

ORIGINAL ARTICLE

Radiographic Analysis of Sexual Dimorphism in Maximum Cranial Length among Adult Indonesian Males and Females

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ABSTRACT

Introduction: The maximum cranial length (MCL), measured as the horizontal linear distance from the glabella to the opisthocranium, is a fundamental parameter in anthropometric studies with important applications in forensic identification and clinical evaluation. Although it has been widely reported in previous research, radiographic-based MCL data across different age groups and sexes in the Indonesian population remain scarce. **Method:** We conducted a linear measurement analysis of the MCL based on the plain skull-lateral view radiographs of 26 men and 26 women in Surabaya, East Java, Indonesia, from five age groups using MicroDICOM software (2024.2). We excluded data from patients with major trauma or congenital abnormality. We performed intra- and inter-observer analysis prior to the final calculations. All data were analyzed using an independent t-test, with a significance level set at $p < 0.05$ (SPSS 24.0). **Results:** MCL was significantly greater in males than females ($p = 0.001$). However, no significant differences were found across the five age groups ($p = 0.895$). Spearman's correlation also showed no significant association between age and MCL ($r = 0.013$, $p = 0.927$), indicating stability of cranial length in adulthood. **Conclusion:** These findings support the use of radiograph cephalometry measurement of the MCL to differ between sexes. Further study is needed to justify our results, with larger sample numbers and other anthropometry parameters.

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INTRODUCTION

Maximum cranial length (MCL), defined as the linear distance between the glabella and the opisthocranium, is a crucial parameter in radiographic analysis, widely used in both forensic and clinical anthropology. It is particularly valuable in sex estimation, as numerous studies have demonstrated males typically exhibit longer cranial lengths than females, with an average difference ranging from 10 to 15 mm across populations (1, 2). In Indonesia, however, previous research has focused more on other craniofacial metrics. For instance, Ramadhani et al. (2024) assessed 116 lateral cephalograms (58 males and 58 females) in Yogyakarta, reporting significant sex-based differences in cranial base length (Ba-N) and total facial height (N-M), with a sex prediction accuracy of 88.8% using logistic regression. Similarly, Aurizanti et

al. (2017) examined 100 cephalograms (50 males and 50 females) from Jakarta, identifying significant dimorphism in ten linear craniofacial parameters, including the Ba-N length. Despite these advances, no recent studies have specifically investigated MCL on lateral skull radiographs in adult Indonesian populations. This highlights a notable gap in localized morphometric data, underscoring the importance of evaluating MCL as a potential parameter for accurate forensic sex estimation in Indonesia's diverse population context (3, 4).

MCL has demonstrated significant forensic relevance due to its sensitivity to anatomical, developmental, and temporal variations. Studies have shown that MCL changes over time and across populations. Jellinghaus et al. (2018) reported a consistent increase of 2–3 mm per decade in the German population, while Al-Shaqsi et al. (2019) found a 4% difference in cranial length in craniostylosis patients before and after surgery. Growth-related changes during childhood and adolescence, as noted by Akbar et al. (2019), further contribute to sexual dimorphism and inter-population

variability, underscoring the need to consider age and ethnicity when using MCL for forensic identification (1, 2, 5).

Previous studies from diverse populations have confirmed the forensic utility of MCL in sex estimation. Shrestha et al. (2015) conducted a craniometric analysis on 200 autopsied individuals (148 males, 52 females) of Nepalese origin, measuring MCL along with other cranial dimensions. They reported a significantly longer MCL in males (mean: 17.8 cm) compared to females (mean: 16.9 cm), and found a moderate to strong correlation between MCL and stature ($r = 0.494$; $p < 0.001$), especially among females (6). Similarly, Cappella et al. (2020) studied 80 dry skulls (40 males, 40 females) from a modern Italian skeletal collection and found that MCL was one of the most sexually dimorphic traits, with males averaging 17.80 cm and females 16.90 cm (7). Sofwanhadi (2001) measured dry skulls from Javanese, Batak, and Chinese students in Jakarta and found Batak males had the longest head length (191.3 mm), with comparable trends among females, although the study dates back over two decades (8). These findings demonstrate that MCL is a consistently dimorphic and population-sensitive measurement that holds strong potential for forensic sex estimation across different ethnic groups (6–8).

