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Sex estimation using lateral cephalograms: A Statistical Analysis

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Highlights

- From the age of 18, sex can be estimated with an accuracy of over 80%.
- Uncalibrated lateral cephalograms can be statistically analysed and utilized in a forensic context.
- The angular measurements emerged as the best parameters in sexing lateral cephalograms.
- Binary logistic regression analysis can be used to develop a standard and feasible sex prediction model.
- Glabella represents a reliable sex discrimination feature.

Abstract

The identification of skeletonized remains requires sex estimation. After the pelvis, skull is considered the best sex predictor in the human skeleton. Lateral cephalograms provide details of the skull's morphology and previous studies have investigated sex analysing calibrated lateral cephalograms of adults aged 20 – 55 years. Due to the lack of studies around age 18 as an important legal age, this study aimed to investigate adults aged 18 – 22 years by exploring linear, angular and areal measurements to investigate the best lateral cephalometric parameters that can be used to create a sex prediction model.

A total of 135 uncalibrated lateral cephalograms (68♂, 67♀) of Caucasians (Canadians and Americans) aged 18 – 26.3 years were analysed using *ImageJ-V*1.51 and *SPSS-V22*. A number of 22 measurements (linear, angular, areal) were obtained by tracing 9 landmarks (G, V, Op, Ba, N, S, ANS, Po, Or). Only 21 parameters were derived and subjected to statistical analysis. Because most of the samples were aged 18 – 22 years, only 119 subjects (59♂, 60♀) from the total sample have been used in the binary logistic regression analysis to create the model.

Sex was estimated with an overall accuracy **82.4%.** Three angular measurements (ΔN-S-V, ΔN-S-G, ΔG-N-S) and one ratio for two areal measurements (G-V-Op-Ba-G/N-S-Ba-ANS-N) were the best parameters. Cranio-facial parameters contribute in sex estimation, mainly angular measurements when subjected to logistic regression analysis. Uncalibrated lateral cephalograms can be used to estimate the sex of subjects aged 18 – 26 years, considering limitations such as bias, ethnicity, and radiological techniques.

Keywords: Forensic science; Identification; Skull; Sex estimation; Lateral cephalogram; Binary logistic regression analysis

Introduction

The medicolegal investigation of the identity in a modern world attempts to primarily construct the biological profile of the human remains that includes the sex[1]. Estimation of sex in forensic context is a keystone to establish the identity of an unknown individual[2]. However, assessing the commingled and skeletonized remains imposes the biggest challenges due to the decomposition of the soft tissues that hold sexual characteristics which are usually assessed by a visual examination[3]. In such cases, sex establishment will be based on the evaluation of the bony structures which usually retain the human sexual dimorphism that develops mostly from the puberty during the course of growth[4].

In the human skeleton, after the pelvis, the skull is considered the best structure for sex estimation. Several approaches - morphological and metrical - have been implemented to assess sex from the skull[4-20]. Despite the good accuracies achieved by these approaches, they do not escape from drawbacks of observer error, developmental bias, population variations, and lack of experience and standard methodologies[4,5]. In this regard, standardized skull radiographs such as lateral cephalometry reveal multiple landmarks for comparison and have the advantages of providing more accurate, precise and reproducible technique to estimate sex by linear, angular and proportional measurements than the morphological or metrical approaches[21].

The relevant previous studies on lateral cephalograms of adults that belonged to different ethnic groups and were aged between 25 - 55 years have reached accuracies (80% - 100%)[21-26]. These studies that focused on metrical approaches in the lateral cephalograms were conducted on several ethnic groups; Caucasians, Taiwanese, Japanese, Indians and immigrant Tibetans[21-26]. In these studies, the magnification percentage of the x-rays utilized were known to the examiner which facilitated a calibration into life-size images[21,22]. According to the majority of these studies, the lower and upper age limits were adopted based on Krogman's proposition that cranio-mandibular parameters become pronounced at puberty and are prone to some variations at senility[21,22,27].

Therefore, this study aimed to explore the possibility of sex estimation using lateral cephalograms of Caucasian adults in an untested age range 18 – 22 years as age 18 represents the start of adulthood in most legal systems. Additionally, the x-rays utilized in this study were uncalibrated by having no scaling marker within the x-ray (i.e. a ruler) which means an unknown magnification rate of the image, and therefore, it can impose a practical challenge in a real forensic scenario, justifying the novelty of this work. Another aim was to explore several cephalometric measurements (linear, angular, and areal) in order to determine the best variables that can be used in building a standardized sex prediction model.

