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Evaluating Cardiothoracic Ratio (CTR) and Its Correlation with Clinical Indications and Body Parameters for Heart Size Assessment in Resource-Limited Settings: A Cross-sectional Study

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ABSTRACT

Introduction

Cardiologists always need to determine heart size, which varies with physiological changes. Advanced measurement techniques are costly and often inaccessible to the common man. Measuring the cardiothoracic ratio (CTR) using Chest X-rays (CXR) is a common and more affordable option, but there's a need for even cheaper alternatives. Therefore, the objective of this study was to determine the relationship between CTR and presenting clinical indications and to relate CTR to the body parameters to find an appropriate relationship that can be utilized in low-resource facilities in determining heart size.

Methodology:

This cross-sectional study involved 386 patients undergoing CXR at Mulago National Specialized Hospital's radiology department. Data were summarized using frequencies and percentages. Associations between the CTR and independent variables were analyzed using Pearson's chi-square, Fisher's exact test, Spearman's correlation coefficient, simple linear regression, and multivariate regression. Statistical significance was set at a p-value of < 0.05.

Results:

The median CTR was 0.46, with an interquartile range of 0.42 to 0.50. Female patients had a higher CTR than males. Significant positive correlations were found between CTR and BMI (p < 0.001, correlation 0.21), BSA (p = 0.016, correlation 0.12), and BSI (p < 0.001, correlation 0.19). The relationship between CTR and BSA showed a fair performance as a predictive tool, with sensitivity, specificity, and positive and negative predictive values of 29.2%, 86.0%, 63.6%, and 59.0% for males, and 8.3%, 98.1%, 75.0%, and 60.7% for females, respectively. Thus, BSA was considered a relatively better predictor of CTR.

Conclusion:

BSA shows a moderately good relationship with CTR, while the influence of body habitus on CTR is minimal. Thus, using body parameters to predict CTR should be approached cautiously.

Recommendation:

We recommend conducting a similar study on a more diverse general population.

Key Words: Cardiomegaly, Cardiothoracic Ratio, Body Mass Index, Body Surface Area, Body Surface Index

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Introduction

The heart is vital, with small dysfunctions causing significant effects. It measures 12cm by 8.5cm by 6cm, and weighs 280-340g in males and 230-280g in females (1). Cardiomegaly, or heart enlargement, occurs when the heart's width exceeds half the chest's width on a PA chest radiograph, indicating pathological(2). Heart size varies by sex, age, height, and weight, making it crucial for cardiologists to establish normal ranges, as slight changes can indicate disease. What's normal for some may suggest pathology in others(3).

The cardiothoracic ratio (CTR) on a PA radiograph measures heart size relative to chest width, calculated as the maximal horizontal cardiac width divided by the maximal inner thoracic diameter. A CTR > 0.5 indicates cardiac enlargement(4, 5). An elevated CTR on Chest X-ray (CXR) is linked to higher morbidity in middle-aged and elderly groups and correlates with increased heart size and coronary heart disease(6). While CXR is cost-effective for detecting cardiomegaly and measuring CTR, CT, MRI, and echocardiography offer more precise but expensive alternatives(7). CTR varies due to pregnancy, ascites, or chest deformities, leading to variability in measurements unrelated to heart conditions. Studies highlight discrepancies in CTR accuracy compared to cardiac MRI(4, 8) and differing correlations with BMI, BSA, and BSI, with obesity and age impacting CTR differently(9, 10). Age reliably increases CTR(11). Although heart size and CTR have been studied in other populations, their relevance to Uganda remains unverified

CTR in Ugandans remains undetermined, with limited evidence on its relationship with body parameters. Low-resource settings face challenges in accessing affordable and accurate CTR measurements. Screening relies on costly methods like echocardiography, MRI, and CT, but most Ugandan clinicians assess heart size using CXR. Although body size influences cardiac dimensions, indexed values like BMI, BSI, and BSA are not widely used to estimate CTR

This study aimed to optimize body parameter use for estimating CTR when X-ray measurement is unavailable, helping cardiologists enhance diagnostics without relying on costly methods. CTR is valuable in hospital emergency departments and intensive care units, aiding risk stratification, treatment, and prognosis across diseases beyond cardiology. The study explored the relationship between CTR and various clinical indications, as well as its association with key body measurements like BMI, BSA, and BSI.

METHODS

Study Design and Setting.

The study used a hospital-based cross-sectional design at Mulago National Referral Hospital's radiology department. A digital Philips X-ray machine (model: SRO33100ROT380, serial: 989000086482) processing 20-30 CXR daily was used. This hospital serves patients from all regions, ensuring nationally representative data.

Study Population

The study included all individuals aged 18 and older who underwent CXR at Mulago National Referral Hospital's radiology department from July to September 2023, selected via consecutive sampling. Exclusions were patients without request forms, critically ill patients, those with heart disease (known to influence CTR), incomplete forms, or chest X-rays with motion artifacts.

