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SEX DETERMINATION BASED ON THE RADIOGRAPHIC EXAMINATION OF THE METATARSAL BONES: A RETROSPECTIVE STUDY IN GHANAIAN HOSPITALS

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Abstract

Background. Sex determination, the process of classifying human remains as either male or female, is a fundamental step in forensic anthropology and archaeological investigations. There is a paucity of literature on the use of metatarsal bones in sex determination. This study, therefore, assessed the accuracy of using metatarsal bones for forensic sex determination in the Ghanaian setting. In this study the accuracy of metatarsal bone length-to-width (L/W) ratios for sex determination, age-related reliability, and sexual dimorphism in a Ghanaian population were evaluated.

Methods. A retrospective cross-sectional design was employed, analysing radiographic image data of 256 individuals (54.3% male, 45.7% female) aged between 20 and 60 years. Measurements of the first (M1) and second (M2) metatarsals were obtained from digital foot radiographs, and L/W ratios were calculated. Statistical analyses included receiver operating characteristic (ROC) curve analysis to assess discriminative power, regression analysis with interaction terms to evaluate age effects, and multivariate analysis of variance (MANOVA) to examine sexual dimorphism.

Results. Most participants (56.6%) were in early adulthood (ages 20–41). The second metatarsal (M2) was longer than the first (M1) (M2: 70.13 ± 6.38 mm vs. M1: 57.84 ± 5.99 mm), while M1 was wider than M2 (M1: 19.64 ± 2.39 mm vs. M2: 13.73 ± 2.14 mm) for both males and females. Males had bigger M1 and M2 than females, lengthwise and in width. ROC analysis revealed poor accuracy for sex determination, with area under the curve (AUC) values of 0.43 for M1 and 0.52 for M2. Age did not significantly influence the reliability of L/W ratios ($p > 0.05$). MANOVA confirmed significant sexual dimorphism in metatarsal dimensions (Wilks' $\lambda = 0.88$, $p < 0.0001$), with males exhibiting larger bone sizes (length: +12 – 14%; width: +15 – 18%).

Conclusion. Metatarsal bone measurements alone are insufficient for reliable sex determination in forensics, particularly in the Ghanaian context. However, when used in conjunction with other skeletal indicators, they can contribute to forensic investigations. Further research on population-specific variations is recommended.

Keywords. Anthropology, archaelogy, foot X-ray, metatarsals, sex determination.

INTRODUCTION

Sex determination, the process of classifying human remains as either male or female, is a fundamental step in forensic anthropology and archaeological investigations. Assessing sex from skeletal remains poses a complex challenge.[1] Accurate sex determination is critical for constructing reliable demographic profiles in archaeological contexts and it increases the likelihood of positive identification in forensic cases.[2] Researchers have developed various population-specific discriminant functions and logistic regression equations based on measurements from different bones, such as the skull,[3] pectoral girdle,[4] sternum,[5] pelvis,[6] and hand and foot bones.[7] However, the accuracy of these methods varies; underscoring the need for continuous refinement and exploration of new skeletal indicators.

The reliability of sex determination relies heavily on the completeness of the recovered remains. In scenarios involving fragmented or damaged skeletons, particularly in mass disasters or archaeological contexts, resilient bones like the metatarsals become invaluable.[8] Metatarsal bones are frequently used in such investigations due to their availability, relatively small surface area, their reduced exposure to taphonomic factors, and their protection within footwear. These smaller bones' robustness make them suitable for analysis when other skeletal elements are compromised. Estimating age and sex from these remains are crucial, especially when ante-mortem data is limited or unavailable.[9] Radiography offers a non-destructive approach to measuring skeletal dimensions,[10] making it a particularly useful tool in forensic anthropology. However, radiography is not without limitations; its key limitation is its two-dimensional (2D) nature.[11]

While existing methodologies in skeletal sex determination commonly involve the analysis of pelvic, skull, and femoral characteristics, the potential of metatarsal bone radiography as a primary or complementary method warrants further investigation.[12] Although some criteria for sex determination based on metatarsal bones have been proposed, their accuracy remains a subject of debate within the scientific community.[13] The lack of reliable criteria derived from metatarsal radiographs hinder forensic anthropology research and practice, potentially leading to inaccurate findings and inconsistencies across studies.[14]