Based on previous positive findings, this study aims to analyze the differences in MCL between males and females as well as among age groups in the adult Indonesian population. By measuring MCL using lateral skull radiographs, this study is expected to provide more accurate data on cranial length differences based on sex and age (2, 7–9). This data will make a significant contribution to forensic identification and clinical evaluation, especially in Indonesia, where population-specific data is still limited. We hypothesize that MCL between adult males are significantly different from adult females based on the calculation using the plain lateral skull X-rays among mongoloid race in Indonesian sample population. MCL differs significantly between sexes but remains stable across adult age groups in the Indonesian population.

MATERIALS AND METHODS

Study Approval and Ethical Considerations

This study received ethical approval with registration numbers 082/KEP/2024 and 25/KEP-RSHU/VIII/2024, from ethical committee in Universitas Airlangga Hospital, Surabaya, East Java, Indonesia and Husada Utama Hospital, Surabaya, East Java, Indonesia. The confidentiality of all subject data was maintained, and data were used solely for research purposes.

Study Design

A cross-sectional study design was employed to measure maximum cranial length (MCL) in the adult Indonesian

population (6). Data collection was based on secondary data from lateral skull radiographs that met specific inclusion and exclusion criteria. This study took place in Surabaya, East Java, and the dates of the radiograph were taken between 2020 and 2024.

Population and Sample

The study population consisted of adult Indonesian males and females who underwent lateral skull radiography between 2020 and 2024 in the two hospitals. A total of 52 subjects were purposively selected based on specific inclusion and exclusion criteria. Purposive sampling was employed due to the targeted nature of this forensic study, where only adult individuals with clear lateral skull radiographs and no cranial abnormalities could provide valid measurements for sexual dimorphism analysis. While this method introduces some selection bias, it is considered appropriate for preliminary morphometric studies with specific population characteristics (10–12). A post-hoc power analysis was performed using G*Power software (version 3.1), setting $\alpha = 0.05$ and power $(1-\beta) = 0.80$. Based on a previously reported effect size (Cohen's $d = 0.94$) derived from comparable cranial length studies, the minimum sample required to detect a significant difference between sexes was estimated at 15 participants per group. Our total sample of 52 (26 males, 26 females) thus met the criteria for sufficient statistical power (13, 14).

Data Collection

Initially, we possessed 74 medical records comprising the lateral plain skull radiographs of the designated individuals. Following multiple screenings utilizing the exclusion criteria, 48 radiographs satisfied the inclusion criteria. The radiographs were imported into MicroDICOM Software (2024.2) in .dcm file format, and calibrated for scale using a standardized skull marker embedded in the imaging protocol. Calibration was performed by measuring the embedded reference marker using the distance tool and inputting the actual length of the marker into the software's calibration function. This allowed the software to adjust all subsequent linear measurements to reflect true anatomical distances in millimeters (mm), ensuring precision across all data points. Calibration ensured that all linear measurements were standardized in millimeters (mm) (15). MCL was defined as the linear distance from the glabella to the opisthocranium, measured using the MicroDICOM software tools (Fig. 1) (16, 17). In the evaluation of the parameter ($n=52$), the skull photographs were classified by sex in a blinded way. Each measurement was conducted twice, initially in a blinded manner by one researcher, followed by a single measurement by a second observer, with a minimum interval of one week between sessions to assess both inter-observer and intra-observer reliability and ensure consistency. The mean \pm standard deviation of the three measurements of each sample was then computed (10).

