[13].

The present study was carried out on a study sample, taken from only one hospital, which is small compared to some similar studies done in other countries. Therefore, a further study is required in Sri Lanka with a larger sample size taken from multiple hospitals in different areas of the country to build up a model to predict the sex of a Sri Lankan person.

CONCLUSION

All the skull length measurements and maxillary and frontal sinus volumes used in this study showed a significant difference among male and female population of Sri Lanka. Moreover, angular forehead measurements except ANV significantly differ

among males and females. Therefore, the sex of a Sri Lankan person can be estimated using Left maxillary sinus volume (ML), right maxillary sinus volume (MR), frontal sinus volume (F), skull length (SL), prostio-bregmatic height (PBH), maximum skull width (MSW), nasofrontal angle (BNC), angle of deviation of actual from ideal forehead slope (ANB) and the angle of inclination of actual forehead slope (BNV).

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CONFLICTS OF INTEREST

There are no conflicts of interest.

ETHICAL ISSUES

None

AUTHOR CONTRIBUTIONS

SHGSS: designing the study, collecting, analyzing and interpreting the data, drafting and revision of the manuscript and approval of the final version to be published; **KMNGF:** designing the study, collecting, analyzing and interpreting the data, drafting and revision of the manuscript and approval of the final version to be published; **GS:** designing the study, collecting, analyzing and interpreting the data, drafting and revision of the manuscript and approval of the final version to be published; **LHMIMH:** designing the study, collecting, analyzing and interpreting the data, drafting and revision of the manuscript and approval of the final version to be published; **WMISW:** designing the study, collecting, analyzing and interpreting the data, drafting and revision of the manuscript and approval of the final version to be published; **RT:** designing the study, collecting, analyzing and interpreting the data, drafting and revision of the manuscript and approval of the final version to be published.

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