Addressing the need for accurate sex determination using radiographic examination of metatarsal bones would provide a valuable resource for forensic and anthropological investigations. It would contribute to improved methods for identifying human remains and enhance the understanding of sexual dimorphism within skeletal samples, particularly in cases where other skeletal elements are unavailable.[15-18] Onuoha et al.[19] compared the feet of Chinese, Nigerian, Malaysian and Indian women. They found that all of them had different foot measurements, with Chinese women having shorter foot lengths. This indicates regional variations in foot anatomy. Given the regional variations in foot anatomy, population-specific data are essential to establish reliable standards for sex estimation.[19] Therefore, this study aimed to evaluate the efficacy of metatarsal bone radiography for sex determination in a Ghanaian population, where such data are currently lacking. The aim of this study was achieved by assessing the accuracy of metatarsal bone length-to-width (L/W) ratios for sex determination, age-related reliability, and sexual dimorphism.

MATERIALS AND METHODS

Ethical considerations

The study was approved by the Institutional Review Board (IRB) of the University of Cape Coast. The data were de-identified before extraction to ensure no identifiable information was present on the radiographic images. The data was stored on a password-protected computer to ensure only the researchers had access to the data.

Research design

This study employed a retrospective cross-sectional design, utilising pre-existing radiographic data to assess metatarsal bones for sex determination. This approach ensured the analysis of existing imaging data while eliminating the need for direct patient interaction.[20] Digital foot radiographs were extracted from the hospital's Picture Archiving and Communication System (PACS) and analysed using specialised measurement tools. The retrospective nature of this study minimised ethical concerns while enabling a cost-effective and efficient review of a large dataset.

Study sites

The study was conducted at two major hospitals in Ghana. These hospitals were selected based on the access to a large volume of high-quality radiographic image data, ensuring a diverse and representative sample, since these two facilities serve a big part of the Ghanaian population.

Target population, sampling and sample size

The study focused on individuals who had foot radiographic examinations between 2020 and 2023 at the two facilities. Radiographic images of both males and females were included since the aim of this study was to assess whether sex can be accurately determined using metatarsal bone measurements. A purposive sampling technique was used to select the digital foot radiographs included in the data set. The inclusion and exclusion criteria were as follows:

Inclusion criteria

- Patients between 20 and 95 years of age
- Male and female patients' foot radiographic images
- High-resolution foot radiographic images with clearly visible metatarsal structures

Exclusion criteria

- Cases with bone diseases or abnormalities affecting metatarsal structures
- Prior foot or lower limb surgeries that could alter natural bone dimensions
- Blurry or incomplete radiographic images

A preliminary survey of the PACS system at both hospitals identified 760 eligible foot radiographs performed between 2020–2023. The sample size was determined using Taro Yamane (1967)[21] formula for finite populations. The sample size was determined to be 262 to ensure representativeness of the target population (n = 262). However, six radiographic images were excluded due to poor image quality (n = 6) yielding a final sample size of 256 foot radiographic examinations (n = 256).

Data collection

Radiographic data were extracted from the PACS system at the two hospitals. The data was de-identified during extraction and stored on password-protected computers. The length (L) and width (W) of the first (M1) and second (M2) metatarsal bones were measured using digital calipers integrated into a radiographic software tool (Spectra PACS). Each measurement was recorded in millimeters (mm) for subsequent statistical analysis. For each radiograph in the dataset, the anatomical length of the first (L1) and second (L2) metatarsals was measured from the most proximal point of the metatarsal bone to the most distal point of the metatarsal head. The widest transverse width of each metatarsal was recorded at the broadest cortical margins. All measurements were taken in a uniform viewing environment, with magnification and scaling controlled by the embedded calibration marker in the system to ensure precision. The first metatarsal (M1) length, second metatarsal (M2) length, width of first metatarsal (W1), and width of second metatarsal (W2) were measured for each radiographic image in the dataset. Figure 1 shows how the measures were performed. To enhance measurement accuracy and inter-observer reliability, two independent senior radiographers, each with over fifteen years of clinical practice experience, reviewed each image. Furthermore, discrepancies in measurements were resolved through consensus.