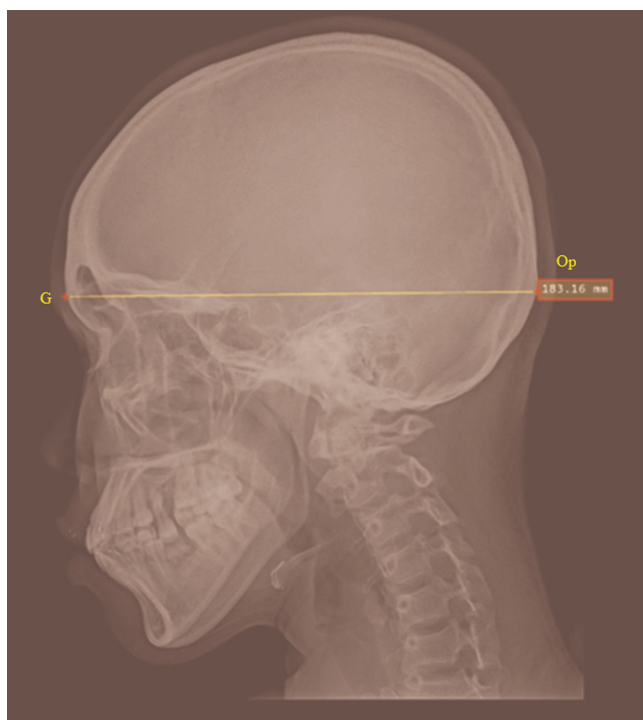


Figure 1: Lateral skull X-ray illustrating the measurement of maximum cranial length (MCL) from the glabella (G) to the opisthocranium (Op). The yellow line represents the linear distance measured using MicroDICOM software, providing an example of cranial length assessment. This image demonstrates the methodology used to determine MCL. Sources: Adapted from (16, 17).

Data Analysis and Processing

The data was then collected in Microsoft Excel 2021 (18). All statistical analyses were conducted using SPSS version 24.0 (19). The Kolmogorov-Smirnov test was used to assess data normality. If data were normally distributed, independent t-tests were employed to compare MCL between sexes and age groups. For non-normally distributed data, the Mann-Whitney U test was used. Additionally, one-way ANOVA was applied to analyze differences across age categories, with the significance level set at $p < 0.05$. MCL measurements were reported as mean \pm standard deviation (SD). For the correlation analysis, the average value of MCL obtained from repeated intra-observer measurements was used to minimize random error and ensure measurement consistency.

RESULTS

The study selection involved identifying 75 lateral skull radiographs taken between 2020 and 2024. After rigorous screening, 52 radiographs were found to meet the inclusion criteria, resulting in a final sample of 26 males and 26 females. The criteria for exclusion included images that were not clear or radiographs indicating cranial deformities, which could affect the accuracy of maximum cranial length (MCL) measurements. Previous studies have also highlighted the importance of using high-quality radiographic images for precise radiographic analysis (6, 7).

The excluded cases mostly involved radiographs that exhibited signs of cranial abnormalities or imaging artifacts that could lead to measurement errors. This strict selection process was necessary to ensure the validity of the findings, given that accurate MCL measurements are crucial for determining sex and age-related differences in anthropometric studies. A sample size of 52 subjects is considered adequate for statistical analysis in forensic anthropometry, providing enough power to detect significant differences in MCL between sex groups. This sample size is supported by previous studies, such as the research by Allareddy et al. (2016) which used a smaller sample of 27 subjects and still yielded meaningful results, thereby reinforcing the strength of the current study's sample size (20).

In this study, intra- and inter-observer reliability analyses were conducted to reduce potential observational bias (10). These analyses involved two measurements by the first observer (intra-observer analysis), which were then compared with measurements taken by a second observer (inter-observer analysis), as shown in Table 1.

Table 1. Intra-observer analysis in men and women from observer, and inter-observer analysis in men and women from observer 1 and 2.