Sample Size estimation

In this cross-sectional study, the formula(12), where, was used to estimate the number of participants needed to determine the relationship between CTR and clinical indication or CTR and body parameters. Pearson's correlation coefficient, r=0.33, was used for clinical indications (13), and r of 0.283 was used for body mass index. To estimate the number of participants needed to describe the proportion of participants with abnormal CXR, we used the Kish-Leslie formula, while factoring in a

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proportion of 0.5 for an infinite sample size because the proportion of Ugandans with abnormal CTR is unknown. Margin of error of 0.05 (and Z score of 1.96 that corresponds to 95% level of confidence. We therefore came up with an overall sample size of 385 participants.

Study Variables

The independent variables were clinical indications such as cough, difficulty in breathing (DIB), and chest pain, along with demographic factors like age, height, weight, BMI, BSA, BSI, and gender. The dependent variable was CTR.

Study Procedure

The Principal and Co-Principal Investigators (PI and Co-PI) supervised data collection by research assistants. Patients with chest X-ray request forms were eligible for enrollment. Research assistants provided consent forms, explaining the study's purpose, ethics, and objectives. After obtaining signed consent, demographic data and clinical indications were extracted from request forms or obtained directly from patients. Patient weight and height were measured to calculate BMI, BSI, and BSA.

The patient underwent a CXR procedure using PA projection with full inspiration. A Research Assistant obtained a soft copy of the X-ray image and securely stored it on a password-protected research computer. All measurements and relevant data were recorded on a data collection form and entered into a data entry screen created with EpiData software version 3.1

Calculating CTR, BMI, BSA, and BSI.

The Radiant DICOM software was employed to measure the transverse cardiac diameter (TCD), calculated by summing the horizontal distances from the heart's right (a) and left (b) lateral borders to the midline (spinous processes of the vertebral bodies).

The widest transverse thoracic diameter (TTD) (c) was determined by measuring the broadest distance between the medial aspects of the ribs, specifically from pleura to pleura.

The CTR was obtained by dividing the TCD by TTD.

$$CTR = \frac{a+b}{c}$$

$$\mathrm{CTR} = \frac{\mathrm{TCD}}{\mathrm{TTD}}$$

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Image demonstrating how CTR was measured.

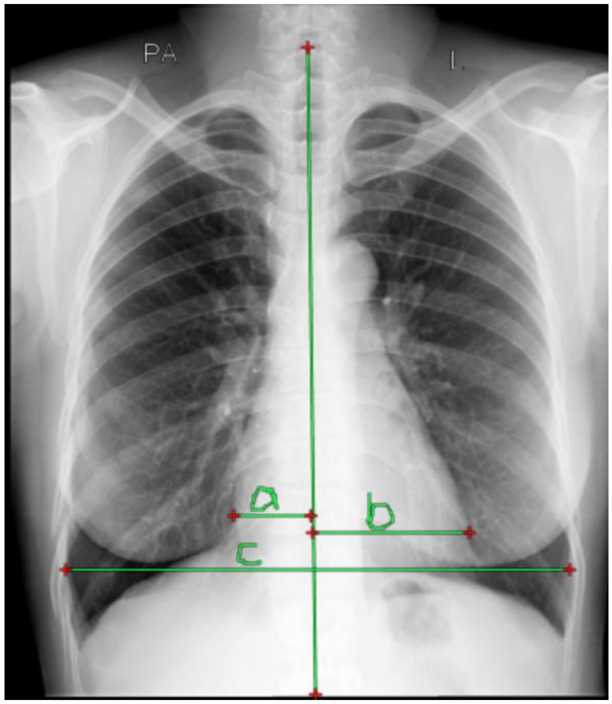

Figure 1; Demonstrating how CTR was measured.

BMI was estimated as a ratio of the patient's weight in kilograms (kg) to the square of the patient's height in meters (m) (14);

$$\mathrm{BMI} = \frac{\mathrm{Weight\ (kg)}}{\mathrm{Height}^2(\mathrm{m}^2)}$$

BSA was estimated from the most widely used technique called the Du Bois and Du Bois formula (15);

$$\mathrm{BSA} = 0.007184 \times \mathrm{Height(m)}^{0.725} \times \mathrm{Weight(kg)}^{0.425}$$

BSI was estimated by dividing both weights by the calculated square root of its BSA. It is mathematically expressed as (16);

$$\mathrm{BSI} = \frac{\mathrm{Weight}}{\sqrt{\mathrm{BSA}}}$$

Bias

Selection bias was minimized through **consecutive recruitment** of all eligible patients undergoing chest X-rays, with clearly defined exclusion criteria to eliminate confounding from pre-existing cardiac conditions. **Measurement bias** was reduced by using standardized procedures, a single digital X-ray machine, and trained research assistants supervised by the PI. Information and observer bias were addressed through pretested tools, validated formulas, and blinded image analysis. Recall and response bias were minimized by relying on objective measurements rather than self-reported data. Confounding bias was controlled by adjusting for key variables such as age, sex, and body parameters in multivariate regression analysis.

Data Management and Analysis

Patient data was recorded in collection forms and reviewed for consistency by the PI before the end of the business day. The validated data were then input into a password-protected interface created with EpiData software version 3.1. A backup of the entered data was stored on an external hard drive.

