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# Determination of Standard Reference Cardiothoracic Ratio and the Relationship with Body Parameters as A Patients Health Indicator for Clinical Application

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## ABSTRACT

The heart is a muscular organ about the size of a closed fist that function by pumping blood throughout the body making the body size extremely important in its performance. Hence, the work done by the heart depend largely on the total body size of the individual, measurements of which depends on the weight and height to estimate BMI, BSA and BSI. The aim of the study was to establish Ghanaian based standard reference values of cardiothoracic ratio and determine the relationship with body parameters for clinical application. The maximum transverse diameter of the heart was obtained by adding the widest distance of the right heart border from the midline and the left heart border to the midline (cardiac diameter). This value was then divided by the maximum transverse diameter of the thorax (the thoracic diameter) to give the cardiothoracic ratio (CTR). Which is described as a ratio of the cardiac width as against thoracic width. The measured CTR was approximately 15: 33 (cm) and is therefore within the normal limit of 50%. This is because a CTR of greater than fifty percent is abnormal, in terms of Posterior - Anterior (PA) or an Anterior - Posterior (AP) view. In addition, the height and weight were measured to estimate the BMI, BSA and BSI and the relationship of these parameters with the measured cardiothoracic ratio. The result shows that BSI better correlate with the cardiothoracic ratio than any other body parameter with 92.53% accuracy rate. The determination of the CTR which represent the size of the normal heart is of the greatest importance to cardiologists. This is because the heart size enlargement is better assess by determining the ratio of size of the heart (cardiac diameter) as against the size of the chest wall (the thoracic diameter). This is use for initial assessment of heart condition by cardiologist, with a standard adult heart having a CTR value of 0.5. The study shows that a normal size is so variable and depends so greatly on the sex, age and body parameters of the study population. In conclusion, the study will serve as basis of the relationship between body parameter and the CTR. It also established that a deviation of heart size with BSI may reveal an underlying pathologic condition, and called for further studies to be conducted for clinical decision.

**Keyword :** Cardiothoracic Ratio, Body Mass Index, Body Surface Area, Body Surface Index and Heart

## I. INTRODUCTION

The heart is a muscular organ about the size of a closed fist that functions as the body's circulatory pump. It takes in deoxygenated blood through the veins and delivers it to the lungs for oxygenation before pumping it into the various arteries (which provide oxygen and nutrients to body tissues by transporting the blood throughout the body). The heart is located in the thoracic cavity medial to the lungs and posterior to the sternum. The heart size enlargement is use for initial assessment of heart condition by cardiologist, with a standard adult heart having a mass of 250–350. Typically, the heart size is assessed as the cardiothoracic ratio (CTR), which is described as a ratio of the cardiac width as against thoracic width. A CTR of greater than fifty percent (50%) is abnormal, in terms of Posterior - Anterior (PA) or an Anterior -Posterior (AP) view. The determination of the size of the normal heart is of the greatest importance to cardiologists. The normal size of this organ is so variable and depends so greatly on the sex, age, height and weight of the individual, that it is necessary that a basis of its normality be established, as the slightest modification of its size may reveal an underlying pathologic condition, for what may be the size of a normal heart in some individuals may in others determine a disease condition. The radiologists have tried to establish a basis of cardiac normality, but because of so many unavoidable sources of error, they have been largely unsuccessful. The most patent errors in the delimitation of the heart area by means of the roentgen ray are: size and contour of the chest, position of the heart, exact centralization of the rays, accurate focusing, deformities of the cardiothoracic ratio (CTR) aids in the detection of enlargement of the cardiac silhouette, which is most commonly from cardiomegaly but can be due to other processes such as pericardial effusion. Some report CTR as a percentage, however this is strictly incorrect, as it is a ratio. The CTR is measured on a PA chest x-ray, and is the ratio of maximal horizontal cardiac diameter to maximal horizontal thoracic diameter (inner edge of ribs / edge of pleura). A normal measurement should be less than 0.5. It should be noted that this measurement is a coarse marker of disease [4]. If the patient is symptomatic then echocardiography is required but the yield of echocardiography is low if performed just for an increased CTR. In some situations, an increased cardiothoracic ratio on a PA radiograph may be a result of a prominent epicardial fat pad and/or due to expiration rather than cardiomegaly. The incidence of total cardiac death has been found to be three times greater in patients with enlarged hearts compared with patients with normal size hearts. The incidence of non-fatal reinfarctions, however, was independent of heart size at baseline. In conclusion, the cardiothoracic ratio is the maximum dimension of the heart divided by the thoracic cavity width at the diaphragm on a standard Posteroanterior chest film. A cardiothoracic ratio of 0.6 is normal in newborns, whereas 0.45 is normal in older children and adolescents.

## OBJECTIVE

The aim of the study was to establish Ghanaian based standard reference values of cardiothoracic ratio;
This specifically led to the:

- Determination of standard reference adult chest wall diameter **(Thoracic Width)** and heart diameter (**Cardiac Width)** for clinical application.
- Review and compare measured parameters with other local measured and international reference values.