Group	p (Saphiro-Wilk)	p (Levene test)	p between (dependent-t test)
Observation 1.1 (M=10, F=10)	0.109(M), 0.632(F)	0.225	
Observation 1.2 (M=10, F=10)	0.390(M), 0.472(F)	0.174	0.627
Mean Observation 1 (M=10, F=10)	0.148(M), 0.572(F)	0.170	
Observation 2 (M=10, F=10)	0.190(M), 0.312(F)	0.202	0.513

Footnotes:

Shapiro-Wilk test:

- Tests the normality of data distribution.
- Results are provided separately for male (M) and female (F) participants.

Levene test:

- Assesses the equality of variances between groups.

Dependent-t test:

- Compares paired means within groups.

Group (M=10, F=10):

- M and F represent male and female groups, with 10 participants each.

Missing values in p between indicate no significant difference detected in paired comparisons.

Results from the intra-observer analysis indicated no significant differences in measurements of Observation 1.1 and Observation 1.2 ($p=0.627$). Likewise, the inter-observer analysis revealed no significant discrepancies between Observation 1 and Observation 2 ($p=0.513$) measurements. This consistency across intra- and inter-observer assessments supports the reliability of the data collected.

The subsequent analysis was conducted on the total sample of 52 individuals. Results from the Kolmogorov-Smirnov test confirmed that the data follows a parametric distribution, with normality indicated by p-values of 0.200 for both males and females across all observations. Levene's test also verified homogeneity of variances,

with p-values of 0.735, 0.994, 0.880, and 0.834 across the respective observations, indicating no significant variance differences between male and female groups.

As shown in Table II, the mean ± SD of the MCL in males was consistently larger than in females across all observations. In Observation 1.1, the average MCL for males was 206.5±12.52 mm, while for females, it was 194.62±13.22 mm, with a statistically significant difference (p=0.002). Similarly, in Observation 1.2, males had a mean MCL of 206.99±12.72 mm compared to 195.14±12.53 mm for females, yielding a p-value of 0.001. The Mean Observation 1 results, which averaged both measurements from Observer 1, showed males with a mean MCL of 206.71±12.59 mm and females with 194.84±12.77 mm, also resulting in a significant difference (p=0.001). Finally, in Observation 2, where measurements were taken by a second observer, males had an MCL of 207.19±13.2 mm, while females averaged 195.42±12.49 mm, with a p-value of 0.002. Fig. 2a-b illustrates this significant difference in MCL between males and females, providing a visual example of the measurements taken between the glabella (G) and opisthocranium (Op) landmarks.

Table II. Comparison of the maximum cranial length between sexes.

Observation	Male (n=26) (μ±SD mm)	Female (n=26) (μ±SD mm)	p (Kolmogorov-Smirnov test)	p (Levene test)	p between (independent-t test)
Observation 1.1	206.5 ±12.52	194.62 ±13.22	0.200(M), 0.157(F)	0.735	0.002
Observation 1.2	206.99 ±12.72	195.14 ±12.53	0.200(M), 0.152(F)	0.994	0.001
Mean Observation 1	206.71 ±12.59	194.84 ±12.77	0.200(M), 0.200(F)	0.880	0.001
Observation 2	207.19 ±13.2	195.42 ±12.49	0.200(M), 0.200(F)	0.834	0.002

Footnotes:

1. Kolmogorov-Smirnov test: Tests the normality of data distribution. Values are reported for male (M) and female (F) groups.
2. Levene test: Tests the equality of variances between groups.
3. Independent-t test: Compares the means between male and female groups.
4. μ±SD mm: Mean ± Standard Deviation in millimeters.

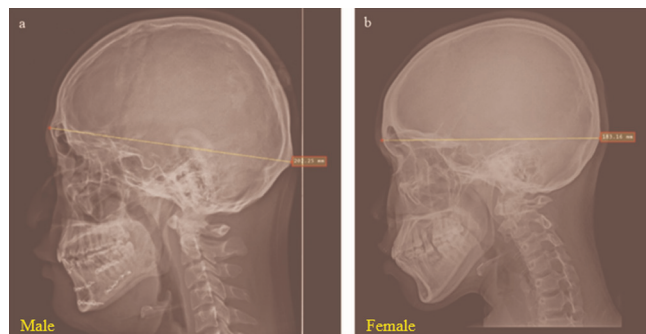


Figure 2a-b: Representative plain skull of maximum cranial length (MCL) between male (a, left side) and female (b, right side) subjects. The images show the linear measurement from the glabella (G) to the opisthocranium (Op), demonstrating a longer cranial length in the male subject compared to the female shown in MicroDICOM Software (yellow line). Sources: Adapted from (16, 17).