Data was summarized using frequencies and percentages. The relationship between CTR and independent variables was analyzed using simple linear regression and

Spearman's correlation coefficient. Significance testing was conducted using Pearson's chi-square and Fisher's exact test, with a p-value < 0.05 considered statistically significant.

The dataset was divided into two parts and analyzed in two stages. The first half was stratified by gender, where multivariate linear regression was employed in each stratum. This analysis accounted for participants' age and individually measured body parameters to establish a linear equation relating these variables to CTR.

The second half of the dataset used the linear equations from the first half to predict CTR values based on measured body parameters and participant characteristics, including age. Both the estimated CTR from the derived equation and the CTR determined by the radiologist were categorized as normal (0.42-0.50) or abnormal (below 0.42 or above 0.50). Sensitivity, specificity, and positive and negative predictive values of the estimated CTR were calculated against the standard CTR determined by the radiologist to diagnose abnormal heart size (including microcardia and cardiomegaly).

Ethical Consideration

The study involved patients referred for X-ray services, using anonymized data (images and clinical information) that cannot be traced to individuals. Ethical approval was granted by the Makerere University, School of Medicine Research Ethics Committee. Approval number: Mak-SoMREC-2022-480 and approval date: 05/06/2023. All investigators completed an online human subjects course before the study began.

RESULTS

Study profile

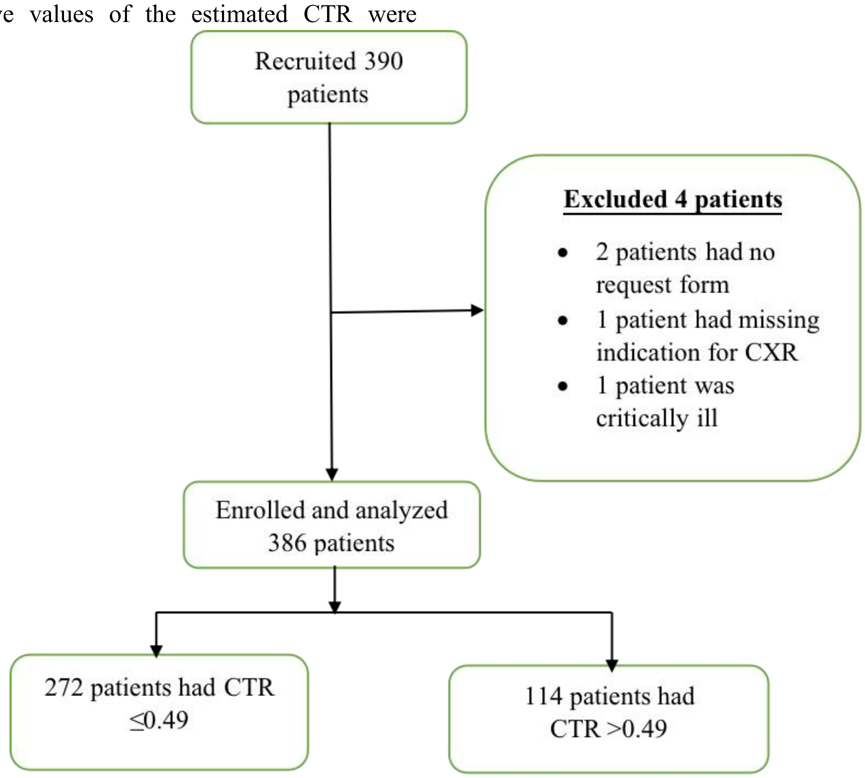

Figure 2; Study profile of patients presenting for chest radiographs in the radiology department at Mulago National Referral Hospital during the study period.

Of the 390 patients initially recruited for the study, 386 were enrolled. Exclusions included two without clinician

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request forms, one with an unclear indication for a chest radiograph, and a critically ill patient.

Characteristics of the Study Participants

The study included 386 patients, of whom 215 (55.7%) were females. The median age was 37 years (IQR: 27-50), with the largest group aged 31-40 (27.7%). The most common indication for chest radiographs was chest pain, reported by 120 patients (31.2%). Details are in Table 1.

Table 1: Characteristics of 386 patients who presented for chest radiographs in the radiology department of Mulago National Referral Hospital during the study.

Characteristics	Frequency	Percentages
Gender		
Female	215	55.7
Male	171	44.3
Age categories		
≤ 20	37	9.6
21-30	92	23.8
31-40	107	27.7
41-50	61	15.8
>50	89	23.1
Indications for CXR		
Chest pain	120	31.2
DIB	114	29.6
Cough	114	29.6
Others	37	9.6

Relationship of Cardiothoracic Ratio (CTR) with Presenting Clinical Indication

The median CTR was 0.46 (IQR: 0.42-0.50), with 114 patients (70.5%) having a CTR > 0.49. Female patients had a higher CTR, with 70 (61.4%), compared to males, but no significant association was found between gender and CTR (P-value: 0.144). Indications for chest radiographs showed no significant association with CTR (P-value: 0.190). However, a significant association was observed between age categories and CTR (P-value < 0.001), as detailed in Table 2.