Materials and Methods

One hundred thirty-five anonymised and digitized lateral cephalograms of Caucasian adults were collected from three of the nine collections of the Craniofacial Growth Legacy published online for researchers without any need of ethical approval by the American Association of Orthodontics Foundation (AAOF)[28]. Including samples only from three collections was based on acquiring the x-rays that show full skull view (Burlington, Denver, and Oregon collections). The images were derived from individuals with malocclusion and mixed orthodontic classification prior to an orthodontic treatment (67 females and 68 males; age range, 18 - 26.3 years) (Fig. 1). Due to the malocclusion and the mixed orthodontic classification of the samples, no landmarks were placed on a mandibular or maxillary structure in this study. These x-rays were captured in the USA and Canada between 1930 and 1985. No information was provided by the AAOF about the radiographical procedure used to capture these images.

After downloading the images in PNG format, they were classified based upon the collection and the sex of each sample. Using an open access image processing program, *ImageJ 1.51v*[29], from the public domain, nine landmarks were traced on each image (Table 1). The landmarks were adopted from Jacobson, 2006[30] and White, 2011[31].

The technical methodology of tracing these landmarks is illustrated in (Fig. 2). All x-rays were first standardized in *Frankfurt Plane Horizontal* that is determined by placing horizontally the line that passes from the highest point on the upper margin of the opening of the external auditory canal, *Porion,* to the low point on the lower margin of the left orbit, *Orbitale*[30]. To standardize tracing the landmarks (Glabella, Vertex, and Opisthocranion), the authors developed a rectangular that touches the outer surface of the skull borders (Pink, Fig. 2). The other landmarks were traced based on the anatomical structures that were coloured in yellow in Fig. 2[31].

After tracing and fixing all the landmarks on each image, a set of 22 cephalometric measurements were obtained using the same image program, *ImageJ 1.51v* [29] (Table 2). These measurements were 12 linear (Fig. 3. a), 2 areal (Fig. 3. b) and 8 angular (Fig. 3. c and d). Some of these measurements were adopted from previous literature[30,31] and relevant conducted analyses[20-22,24,25]. However, many of them were developed by the authors (i.e. areal and angular) based on an assumption that placing landmarks on sexually dimorphic features could be statistically significant. Using *ImageJ*, the tools of linear, angular and areal measurements were obtained for each image and these values were transferred into an Excel sheet in order to be statistically analysed.

Using *IBM SPSS* software*, V22,* the statistical analysis was conducted on three different phases:

1. Intra- and Inter-observer analysis: To test the reliability of measuring the scores, 30% of the samples were re-traced and re-measured by the main investigator (a forensic odontologist) in interval of 2 weeks and 10% of the samples were traced and measured by another investigator who was a dentist. Intraclass correlation

coefficient (ICC 2, 1: Two-way random for consistency in SPSS) tests were used to analyse the results.

2. Descriptive analysis: Because most of the samples were aged 18 – 22 years and to ensure a balance in the age distribution of the samples used in building the model, a filter that removed all the samples aged 22 years and above was created. Therefore, the number of samples utilized in the further analysis was 119 (59 males, 60 females).

   Not all of the x-rays provided a scale, which meant that it was not possible to utilise physical size measurements as predictors. Instead, ratios were calculated between pairs of measurements. This can be done as easily in pixels as it can in mm, and it renders this technique usable with a wider range of evidence sources. For each image, each linear value (M1 to M12) was divided on M9=NS. Additionally, the areal value M13 was divided by M14. The 12 ratios (R1 to R12) which were explored as part of this novel methodology, are illustrated in table 3, and the 8 angular measurements (M15 to M22) were then utilized in the descriptive analysis before creating the regression model.

   Data were then split by sex and coded "0" for females and "1" for males to produce one set of outputs for each sex. The descriptive statistics were then generated for all variables.

3. Binary Logistic Regression analysis was then performed to create the sex prediction model.

Results

1. Intra- and Inter-observer analysis: The single measures of (ICC) tests of all variables were significant with ICC scores above 0.859 which can be interpreted to a very good reliability (Table 4). While there is not a single criterion for what constitutes "acceptable" reliability when using the ICC, and results always need to be interpreted in light of the specific population being studied, the achieved ICC of 0.859 is consistent with what researchers through the years have considered acceptable[32]

2. The biggest mean differences between males and females were found on the predictors M15, M20, M21, M22, and R12 (Table 5). Therefore, these predictors were considered most informative amongst all the variables and were therefore analysed prior to utilize them in building the regression model.

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3. Binary Logistic Regression Analysis:

i. Using the aforementioned 5 predictors with the biggest mean differences, an initial regression model was created to judge the significance of these variables in building the model. All the predictors were significant contributors to the model with probability values ($p<.05$) except for M21 ($p>.05$) (Table 6). Among all variables, M15, M20, M22 and R12 were considered the best predictors of sex (Table 7). M21 was deleted from the final iteration of the model since it was found to be a non-significant predictor.

ii. The predictions generated by the regression model are represented by this formula:

$$\boldsymbol{PoM} = \frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{e}^{-(-\mathbf{37.826}+(\boldsymbol{NSVan}.*\mathbf{0.209})+(\boldsymbol{NSGan}*-\mathbf{0.421})+(\boldsymbol{GNSan}*\mathbf{0.329})+(\boldsymbol{R12}*-\mathbf{4.411}))}}$$

Where:

PoM= Probability of being male, ***e***= 2.718, ***NSVan***= Angle Nasion-Sella-Vertex (M15), ***NSGan***= Angle Nasion-Sella-Glabella (M20), ***GNSan***= Angle Glabella-Nasion-Sella (M22), and ***R12***= Ratio of the areal measurements M13/M14.