These findings demonstrate a consistent, statistically significant difference in MCL between males and females across all observations, with males having a significantly larger MCL than females (p<0.05). This pattern supports the use of MCL as a reliable marker of sex differences in cranial measurements.

The results presented in Table III examine the correlation between MCL and age across different observations. Observation 1.1 shows that the homogeneity test has a p-value of 0.755, indicating homogeneity across age groups. The ANOVA F-value for this observation is 0.200, with a corresponding p-value of 0.896, suggesting no statistically significant difference in MCL across age groups for this observation.

Table III. Comparison of maximum cranial length between 5 age groups.

Observation	Homogeneity (p-value)	ANOVA (F-value)	ANOVA (p-value)
Observation 1.1	0.755	0.200	0.896
Observation 1.2	0.861	0.160	0.923
Mean Observation 1	0.835	0.168	0.917
Observation 2	0.870	0.228	0.876

Footnotes:

- Homogeneity (p-value): Refers to the Levene's test for homogeneity of variances.
- ANOVA (F-value): The F-statistic resulting from the analysis of variance test.
- ANOVA (p-value): Indicates the probability that the observed results occurred by chance.
- All abbreviations are standard, except as defined:
- Observation: Refers to sub-grouped data points within the study.
- Mean Observation: The average value across Observations 1.1 and 1.2.

Similarly, Observation 1.2 has a homogeneity p-value of 0.861, confirming variance consistency. The ANOVA analysis for this observation yields an F-value of 0.160 and a p-value of 0.923, indicating no significant difference in MCL across age categories. The Mean Observation 1, which averages Observations 1.1 and 1.2, also reflects consistent homogeneity with a p-value of 0.835. Its ANOVA F-value is 0.168, and the p-value is 0.917, both pointing to non-significant differences in MCL across age groups.

In Observation 2, the homogeneity test results in a p-value of 0.870, suggesting consistent variance. The ANOVA F-value for this observation is 0.228, with a p-value of 0.876, further confirming the lack of significant correlation between MCL and age across all observations.

A Spearman's rank correlation test was conducted to assess the relationship between MCL and age across different observations. As shown in Table IV, all correlation coefficients were near zero and not statistically significant: Observation 1.1 (r = -0.048, p = 0.738), Observation 1.2 (r = 0.005, p = 0.970), Mean Observation 1 (r = 0.013, p = 0.927), and Observation 2 (r = 0.006, p = 0.969). These consistent results indicate that age does not have a meaningful association with MCL in this adult sample. The absence of correlation may be attributed to the biological stability of cranial

Table IV. Correlation of maximum cranial length and age groups.

Observation	Correlation (r)	p-value
Observation 1.1	-0.048	0.738
Observation 1.2	0.005	0.970
Mean Observation 1	0.013	0.927
Observation 2	0.006	0.969

Footnotes:

Data represent correlation values (r) using Spearman's rank correlation test.
 Observation 1.1 and 1.2 indicate subgroup analyses within the same primary group.
 Mean Observation 1 is the average correlation of Observations 1.1 and 1.2.
 A p-value < 0.05 is considered statistically significant.
 All correlations were analyzed two-tailed.

morphology after adolescence and the relatively narrow age range of the participants. These findings reinforce the understanding that MCL remains stable throughout adulthood, limiting its utility in assessing age-related cranial changes (5, 19).