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Table 2: Relationship between patient characteristics and CTR among patients who presented for chest radiographs in the radiology department of Mulago National Referral Hospital during the study period.

	CTR categorized		
Characteristics	**≤0.49**	**>0.49**	**P-value**
Gender			0.144
female	145 (53.3)	70 (61.4)	
male	127 (46.7)	44 (38.6)	
Age categorized			<0.001
≤ 20 years	32 (11.8)	5 (4.4)	
21-30	77 (28.3)	15 (13.2)	
31-40	82 (30.2)	25 (21.9)	
41-50	37 (13.6)	24 (21.1)	
>50	44 (16.2)	45 (39.5)	
Indications for CXR			0.190
chest pain	88 (32.4)	32 (28.3)	
DIB	86 (31.6)	28 (24.8)	
Cough	72 (26.5)	42 (37.2)	
others	26 (9.6)	11 (9.7)	

Relationship between CTR and BMI

Table 3 shows a positive correlation between the CTR and BMI, which is statistically significant ($P < 0.001$) but weak (Spearman's $r = 0.21$). For female patients, the correlation is weak and significant ($r = 0.22$, $P < 0.001$), while for male patients, it is also weak but significant ($r = 0.16$, $P = 0.033$) (Figure 2 and Table 3)

Table 3 also indicates that patients aged 41-50 years had a statistically significant positive correlation between CTR and BMI ($r = 0.29$, $P = 0.023$), although the correlation was weak. Other age categories showed weak positive correlations between BMI and CTR, but these were not statistically significant (all P-values > 0.05).

Stratifying BMI by chest X-ray indications revealed a statistically significant but weak positive correlation with CTR for patients with chest pain ($r = 0.25$, $P = 0.006$) and difficulty breathing ($r = 0.26$, $P = 0.005$). However, no significant correlation was found between BMI and CTR for patients with cough or other indications.

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Table 3: Relationship between patient BMI and CTR among patients who presented for chest radiographs stratified by gender, age, and indication at the radiology department of Mulago National Referral Hospital during the study period.

		CTR	
	Characteristic	**Spearman's correlation coefficient (*r*)**	**p-value**
BMI stratified by independent variables	**BMI**	0.21	**<0.001**
	Gender		
	female	0.22	**<0.001**
	male	0.16	0.033**
	Age categorized (years)		
	≤ 20	0.14	0.400
	21-30	0.11	0.282
	31-40	0.06	0.528
	41-50	0.29	0.023**
	>50	0.13	0.215
	Indications for CXR		
	chest pain	0.25	0.006**
	DIB	0.26	0.005**
	Cough	0.12	0.198
	others	0.22	0.192

Figure 3 below shows that BMI for both males and females positively increased as the cardiothoracic ratio of both sexes increased; however, the increase was gradual and almost flat.

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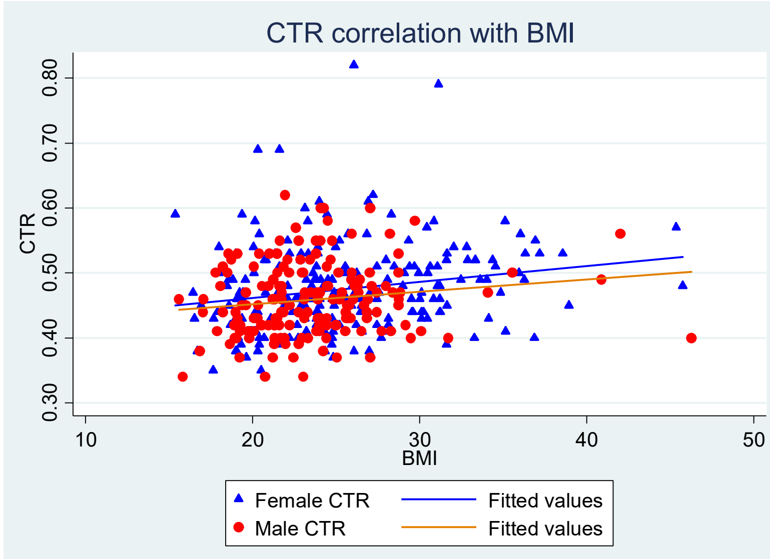

Figure 3; Correlation between strata of BMI by gender with CTR.

Relationship between CTR and BSA

Table 4 shows a positive correlation between CTR and BSA, which was significant (P = 0.016) but very weak (r = 0.12). For female patients, the correlation with CTR was weak but significant (r = 0.20, P = 0.004). In contrast, the correlation among male patients was positive but not significant (r = 0.09, P = 0.260). BSA strata across all age categories were not significantly associated with CTR (all P-values > 0.05).