Mathematically, this equation could be used by manually inputting the values of the variables in it to get the result. It will produce a number between (0 – 1) where “0” refers to 0% probability of being male and “1” refers to 100% probability of being male. Creating the equation as a probability of being male instead of female was a consequence of the way binary logistic regression works and could equally have been expressed as a probability of being female. If the result was less than 0.5 (50%) then it reflects lower probability of being male and higher probability of being female (reverse percentage). A value of 50% would indicate an equal probability of being male or female. For all percentages above 50% the estimated sex produced by the model was “male”, and for all percentages below 50% the guess of the model was “female”.

iii. Using these predictors, it was possible to correctly classify 83.3% of females and 81.4% of males within the sample used to develop the model (Fig. 4) with an **overall accuracy** of **82.4%** for both sexes.

iv. Based on the binary logistic regression model created from the data of the 119 samples and with the assistance of a research methodologist, a calculator has been developed where the values of the 4 variables (M15, M20, M22, and R12) can be manually inputted and the sex type will then be automatically generated. A screenshot of this calculator is shown in table 8, which is developed on an Excel sheet. This calculator eases the utilization of the model and overcomes the mathematical complexity of its equation

If the probability of being male value was less than 50% the predicted sex will be generated as female, whereas a value greater than 50% will predict the sex as male. This calculator is publicized online for public use and can be downloaded at this link: https://drive.google.com/open?id=19BWocaZevNtQsGFmLDnsM6qwPvjo9-wF

Working on this calculator is not possible online and therefore, it must be downloaded prior to any usage.

To assess the applicability of the developed regression model on different data, the calculator was tested using the data of the 15 subjects, aged above 22 years which were not included in the development of the model. The calculator was able to correctly sex 86.66% of the 15 samples tested (Table 9).

Discussion

Sexing the skull represents an aid for human identification[3]. Several studies on morphological and morphometric approaches implemented in sexing the adult skull have been published; the tested morphological features reached an accuracy between (62% - 92%)[5-9,33]; the morphometric studies resulted in an accuracy range between (70% - 92%)[10-19]. These approaches were applied on dry skulls to investigate the sexual dimorphic features that were sometimes statistically analysed (morphometrically) in order to avoid errors[11-20]. However, numerous factors may affect the previous approaches in sexing the skull correctly: variations between populations; genetics, diet, mental health, physical activity and examiner's subjectivity[4]**.** For such reasons, these approaches cannot be universalized, and thus more objective ones need to be implemented and adopted[21]. Therefore, the morphometric methodologies can be performed on lateral cephalograms followed by a statistical analysis to overcome several challenges that may affect the accuracy of skull's sexing[21]. From a search of the literature it appears that only 6 studies (1979 to 2010) on estimating sex using the lateral cephalograms of adults have been published. Also, some studies have been conducted on juveniles to estimate sex using lateral cephalometric analysis[34]. The studies on adults were conducted on several populations; Caucasians, Taiwanese, Japanese, Indians and immigrant Tibetans[21-26]. The age 18 was only investigated in the Japanese study, whereas the other studies tested individuals from 20 and above 20 – 55 years[26]. The tendency by those authors to examine samples aged 25 – 55 years was based on Krogman's proposition which states that cranio-mandibular parameters are age phenomena which become more pronounced at puberty and are affected by the variations of senility[27].

Although many researchers may argue that the development of sexual characteristics at age 18 is very variable due to the various factors affecting it[4,5] , this age range is very important in forensic practice as adulthood starts from 18 years old, which is thus worth exploration. In addition to the binary logistic regression analysis that was applied in this study to estimate sex from lateral cephalograms, other statistical approaches such as discriminant function analysis were utilized in sexing the lateral cephalograms[21,22].

The reliability test in this study has been performed to test the methodology when repeated by the main investigator and by another examiner who was a dentist; the results were statistically reliable as recorded by Hsiao et al.[24] and Naikmasur et al.[21] in their studies.

The overall results of this study are in concordance with the previously reported results; among the samples used to develop the model, the accuracy of sex estimation using the lateral cephalograms was 82.4% that is within the accuracy range of the previous ones (81.5% – 100%)[21-26]. When applied to a novel sample which was not used to develop the model, the accuracy was found to be 86.66%, indicating a good validation of the calculator.