DISCUSSION

In our study, males demonstrated significantly greater maximum cranial length (MCL) than females, reaffirming its role as a reliable indicator of sexual dimorphism. MCL was measured using lateral skull radiographs to ensure precision and reproducibility. This finding is consistent with previous studies across diverse populations. Ekizoglu et al. (2016) analyzed 400 Turkish adults using multidetector CT and reported significantly longer MCL in males (179.5 mm) than in females (171 mm), attributing the difference to structural cranial robustness (21). Paulinus et al. (2019) assessed 200 Nigerian individuals using CT and found similar results, with males having longer MCL (182.9 mm vs. 178.5 mm) and broader cranial widths (22). In Brazil, Capp et al. (2021) examined 100 dry skulls and 200 CT scans, applying 29 landmarks and 51 cranial measurements, and reported a significant sex difference in MCL (180.5 mm vs. 172.0 mm), with classification accuracy ranging from 82% to 90% (23). Locally, Sofwanhadi (2001) investigated cranial dimensions among Javanese, Batak, and Chinese university students in Jakarta aged 19–26 years using dry skull anthropometry. Batak males had the longest head length (191.3 mm, SD = 5.72), followed by Javanese males (184.3 mm, SD = 6.45), with consistent patterns observed among females. These findings support the cross-cultural validity of MCL as a morphometric parameter for sex differentiation, while also highlighting its relevance in regional forensic applications (8).

No significant correlation was found between MCL and age across all observations in our sample. These results indicate a negligible relationship between age and MCL, suggesting that while MCL is a reliable parameter for sex estimation, it has limited utility in detecting age-related cranial variation among adults. This finding is likely explained by the biological stability of cranial morphology after adolescence. As noted by Roche et al.

(1977), cranial growth slows significantly after skeletal maturity, which may account for the lack of variation observed across adult age groups in our study (24). A contrasting result was reported by Khanduri et al. (2021), who found a statistically significant association between MCL and age in a North Indian population. However, their sample included individuals aged 6 to 95 years, encompassing the full range of cranial development from childhood to late adulthood. In contrast, our study focused exclusively on adult participants, with no inclusion of growing individuals that likely explains the differing outcomes (25).

The primary advantage of MCL measurement lies in its simplicity and non-invasive nature. Using radiographic techniques, MCL can be measured with high accuracy and repeatability, with a standard deviation of 1.25 cm for males and 1.32 cm for females in this study. This makes it an ideal tool for forensic identification and clinical assessments, particularly in cases where determining sex from skeletal remains is essential (26, 27). Furthermore, MCL measurement has been shown to be highly reliable across different populations, enhancing its usefulness in comparative studies of human variation (23).

Despite its advantages, MCL measurement also has limitations. For instance, MCL alone may not provide comprehensive information about cranial morphology or be sufficient for diagnosing complex cranial deformities. In this study, no significant correlation was found between MCL and age, which limits its utility in assessing age-related cranial changes. Additionally, while the mean difference between male and female MCL was statistically significant (1.17 cm, $p < 0.002$), this difference may not be sufficient for sex estimation in all cases. Furthermore, MCL measurements can be influenced by inter-observer variability, although modern imaging techniques like CT scans can reduce this issue by providing more accurate and detailed measurements (21, 22).

In this study, the limited sample population was based on previous similar studies involving radiographic anthropometry (11, 12, 20). However, this study can be further developed using a larger sample size to increase the power of the study. Arguably, our study is among the first to report radiographic anthropometry using plain skull X-rays in adult Indonesian populations. To enrich the current knowledge in forensic anthropology, future studies should consider incorporating larger, more diverse samples and explore the use of 3D imaging techniques or artificial intelligence algorithms to advance digital radiography in forensic and anthropological fields (22, 27).

CONCLUSION

In the current study, the maximum cranial length (MCL) in adult males of Indonesian sample population is

significantly larger than in adult females shown on the radiography of plain skull X-rays. Although, the sample population here can be added in the future study to increase the power of the study, the current findings give a clear result that can be a basis of data for the next research. Furthermore, the radiograph is shown to be a reliable and relatively convenience methods compared to the post-mortem and/or living anthropometry measurement.

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