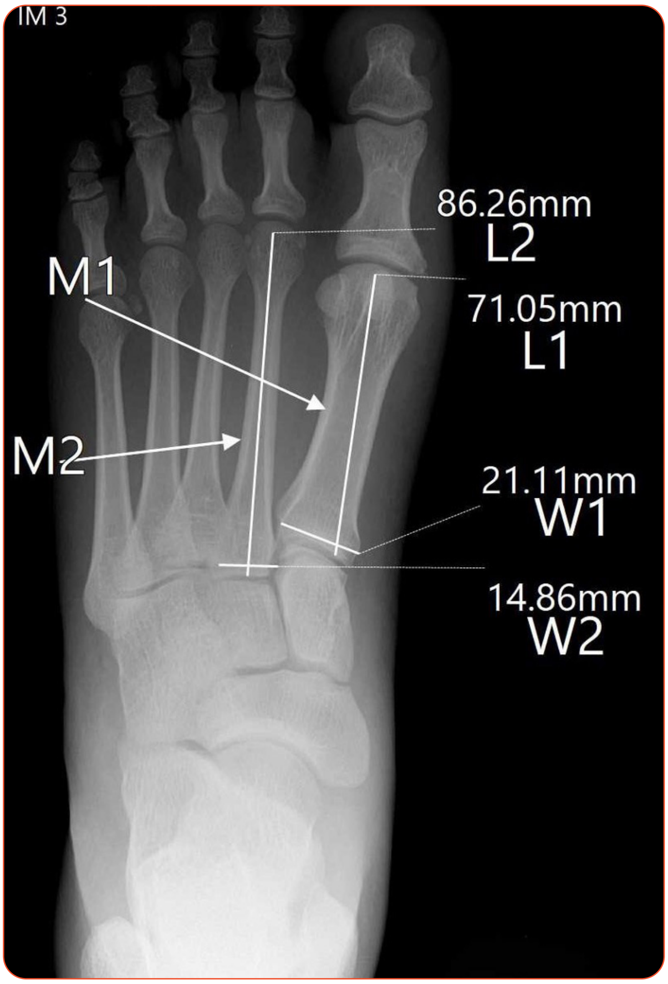

Figure 1. Shows how length (L1, L2) and width (W1, W2) were measured.

Data analysis

Statistical analysis was performed using SPSS (Version 26) and Microsoft Excel (2019). Descriptive statistics, which included measures of central tendency (distribution frequency, percentages, mean & median) and variability (standard deviation & range) were used to summarise metatarsal measurements. Independent samples t-test was applied to compare metatarsal length, width and the L/W ratio between males and females. The accuracy of sex determination was evaluated using the L/W ratio of the first and second metatarsal bones. ROC curves were used to assess the discriminative power of these ratios, with the AUC serving as a critical metric for overall accuracy. An interaction analysis was conducted to examine how age interacts with the L/W ratio of the first and second metatarsal bones in predicting sex. The key metrics evaluated include the coefficients, standard errors, z-scores, *p*-values, and confidence intervals for each variable, allowing us to assess the statistical significance and potential impact of age on the accuracy of sex determination. A multivariate analysis of variance (MANOVA) was conducted to examine the differences in the lengths and widths of the first (M1) and second metatarsal bones (M2) between males and females in the study population. A *p*-value less than 0.05 were considered statistically significant.

RESULTS

Demographic characteristics

The study included 256 participants, with 54.3% males and 45.7% females. The majority participants (56.6%) were age between 20–41 years (Table 1).

Table 1. Demographic distribution of participants

Variable	Frequency (n)	Percentage %
Biological sex		
Male	139	54.3%
Female	117	45.7%
Age group		
Early adulthood (18–41)	145	56.6%
Late adulthood (42–66)	104	40.6%
Geriatric (67–95)	7	2.7%

Metatarsal bone measurements

Sexual dimorphism in the metatarsal bone dimensions was found. The second metatarsal (M2) was longer than the first (M1) (M2: 70.13 ± 6.38 mm vs. M1: 57.84 ± 5.99 mm), while M1 was wider (M1: 19.64 ± 2.39 mm vs. M2: 13.73 ± 2.14 mm). M2 exhibited a higher average length-to-width (L/W) ratio across sexes (5.20 ± 0.77) compared to M1 (2.99 ± 0.45)

Table 2. Sex differences in metatarsal bone measurements using independent-samples t-tests and Cohen's d effect sizes (n = 256)