In relation to the 12 craniofacial linear measurements utilized in this study, some of those have been adopted from previous studies: G-Op was used by Giles & Elliot[20] and Patil & Mody[22]; Ba-N, Ba-ANS, and N-ANS were used by Naikmasur[21] and Patil & Mody[22]; and S-N was utilized by Bibby[23], whereas the other measurements were developed by the author based on the assumption that the distances between landmarks placed on any sexually dimorphic anatomical region could be statistically significant. The obtained linear values were not compared directly one to another between the males and females due to the unavailability of magnification rate of the x-rays utilized. For this reason, each linear measurement was converted to a ratio by dividing it on the S-N value that belongs to the same sample before performing the comparison and the statistical analysis. Choosing S-N as a reference value for the ratios by the authors was based on: (1) the cranial base stops development at approximately 7 years old[35]; (2) although the closure of the synchondroses could be variable due to several factors (nutritional and health status, general growth and development of the bones, and to some extent race)[36] the synchondroses of the cranial base like spheno-occipital synchondrosis close at about 18 years old in males and females[37] making it possibly comparable at this; and (3) the authors' believe that the internal position of the cranial base that makes its development less affected by the external factors (i.e. physical trauma). Although, the results of the linear measurements in this study cannot be compared directly to the previous ones due to the conversion to ratios, they can still be compared as to contribute or not in sexing the lateral cephalograms. The results in this investigation regarding linear measurements were not in agreement with the results of the previous studies[21-26]; the descriptive statistics have shown that the mean value differences between males and females for each variable were very small and not informative as opposed to previous studies. In many previous studies, the linear measurements have yielded higher scores in skull's sex estimation not only by assessing the dry skulls as conducted by Steyn and Işcan, 1998[38], and Robinson and Bidmos 2009[39], but also by the radiological assessment of the skulls as conducted by Hsaio et al.[24] and Veyre-Goulet et al.[25]. A possible explanation of this disagreement could be the conversion of the linear parameters to ratios that may have jeopardized the assessment of sexual dimorphism of each linear value. Another possibility could be the selection of an unappropriated reference value (S-N) to calculate the ratios. Additionally, having radiographs of the skull from different collections may affect the values when converted to rations due to the utilization of different equipment. This failure of the ratios which were derived from linear measurements obtained on unscaled lateral cephalograms highlights the challenges of estimating sex for a radiograph of a skull that is not scaled.

With regard to the angular measurements, among the 8 variables investigated in this study only 3 were statistically significant. These significant angles were mostly composed of landmarks (Glabella, Nasion) located at the forehead around the superciliary and frontal sinus areas. By contrast to Bibby[23] who found that the cephalometric angular measurements have shown no sexual dimorphism, this study, similarly to Hsaio et al.[24] and Veyre-Goulet et al.[25], has found that the angles in the lateral cephalometric analysis can be useful in sex prediction with accuracy greater than 80%. Additionally, it can be noted that the projection of the Glabella, due to the frontal sinus development, represents a reliable sexual dimorphic feature that can be very helpful in predicting sex correctly in adults. Another support for that is added by the study of Funayama[26] on the Japanese population which demonstrated that the eminence of Glabella develops much more markedly in males than females making it a characteristic sexual feature.

A proportional variable was introduced in the present study. Two areal measurements; one in the neurocranium; and another in the nasomaxillary component, have been converted to a ratio. The objective was to study the relationship between a two-dimensional (2D) area of the *neurocranium* and a 2D area of the *splanchnocranium.* Among all the ratios calculated in this study, the ratio of the two areal measurements reported the biggest mean differences between both sexes, with mean female values being bigger than male values. Therefore, this ratio was utilized in creating the model with the three significant angular variables.

Some limitations of the present study are: (1) the development of the skull between 18 – 22 years old will vary between individuals in the same ethnic group having potentially obscuring the sexually dimorphic characteristics, (2) the suitability of this approach for identifying the sex of individuals far outside the 18 – 22 age range has not yet been demonstrated, (3) for use with this approach, the lateral cephalograms need to reveal a full view of the skull while at the present time they usually reveal only a part view to reduce the radiation's risks, (4) the reliability of obtaining measurements from x-rays does not escape drawback of observer error and bias, and (5) the validation of the sex prediction model was conducted on samples from the same collections of the ones used in developing the model. Also, the cross-validation was performed on samples from different age group. A validation on different samples would be preferable to examine the model accuracy on novel data.

Conclusion

This study has demonstrated that measurements derived from uncalibrated lateral cephalograms of Caucasian adults aged between 18 – 22 years can be utilized in sex estimation. The angular measurements were the most informative parameters whilst the linear measurements were mostly not significant when converted to ratios. Finally, it has been observed that the projection of the glabella represents a reliable sex estimation feature.

Conflicts of interest

The authors declare no conflict of interest.

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Figure 1 – Samples' number distribution and percentages according to age and sex. (X= age range, Y= percentage). Sample's number is shown within the bars.