DIB as a BSA stratum had a weak but significant positive correlation with CTR (r = 0.20, P = 0.030). Chest pain, cough, and other indications showed no significant correlations (p-values > 0.05)

Table 4: Relationship between patient BSA and CTR among patients who presented for chest radiographs stratified by gender, age, and indication at the radiology department of Mulago National Referral Hospital during the study period

		CTR	
	Characteristic	**Spearman's correlation coefficient (*r*)**	**p-value**
BSA stratified by independent variables	**BSA**	0.12	0.016**
	Gender		
	female	0.20	0.004**
	male	0.09	0.260
	Age categorized (years)		
	≤ 20	0.13	0.443
	21-30	0.05	0.666
	31-40	-0.10	0.307
	41-50	0.05	0.716

>50	-0.07	0.497
Indications for CXR		
chest pain	0.12	0.195
DIB	0.20	0.030**
Cough	0.03	0.778
others	0.18	0.295

Figure 4 below shows that BSA for both males and females positively increased as the cardiothoracic ratio of both sexes increased; however, the increase was gradual and almost flat.

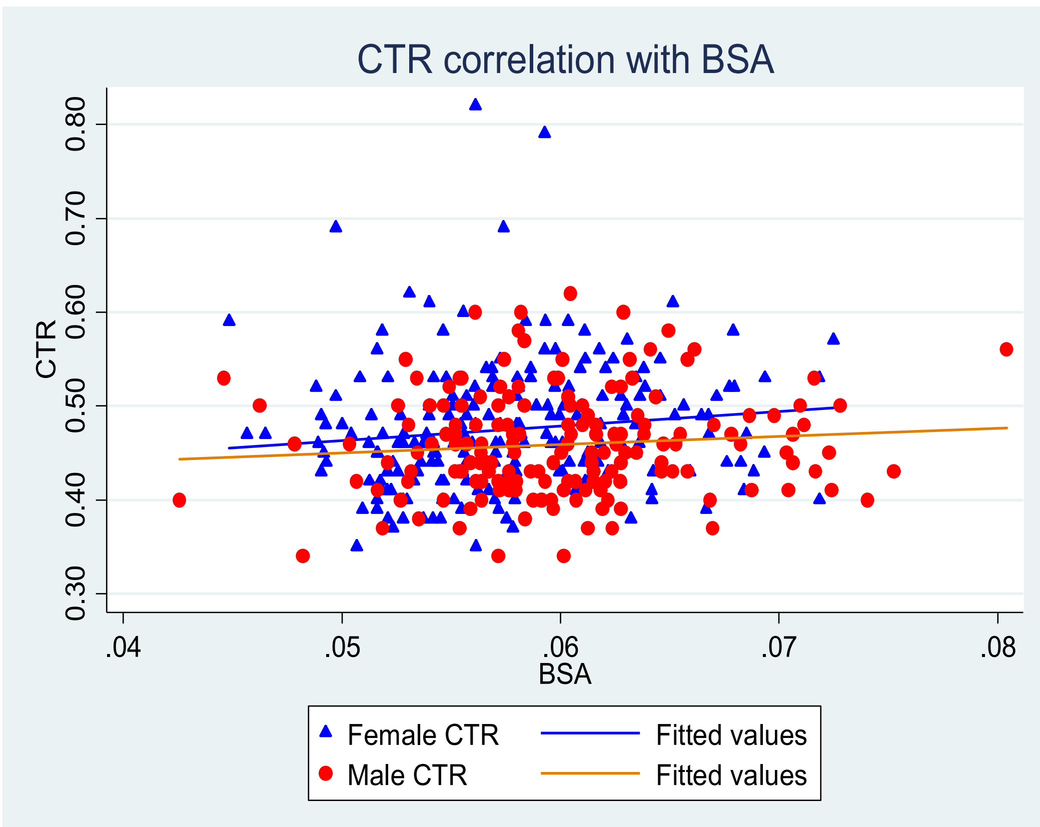

Figure 4; Correlation between strata of BSA by gender with CTR.

Relationship between CTR and BSI

Table 5 shows a positive but very weak correlation between CTR and BSI (r = 0.19, P < 0.001). For female patients, the correlation was weak but significant (r = 0.24, P < 0.001). Among male patients, the correlation was positive but not significant (r = 0.13, P = 0.088).

Table 5 also shows no significant association between BSI strata by age categories and CTR (p-values > 0.05). Difficulty in breathing (DIB) as a BSI stratum had a weak but significant positive correlation with CTR (r = 0.25, P = 0.007). Chest pain also showed a weak but significant correlation (r = 0.22, P = 0.017)

Table 5: Relationship between patient BSI and CTR among patients who presented for chest radiographs stratified by gender, age, and indication at the radiology department of Mulago National Referral Hospital during the study period.

		CTR	
	Characteristic	**Spearman's correlation coefficient (r)**	**p-value**
BSI stratified by independent variables	**BSI**	0.19	<0.001**
	Gender		
	female	0.24	<0.001**
	male	0.13	0.088
	Age categorized (years)		
	≤ 20	0.14	0.396
	21-30	0.08	0.436
	31-40	-0.01	0.883
	41-50	0.18	0.151
	>50	0.03	0.811
	Indications for CXR		
	chest pain	0.22	0.017**
	DIB	0.25	0.007**
	Cough	0.09	0.361
	others	0.22	0.189

Figure 4: below shows The BSI for both males and females positively increased as the cardiothoracic ratio of both sexes increased; however, the increase was gradual and almost flat.