Measurement	Male (n=139) Mean ± SD	Female (n=117) Mean ± SD	Mean difference	t-value	*p*-value	Effect size (d)	Interpretation
Length-M1 (mm)	59.10 ± 5.80	56.20 ± 5.20	2.90	4.21	<0.001	0.49	Males significantly longer
Width-M1 (mm)	20.40 ± 2.30	18.70 ± 2.20	1.70	5.23	<0.001	0.63	Males significantly wider
L/W-M1 ratio	2.92 ± 0.40	3.08 ± 0.48	–0.16	–2.82	0.005	0.36	Females showed higher L/W ratio
Length-M2 (mm)	72.40 ± 6.20	68.10 ± 6.10	4.30	5.18	<0.001	0.64	Males significantly longer
Width-M2 (mm)	14.40 ± 2.20	13.10 ± 2.10	1.30	4.28	<0.001	0.53	Males significantly wider
L/W-M2 ratio	5.05 ± 0.80	5.31 ± 0.75	–0.26	–2.51	0.013	0.32	Females showed higher L/W ratio

(Table 2). Both the first (M1) and second (M2) metatarsal bones were found to be significantly longer in males than in females ($p < 0.001$). The effect sizes ranged from 0.49 to 0.64, indicating a moderate degree of sexual dimorphism in bone length. Similarly, width measurements for both M1 and M2 were significantly greater in males ($p < 0.001$). The effect sizes further support a moderate degree of sexual dimorphism in bone width (d = 0.53–0.63). It was found that females had higher L/W ratios for both metatarsals (M1 & M2), suggesting that although males possess larger absolute metatarsal dimensions, females generally exhibit more slender bone morphology. These ratio differences were statistically significant ($p_{M1} = 0.005$, $p_{M2} = 0.013$), with effect sizes between 0.32 and 0.36, reflecting small-to-moderate but meaningful variations in bone shape between sexes.

Accuracy of sex determination using L/W ratios

Receiver operating characteristic (ROC) analysis showed poor discriminative power for sex determination using L/W ratios. The AUC for M1 was 0.43 (95% CI: 0.35–0.51), and for M2, 0.52 (95% CI: 0.44–0.60), indicating limited utility as standalone metrics (Figure 2 and Figure 3).

Influence of age on sex determination

Interaction analysis revealed no significant effect of age on the reliability of L/W ratios for sex determination (L/W-M1 × age: $p = 0.22$; L/W-M2 × age: $p = 0.90$) (Table 3).

Sexual dimorphism in metatarsal dimensions

Multivariate analysis of variance (MANOVA) confirmed significant differences of the metatarsal measurements between males and females (Wilks' $\lambda = 0.88$, $p < 0.0001$). Males exhibited larger dimensions for both length (M1: +12.1%, M2: +14.3%) and width (M1: +18.5%, M2: +15.2%) compared to females (Figure 4).

DISCUSSION

This study investigated the utility of metatarsal bone measurements for sex determination, focusing on the predictive power of L/W of M1 and M2 metatarsals, the potential influence of age on these measurements, and the inherent differences in lengths and widths between males and females. The findings reveal a nuanced picture of the applicability of these measurements, underscoring both their strengths and limitations within forensic and anthropological contexts.

It was found that L/W ratios of the first and second metatarsals, when used in isolation, demonstrate limited accuracy in sex determination (Table 2). This aligns with the existing research, which suggests that while metatarsals exhibit some degree of sexual dimorphism, their effectiveness as sole indicators for sex prediction are generally limited.[22] The key implication of this finding is that practitioners should exercise caution when relying solely on L/W ratios for sex determination. Instead, these ratios should be considered as supplementary information that contributes to a more holistic assessment. To improve accuracy, future studies should integrate L/W ratios with other skeletal metrics or employ advanced statistical models that can account for the complex interplay of variables influencing bone morphology.[22]

Interestingly, the study's findings indicated that age does not significantly influence the reliability of sex determination when using metatarsal L/W ratios (Table 3). This suggests potential stability in the geometric properties of met-

Table 3. Interaction analysis of age and L/W ratios

Variable	Coefficient	Std. error	*p*-value
Age × L/W-M1	-0.03	0.03	0.22
Age × L/W-M2	-0.002	0.01	0.90