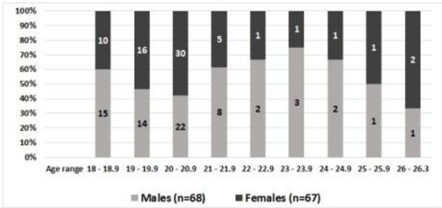

Figure 2 – The method utilized in tracing the lateral skull points*;* three highlighted anatomical structures (yellow) and a rectangle (pink) can guide the process of tracing the lateral cephalometric landmarks. Image standardized in *Frankfurt Plane Horizontal (red)*.

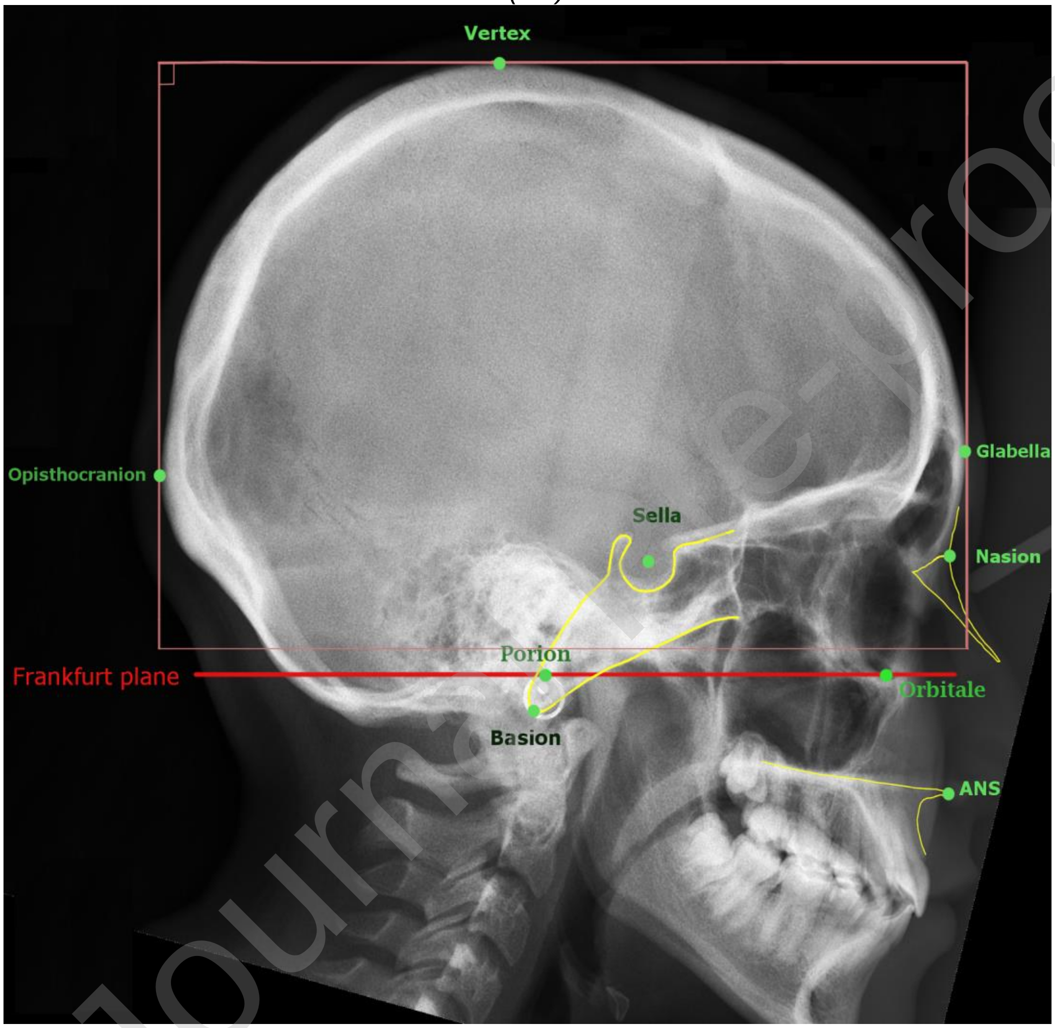

Figure 3 – The 22 obtained measurements; **(a)** linear measurements (M1 - M12), **(b)** areal measurements (1) M13. G-V-Op-Ba-G (2) M14. N-S-Ba-ANS-N, **(c)** and **(d)** angular measurements ((1) M15, (2) M16, (3) M17, (4) M18, (5) M19, (6) M20, (7) M21, (8) M22).