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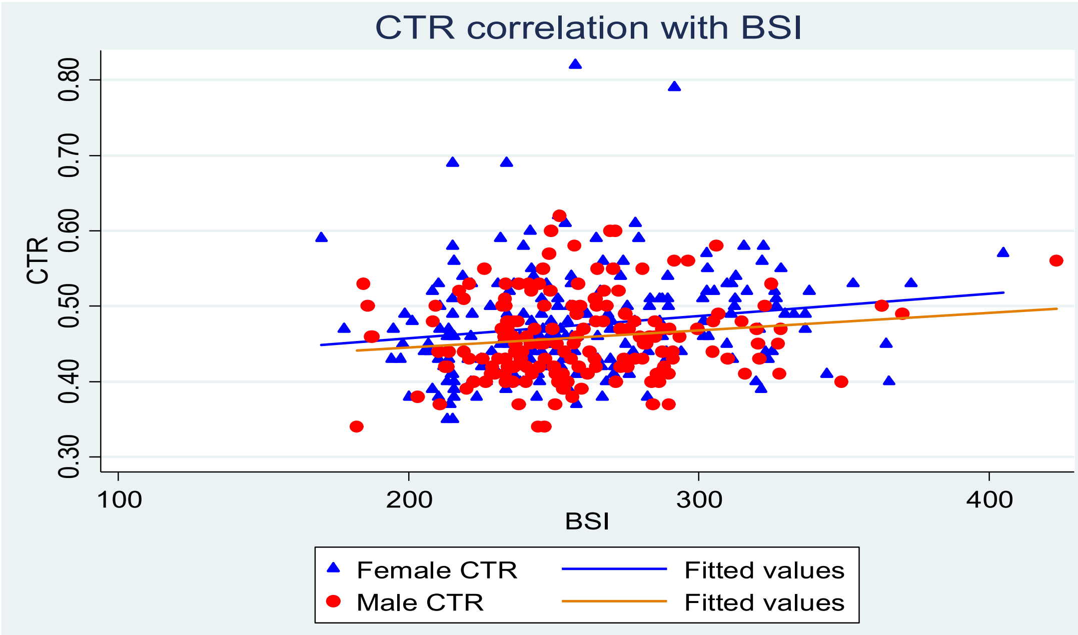

Figure 5; Correlation between strata of BSI by gender with CTR.

Linear relationship between CTR, measured body parameters, and age among male and female participants

Table 6 shows that for female patients, CTR increased by 0.0015 per unit change in BMI (age constant) and by 0.0017 per unit change in age (BMI constant). The model's R-squared was 0.203, indicating 20.3% of CTR variation was explained by BMI and age. Despite the low R-squared, the F-statistic of 13.6 was significant ($P < 0.001$).

The study found that for male patients, CTR increased by 0.0002 per unit change in BMI (age constant) and by 0.00067 per unit change in age (BMI constant). The R-squared was 0.032, meaning only 3.2% of CTR variation was explained by BMI and age. The F-statistic of 1.33 was not significant ($P = 0.270$).

Table 6: Linear relationship between measured body parameters and CTR among patients who presented for chest radiographs at the radiology department of Mulago National Referral Hospital during the study period.

Measured body parameter	Linear equation relating body parameter to CTR	
	Female	**Male**
BMI	CTR = 0.37218 + 0.001510**BMI** + 0.001650**AGE**	CTR = 0.42547 + 0.0002**BMI** + 0.00067**AGE**
BSA	CTR = 0.37081+ 0.676410**BSA** + 0.001679**AGE**	CTR = 0.536476 -1.98265**BSA** + 0.001004**AGE**
BSI	CTR = 0.368608 + 0.0001642**BSI** + 0.001635**AGE**	CTR = 0.46353 - 0.000152**BSI** + 0.000817**AGE**

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For females as shown in table 7, the sensitivity of the estimated CTR (based on regression of CTR against BSA and age) compared to the radiologist's CTR was 29.2% (95% CI: 17.0-44.1), specificity 86.0% (95% CI: 74.2-93.7), with positive and negative predictive values (PPV and NPV) of 63.6% (95% CI: 40.7-82.8) and 59.0% (95% CI: 47.7-69.7), respectively.

For males, as shown in Table 7, the sensitivity of the estimated CTR (based on regression of CTR against BSA and age) compared to the radiologist's CTR was 8.2% (CI: 1.8-22.5), with a specificity of 98.1% (CI: 89.7-100.0). The PPV was 75% (CI: 19.4-99.4), and the NPV was 60.7% (CI: 49.5-71.2).