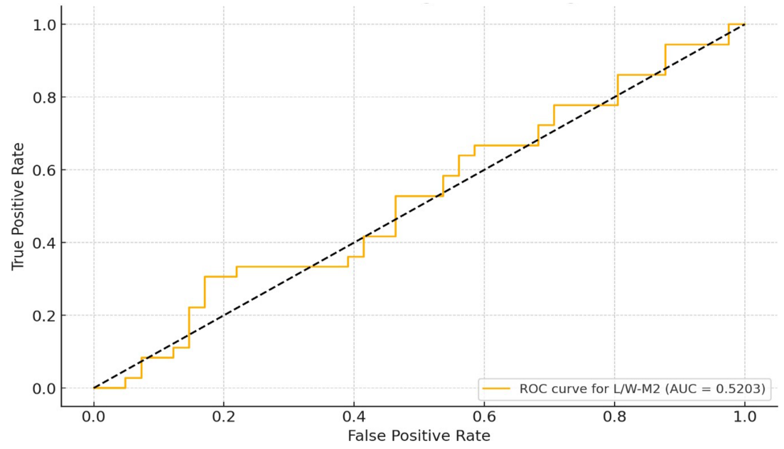

Figure 2. ROC curve for sex prediction using L/W-M2.

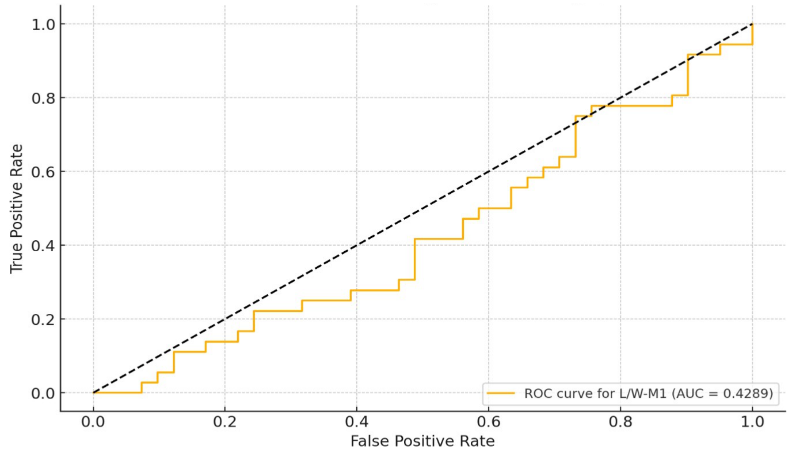

Figure 3. ROC curve for sex prediction using L/W-M1.

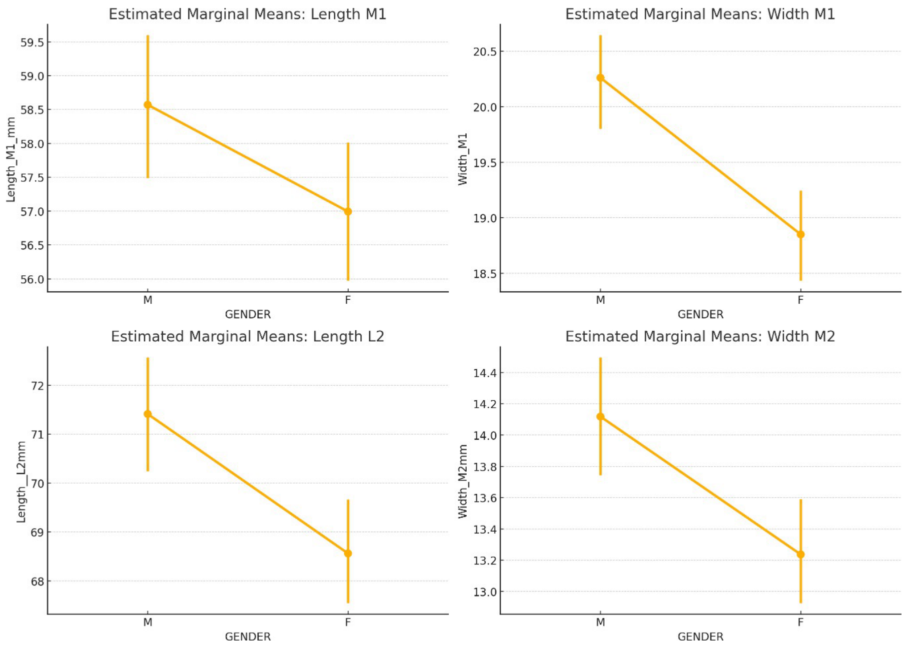

Figure 4. Estimated marginal means of metatarsal dimensions by sex.

atarsal bones across different age groups, adding a layer of consistency for forensic applications. While a prior study acknowledged that bone morphology can change with age due to factors such as bone density loss and degenerative processes,[23] these age-related changes do not seem to significantly impact the L/W ratios examined in our research study. This finding contrasts with some research indicating that age-related changes in cortical bone could influence morphometric analyses used for sex estimation.[24] The lack of significant interaction between age and L/W ratios in our study might be attributed to the robustness of these ratios in maintaining dimensional characteristics, as suggested by Torres et al.[25] Therefore, the findings suggest that age-related corrections may not be necessary when using L/W ratios of metatarsals for sex determination.