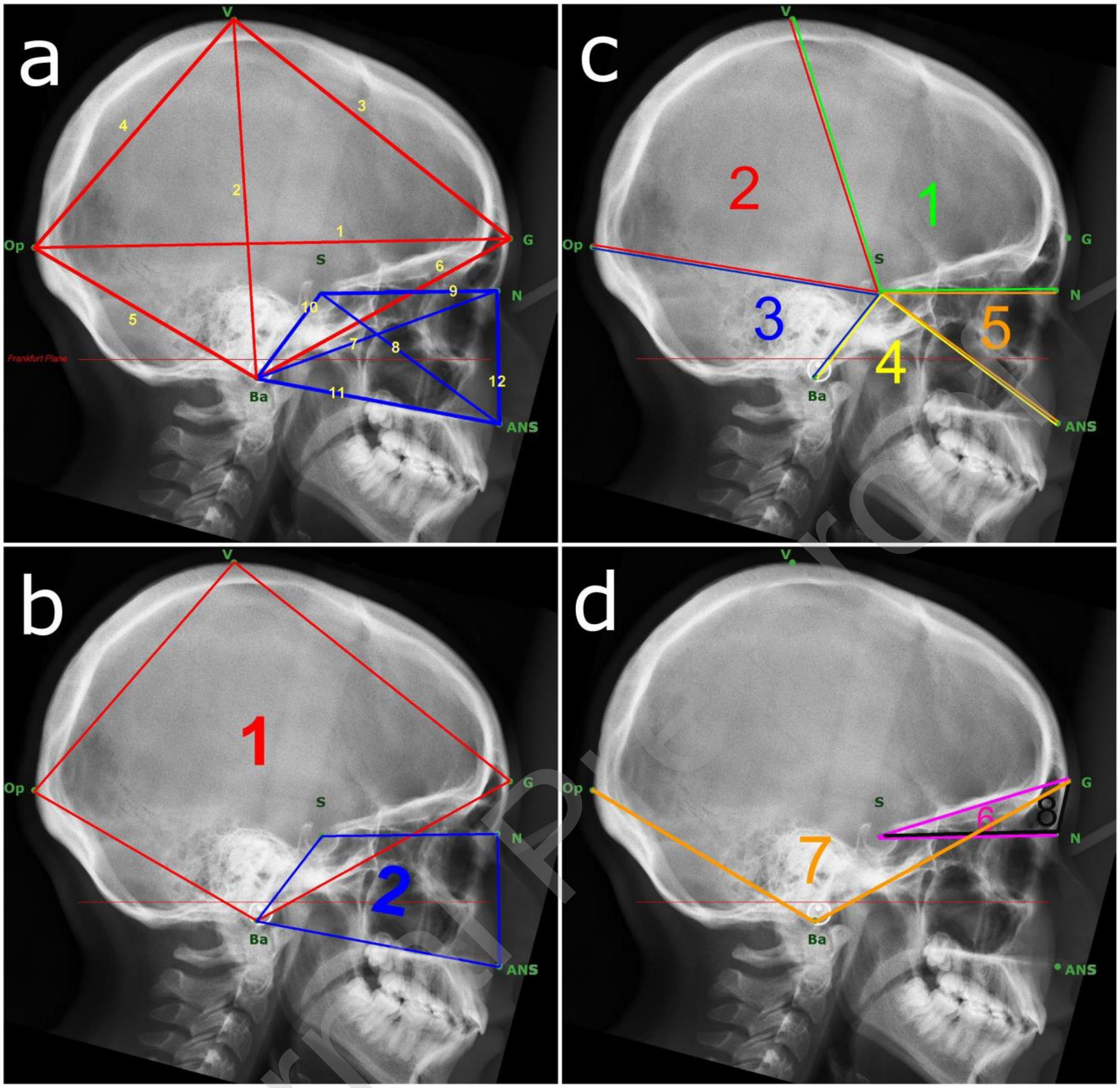

Figure 4 – Percentage of correct and wrong sex prediction obtained during the model development.

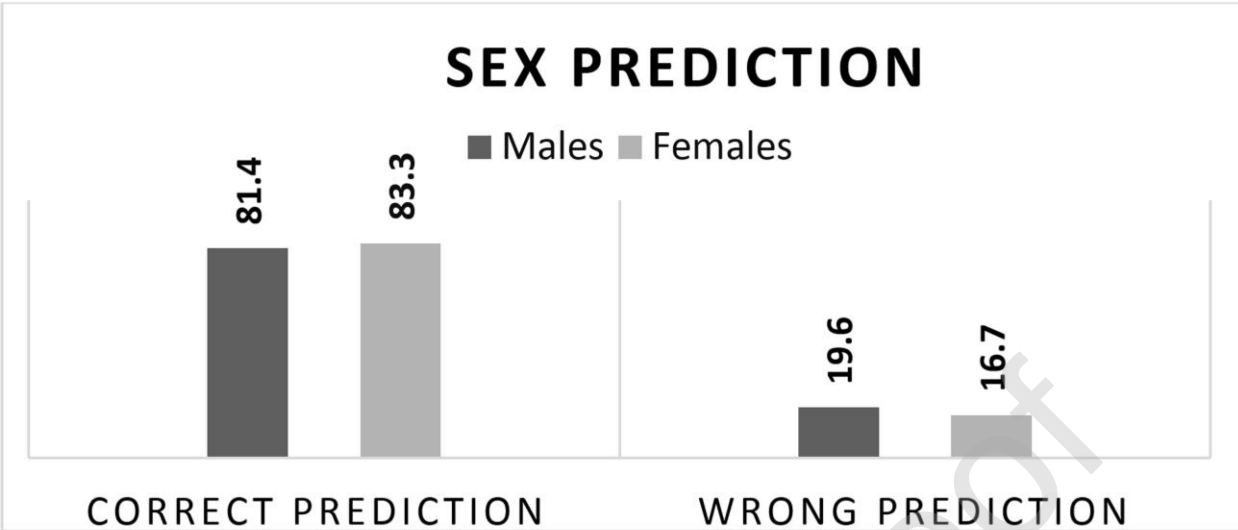
SEX PREDICTION
Males
Females
81.4
83.3
19.6
16.7
CORRECT PREDICTION
WRONG PREDICTION