Table 7: Sensitivity and Specificity of estimated CTR based on regression of CTR with BMI, BSA, and BSI, Positive and Negative Predictive Values among females and males

	Female		**Male**	
Parameters and corresponding performance indicators	**Percentage**	**95%CI**	**Percentage**	**95%CI**
BMI				
Sensitivity	31.3	18.7-46.3	0.0	0.0-9.7
Specificity	86.0	74.2-93.7	98.1	89.7-100.0
Positive predictive value	65.2	42.7-83.6	0.0	0.0-97.5
Negative predictive value	59.8	48.3-70.4	58.6	47.6-69.1
BSA*				
Sensitivity	29.2	17.0-44.1	8.3	1.8-22.5
Specificity	86.0	74.2-93.7	98.1	89.7-100.0
Positive predictive value	63.6	40.7-82.8	75.0	19.4-99.4
Negative predictive value	59.0	47.7-69.7	60.7	49.5-71.2
BSI				
Sensitivity	31.3	18.7-46.3	0.0	0.0-9.7
Specificity	86.0	74.2-93.7	98.1	89.7-100.0
Positive predictive value	65.2	42.7-83.6	0.0	0.0-97.5
Negative predictive value	59.8	48.3-70.4	58.6	47.6-69.1

BSA was observed to have a moderate relationship with CTR, and it provides a fairly better performance indicator for both males and females

DISCUSSION

The CTR is a simple measurement that serves as a practical indicator of cardiac size during cardiovascular screenings. This study aimed to investigate the relationship between CTR and clinical indications, as well as BMI, BSA, and BSI, using a hospital-based cross-sectional design.

Relationship between CTR and

Demographics

This study found a median CTR of 0.46 for both males and females, with an IQR of 0.42-0.50. This range aligns with Truszkiewicz's (2021) and Mohammadi's (2016) study findings, which also identified normal CTR values between 0.42 and 0.50 (8, 17). Studies suggest that CTR values above 0.5 or below 0.42 indicate pathological conditions like cardiomegaly or microcardia, respectively(8, 17-19)

Among participants with a high CTR (>0.49), female patients outnumbered males, consistent with Ominde's (2023) and Ali's (2019) study findings, which attributed the higher CTR in females to a smaller thoracic diameter (20, 21). Men typically engage in more physically demanding activities, leading to a wider thoracic diameter (17). While our study found no significant association between gender and CTR ($p = 0.144$), Ominde (2023) and Ali (2019) reported a significant relationship (20, 21). Additionally, our findings contradicted Brakohiapa's (2021) study in Ghana, which found a significant difference in CTR by gender ($p = 0.001$) (19).

In this study, CTR increased with age, showing a statistically significant association ($p < 0.001$), consistent with Brakohiapa's (2021) and Mohammadi's (2016) study findings (11, 17, 19). The rise in CTR with age is attributed to ventricular muscle thickening due to higher vascular resistance or loss of elasticity in major blood vessels(11, 17). However, the overall correlation (r) between CTR and age groupings was weak, contrasting with Ekedigwe's (2014) study, which found a significant correlation in males and a slightly lower one in females(9).

Relationship between CTR and BMI

This study found a significant association between CTR and BMI ($p < 0.001$), aligning with Emegoakor (2018), which showed significant differences ($p < 0.05$) in CTR relative to BMI for both genders (10). A modest positive association was observed, with correlation coefficients of 0.16 for males and 0.22 for females, consistent with findings by Mehra (2019), Ekedigwe (2014), and Emegoakor (2018) (9-11). While one might expect a stronger correlation, our study did not demonstrate this, possibly due to unaccounted physiological variations. Ugandans' physical fitness from moderate-intensity work (22) may elevate CTR despite low BMI levels. Additionally, the study's reliance on clinical indications in request forms may have overlooked patients with undisclosed cardiac conditions.

This study found a stronger association between CTR and BMI in females ($p < 0.001$) than in males ($p = 0.033$), a trend not consistently reported in prior research, warranting further investigation. Across age categories (<20, 21–30, 31–40, and >50 years), no significant relationship between CTR and BMI was observed; only weak positive correlations were observed. The only statistically significant result ($p = 0.023$) was in the 41–50 age group, though the reason for this remains unclear.

Thus, it is important to recognize that CTR has a weak association with BMI. BMI alone does not effectively determine CTR, as it does not consider age, which is significantly linked to CTR

Relationship between CTR and BSA

This study found a significant association between CTR and overall BSA ($p = 0.016$), though the correlation was weak ($r = 0.12$). This aligns with Emegoakor (2018) and Mehra (2019), who also reported significant and weak correlations, respectively(10, 11). In females, CTR showed a significant association with BSA ($p = 0.004$) and a weak correlation. The weak correlation indicates that a twofold increase in BSA does not lead to a twofold increase in CTR, consistent with Emegoakor's (2018) findings (10).

A 2020 study on cardiac geometry variations in neonates with abnormal growth found that adiposity affected BSA, leading to underestimated cardiac dimensions(23). This raises concerns about using BSA or body weight as a universal parameter for estimating CTR. Conversely, Shiraz's (2019) study established a predictive relationship of 90.32% between CTR and BSA among Ghanaians (24). However, its limitations include a lack of statistical significance and correlation coefficients, which limit its reliability.

This study found BSA to be a more effective performance indicator for both genders, with sensitivity, specificity, PPV, and NPV of 29.2%, 86.0%, 63.6%, and 59.0% for males, and 8.3%, 98.1%, 75.0%, and 60.7% for females. This highlights its superiority over BMI as an indexing tool.