The study also found sexual dimorphism in metatarsal bone dimensions, with males exhibiting larger measurements than females (Table 2). This finding is consistent with the existing body of knowledge highlighting the influence of biological sex on bone morphology, particularly in the lower extremities.[25] The observed sexual dimorphism may be attributed to differences in overall body size, physical activity patterns, and hormonal influences, which contribute to variations in bone density and growth.[26] These findings highlight the importance of considering biological sex as a key factor when analysing metatarsal bone measurements in forensic and anthropological contexts, where such measurements are frequently used for sex determination.[26] But, caution is warranted in practical applications due to the overlap in measurements between males and females, which necessitates the integration of these measurements with other skeletal indicators to improve the accuracy of sex determination.[27]

Beyond the direct applications in forensic science and anthropology, the study's findings have broader implications for clinical practice. The identified variability in metatarsal bone dimensions underscores the importance of personalised approaches in orthopaedic interventions and footwear design.[28] Recognising and accommodating individual differences in bone structure can lead to more effective interventions and improved outcomes for patients.

The findings of this study encourage a more nuanced approach to interpreting metatarsal bone measurements. While these measurements can provide valuable insights, they should not be used in isolation. Instead, they should be integrated into a more comprehensive framework that considers other skeletal indicators, demographic factors, and advanced statistical models. Future research should focus on exploring the potential of machine learning algorithms to combine metatarsal measurements with other skeletal data to create more accurate sex determination models. It is also essential to conduct population-specific studies to account for regional variations in bone morphology. As highlighted by Komza and Skinner[29] and Welte et al.,[30] continued interdisciplinary collaboration among forensic scientists, anthropologists, and clinicians is essential to unravel the complexities of human skeletal anatomy and to enhance the accuracy and reliability of sex determination methods. Ultimately, this research contributes to the ongoing effort to improve the precision and reliability of forensic identification techniques. These techniques can further contribute positively to understanding past populations as well as assist in medico-legal cases. Our work contributes not only to the understanding of human variation but also to the development of evidence-based practices in forensic science and clinical medicine.

LIMITATIONS OF THE STUDY

The study is limited since it relied mainly on length-to-width (L/W) ratios of the first and second metatarsal bones. As depicted by the low AUC values, these ratios alone have poor discriminative power for sex determination, which limits the overall applicability of the results in forensic contexts. Moreover, manual measurement of lengths and widths on digital foot radiographic images may be prone to human error, particularly when anatomical landmarks are unclear. Also, the study did not account for factors such as occupation, physical activity or footwear habits, which could influence metatarsal morphology and confound sex determination results. As a recommendation, a future study could assess the influence of occupation, physical activity, or footwear habits on metatarsal morphology.

CONCLUSION

This study demonstrates that metatarsal L/W ratios have limited standalone utility for sex determination due to low discriminative power, despite significant sexual dimorphism. However, L/W ratios' stability across age groups and compatibility with composite methodologies position them as valuable adjuncts in forensic anthropology. Practitioners are advised to employ these metrics within multifactorial frameworks to improve sex determination accuracy in challenging cases.

ETHICS APPROVAL

Ethics approval was obtained from the Institutional Review Board (IRB) at the Cape Coast Teaching Hospital (reference number: CCTHIRB-705/2024). The study was examined by the IRB to make sure it complied with institutional policies and procedures and was ethical.

FUNDING

This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

COMPETING INTERESTS

The authors declare that there are no conflicts of interest.

AVAILABILITY OF DATA

Data required for this study may be made available by the authors upon reasonable request.

GENERATIVE AI USE

Generative AI was not used during any stage of the research study or manuscript compilation.

AUTHOR CONTRIBUTIONS

All authors were involved in the conceptualisation, data collection and analysis, and manuscript preparation.

DISCLAIMER

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