Table 1. Landmarks utilized in this study.

Cranial Landmarks	**Facial Landmarks**
Vertex **V.** Opisthocranion **Op**. Basion **Ba**. Porion **Po**. Sella **S**.	Glabella G**.** Nasion **N**. Orbitale **Or**. Anterior Nasal Spine **ANS**.

(Jacobson, 2006 and White, 2011)

Table 2. Cephalometric Measurements utilized in this study.

Measurements	Description
LINEAR	*Distance from one point to another*
M1. G-Op	**Glabella** G. to **Opisthocranion** Op. – *Maximum Cranial Length.*
M2. V-Ba	**Vertex** V. to **Basion** Ba. – *Cranial Height*
M3. G-V	**Glabella** G. to **Vertex** V.
M4. V-Op	**Vertex** V. to **Opisthocranion** Op.
M5. Op-Ba	**Opisthocranion** Op. to **Basion** Ba.
M6. Ba-G	**Basion** Ba. to **Glabella** G.
M7. N-Ba	**Nasion** N. to **Basion** Ba.
M8. S-ANS	**Sella** S. to **Anterior Nasal Spine** ANS.
M9. N-S	**Nasion** N. to **Sella** S.
M10. S-Ba	**Sella** S. to **Basion** Ba.
M11. Ba-ANS	**Basion** Ba. to **Anterior Nasal Spine** ANS.
M12.ANS-N	**Anterior Nasal Spine** ANS. to **Nasion** N.
AREAL	*Area of a Polygon with four vertices (points or corners)*
M13. G-V-Op-Ba-G	**Glabella** G., **Vertex** V., **Opisthocranion** Op., and **Basion** Ba.
M14. N-S-Ba-ANS-N	**Nasion** N., **Sella** S., **Basion** Ba., **Anterior Nasal Spine** ANS.
ANGULAR °	*Angle between two lines*
M15. ∠N-S-V	Nasion to Sella line **(N-S)** and Sella to Vertex line **(S-V)**
M16. ∠V-S-Op	Vertex to Sella line (**V-S**) and Sella to Opisthocranion line **(S-Op)**
M17. ∠Op-S-Ba	Opisthocranion to Sella line **(Op-S)** and Sella to Basion line **(S-Ba)**
M18. ∠Ba-S-ANS	Basion to Sella line **(Ba-S)** and Sella to Anterior Nasal Spine line **(S-ANS)**
M19. ∠ANS-S-N	Anterior Nasal Spine to Sella line **(ANS-S)** and Sella to Nasion line **(S-N)**
M20. ∠N-S-G	Nasion to Sella line **(N-S)** and Sella to Glabella line **(S-G)**
M21. ∠G-Ba-Op	Glabella to Basion line **(G-Ba)** and Basion to Opisthocranion line **(Ba-Op)**
M22. ∠G-N-S	Glabella to Nasion line **(G-N)** and Nasion to Sella line (**N-S)**

Table 3. Ratios calculated for the analysis.

Ratio	Description
R1	M1/M9
R2	M2/M9
R3	M3/M9
R4	M4/M9
R5	M5/M9
R6	M6/M9
R7	M7/M9
R8	M8/M9
R9	M10/M9
R10	M11/M9
R11	M12/M9
R12	M13/M14

Table 4. The single measures of Intraclass Correlation Coefficient (ICC) obtained for testing the reliability.

Variables	Intra-Observer measures	Inter-Observer measures
M1	1.000	1.000
M2	.999	.999
M3	.997	.997
M4	.996	.985
M5	.998	.994
M6	.998	.997
M7	.998	.998
M8	.997	.993
M9	.997	.997
M10	.995	.981
M11	.998	.997
M12	.996	.997
M13	1.000	1.000
M14	.998	.998
M15	.872	.958
M16	.985	.838
M17	.975	.888
M18	.985	.951
M19	.966	.944
M20	.859	.932
M21	.977	.931
M22	.910	.862

Table 5. Means and standard deviations for 22 measurements and 12 ratios by sex.