Additionally, there was no statistical significance between CTR and BSA across age groups, as BSA does not account for age, which directly influences CTR.

Relationship between CTR and BSI

Our study found a significant association ($p < 0.001$) between CTR and overall BSI, with a weak positive correlation ($r = 0.19$). The association was less significant, and correlation was slightly stronger among females ($r = 0.24$) but less significant in males. Limited literature exists on the CTR-BSI relationship, indicating its limited predictive utility.

In contrast, Shiraz et al. showed that BSI offered a more accurate estimate of body size than BMI and BSA, with an average predictive relationship between CTR and BSI of 92.53% (24). However, their study lacked sensitivity and specificity analysis, affecting the reliability of their findings.

This study found that incorporating age into the CTR-BSI relationship through multivariate regression yielded better sensitivity and specificity values for males than for females, suggesting that BSI may be a less effective predictor of CTR in females.

Relationship between CTR and Clinical Indications

This study found no significant association between CTR and clinical indications ($p = 0.190$), likely due to the exclusion of patients with conditions like hypertension, renal failure, and other cardiac diseases known to affect CTR, as noted in Hailu's (2017) and Chou's (2023) studies (25-27).

A significant association was found between CTR and BMI for chest pain ($p = 0.006$) and DIB ($p = 0.005$). However, no significance was observed for cough or other clinical indications regarding CTR. Similarly, no significant associations were found between CTR and BSA or BSI, suggesting that the clinical indications presented did not strongly influence CTR, which appears primarily affected by factors directly related to cardiac conditions.

Diagnostic performance of a linear equation containing BSA and the radiologist's manual method for estimation of CTR

In this study, the linear equation derived from multilinear regression using BSA and age demonstrated low sensitivity (29.2%) and relatively high specificity (86.0%) for CTR among males, and very low sensitivity (8.3%) with high specificity (98.1%) for females. Few studies have used BSA and other body parameters to estimate CTR; most have relied on artificial intelligence or deep learning methods rather than manual estimation by radiologists. Those studies reported higher sensitivity and specificity. Li's (2019) study using deep learning showed high sensitivity (97.2%) and specificity (92.7%) in estimating CTR(28). Similarly, Saiviroonporn (2021) reported an unsupervised AI algorithm with a sensitivity of 97.5% and specificity of 82.8% for CTR estimation (29). The discrepancies between these studies and ours likely stem from differing estimation methods. However, deep learning and AI techniques may be unreliable or inaccessible, as stable electricity and computer access remain challenges in many African countries, including Uganda.

Generalizability

These findings may not generalize to the broader population, as the study was conducted in a hospital setting with patients who had underlying medical conditions that could have influenced their CTR.

CONCLUSION

This study found that CTR shows minimal correlation with body parameters such as BMI, BSA, and BSI, suggesting these factors are not reliable determinants of CTR and should be used cautiously. Instead, CTR appears to be more influenced by age and sex. We observed a positive correlation between CTR and age, with higher values in females compared to males, underscoring the effectiveness of CTR measured from chest radiographs in screening for cardiomegaly in resource-limited settings.

This study showed a weak association between BSA and CTR. However, in multivariate regression including age, BSA outperformed BMI and BSI, with sensitivity, specificity, PPV, and NPV of 29.2%, 86.0%, 63.6%, and 59.0% for males, and 8.3%, 98.1%, 75.0%, and 60.7% for females. This suggests BSA may be a better predictor of CTR than BMI and BSI.

LIMITATION(S) OF THE STUDY

1. Possible inclusion of patients with **undiagnosed cardiac or thoracic abnormalities** may have caused residual confounding.
2. **Body measurements** (height and weight) did not account for factors such as fluid retention, ascites, or pregnancy that can influence BMI, BSA, and BSI.
3. The **cross-sectional design** limits causal inference between CTR and body parameters

RECOMMENDATION(S)

We recommend a similar study in a more diverse population with varied characteristics.

LIST OF ABBREVIATIONS

BMI – Body Mass Index
BSA – Body Surface Area
BSI – Body Surface Index
CTR – Cardiothoracic Ratio
CXR – Chest X-ray
CT – Computed Tomography
CI – Confidence Interval
DIB – Difficulty in Breathing
IQR – Interquartile Range
Mak-SoMREC – Makerere University School of Medicine Research Ethics Committee
MRI – Magnetic Resonance Imaging
NPV – Negative Predictive Value
PPV – Positive Predictive Value
PA – Posterior Anterior

Consent for Publication

Not Applicable

Availability of Data and Materials

The data supporting this study are available upon request from the Co-Responding Author.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Author's contributions

AM conceptualized the study, coordinated the project, and contributed to writing and reviewing the manuscript. RN managed the project finances and contributed to writing and reviewing the manuscript. ON, DB, IS, FO, RM, and VN all contributed to writing and reviewing the manuscript, with DB serving as the project radiologist, IS as the radiographer, and FO as the data analyst. AGM provided overall mentorship for the project and contributed to writing and reviewing the manuscript

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