	Female (N = 60)		Male (N = 59)	
Variable	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**
M1_ G-Op[a]	511.64	68.39	539.92	79.86
M2_ V-Ba[a]	393.56	52.91	412.91	62.26
M3_ G-V[a]	371.72	47.89	399.85	61.59
M4_ V-Op[a]	327.05	48.95	342.63	55.93
M5_ Op-Ba[a]	287.86	43.20	295.59	47.72
M6_ Ba-G[a]	312.22	40.30	331.55	48.31
M7_ N-Ba[a]	280.71	35.22	301.87	46.24
M8_ S-ANS[a]	225.34	25.46	244.15	34.54
M9_ N-S[a]	188.03	22.38	202.05	28.52
M10_ S-Ba[a]	119.22	16.57	131.39	21.94
M11_ Ba-ANS[a]	258.55	31.42	278.61	41.41
M12_ ANS-N[a]	141.01	18.83	149.58	24.21
M13 _ GVOpBaG[a]	102025	27222	113267	33837
M14 _ NSBaANSN[a]	26948	6373	31632	9404
M15_angNSV	101.27	5.02	102.97	4.90
M16_angVSOp	62.98	4.54	64.21	6.26
M17_angOpSBa	65.09	4.34	64.45	5.08
M18_angBaSANS	92.03	4.46	90.85	4.99
M19_angANSSN	38.38	2.39	37.55	2.27
M20_angNSG	11.79	2.37	9.43	1.96
M21_angGBaOp	116.93	4.05	118.83	4.51
M22_angGNS	110.52	3.95	115.63	5.55
R1_M1_M9	2.72	0.11	2.67	0.10
R2_M2_M9	2.09	0.11	2.04	0.12
R3_M3_M9	1.98	0.11	1.98	0.13
R4_M4_M9	1.74	0.11	1.70	0.13
R5_M5_M9	1.53	0.11	1.46	0.11
R6_M6_M9	1.66	0.07	1.64	0.06
R7_M7_M9	1.49	0.05	1.49	0.06
R8_M8_M9	1.20	0.05	1.21	0.06
R9_M10_M9	0.64	0.06	0.65	0.06
R10_M11_M9	1.38	0.06	1.38	0.06
R11_M12_M9	0.75	0.05	0.74	0.05
R12_M13_M14	3.77	0.27	3.59	0.26

a – The data were gathered from unscaled cephalograms so the conversion factor to real world measurements is unknown and varies for each image. Values are given in pixels. If it is assumed that the mean scaling factor is similar between males and females, then these values can be used to identify sex differences.

Table 6. P-values of predictors in first iteration of the model (p<.05 significant).

Variables in the Equation					
Variable	M15	M20	M21	M22	R12
P-value	0.001	0.005	0.507	0.000	0.000

Table 7. Regression table

Parameter	b (se)	Odds Ratio (lower 95% CI, upper 95% CI)
Intercept	-37.826 (11.002)	N\A
M15	0.209 (0.061)	1.233 (1.093, 1.391)
M20	-0.421 (0.148)	0.656 (0.491, 0.878)
M22	0.329 (0.072)	1.39 (1.206, 1.602)
R12	-4.411 (1.242)	0.012 (0.001, 0.138)

R^2 = .478 (Cox-Snell), .637 (Nagelkerke), model χ^2 (4) = 77.303, p <.001

Table 8. Sex Calculator
Cells for input (grey), automatic generated data (probability of being male and predicted sex). Values of one subject are inputted to the calculator; Variables description can be found in table 2.

NSV Angle	NSG Angle	GNS Angle	G-V-Op-Ba-G to N-S-Ba-ANS-N Ratio	Probability of Being Male	Predicted Sex
104	5	107	3.99	34.13%	Female

Table 9. The agreement of predicted sex using the developed calculator with the real sex of 15 subjects not included in building the regression model.

Subject	Probability of being male (%)	Predicted sex	Real sex	Agreement
1. M575-26y4m-D	94.32	Male	Male	✓
2. F-132-26y-O	0.77	Female	Female	✓
3. F-304-26y-O	0.62	Female	Female	✓
4. M563-25y7m-D	39.27	Female	Male	✕
5. F-305-25y-O	0.62	Female	Female	✓
6. M600-24y2m-D	96.16	Male	Male	✓
7. M984-24y1m-D	99.08	Male	Male	✓
8. F-250-2-24y-O	3.07	Female	Female	✓
9. F-100-1-23y11m-O	71.45	Male	Female	✕
10. M523-23y2m-D	92.06	Male	Male	✓
11. M528-23y-D	88.01	Male	Male	✓
12. M589-23y-D	96.85	Male	Male	✓
13. F98-22y11m-D	2.69	Female	Female	✓
14. M552-22y9m-D	86.99	Male	Male	✓
15. M517-22y7m-D	96.90	Male	Male	✓