## II. LITERATURE

Heart size is not assessed by an absolute measurement, but rather is measured in relation to the total thoracic width - the Cardio-Thoracic Ratio (CTR).

$$\textbf{CTR = Cardiac Width: Thoracic Width} \qquad (1)$$

The CTR is frequently expressed as a percentage. A CTR of greater than 1:2 (50%) is considered abnormal.

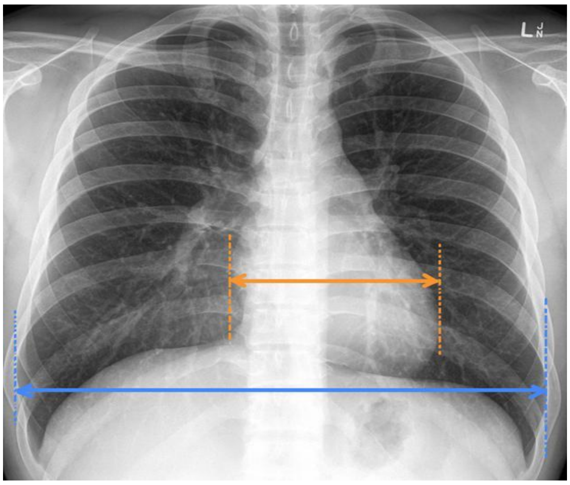


**Figure1:** Measurements of small Cardiac Width

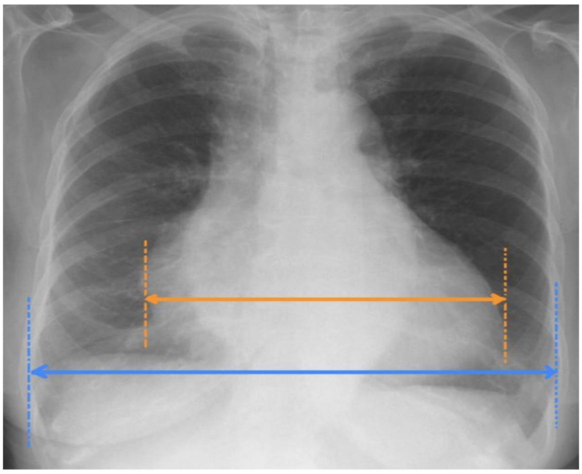

**Figure 2:** Measurements of large cardiac width

Accurate assessment of heart size assumes the projection is Posterior-Anterior (PA), and that cardiac size is not exaggerated by factors such as patient rotation. **Increased cardiothoracic ratio** describes widening of the cardiac silhouette on a chest radiograph. This is only of use when assessing a PA chest x-ray since the AP chest x-ray causes the artefactual magnification of the heart and the cardiothoracic ratio is altered

Body Mass Index

A BMI scale provides information about whether an individual body weight is appropriate for the individual body height. A Belgian Polymath Adolphe Quetelet (1796-1874) who formulated a method to evaluate the body index first estimated this during the path of developing social physics (Eknoyan, 2008). It was known as the Quetelet Index until it was later termed as he Body Mass Index (BMI) in 1972 by Ancel Keys (Du Bois & Du Bois, 1916). The universal unit for BMI is the kg/m$^2$. Basically, it represents the human body fat between ages 18 and 65 years. Available publications show that, the average Ghanaian adult BMI is 25.7 kg/m$^2$ for male and 21.65 kg/m$^2$ for female (Frempong, 2013).

Generally, the body mass index is estimated mathematically as the ratio of the body weight to the height square. Described mathematically as

$$\text{BMI} = \frac{\text{WEIGHT}}{Height^2} \tag{2}$$

The relationship between organ mass/volume and BMI is used to study the progressive development of the human body in relation to renal development. The relationship between BMI and organs mass/volume can be analysed using major axis regression analysis with Minitab statistical application tools as applied to any two or more unknown relationship.

Body Surface Area and Body Surface Index

Since the development of BMI, two other body parameters have been developed in an attempt to determine the relationship between body height and weight. These are the body surface area (BSA) and body surface index (BSI). To evaluate the surface region of a human body in relation to height and weight, the term body surface area was invented. It is specified as an estimated value that shows the relationship between the average body sizes to the height and normally increases with increasing age. The estimated body surface area of a human body is a measured total surface area of human body (Du Bois & Du Bois, 1916). Several scientists and authors have designed formulas to determine the body parameters and the relationship with the organ dimensions, this has contributed significantly to the understanding and solution to human health (Ferreira & Duarte, 2014; Sardinha, Silva, Minderico & Teixeira, 2006; Verbraecken, Van de Heyning, De Backer & Van Gaal, 2006; Shuter, 2000; Current, 1997; Mosteller, 1987; Haycock, Schwartz & Wisotsky, 1978; Gehan & George, 1970; Fujimoto, Watanabe, Sakamoto, Yukawa & Morimoto, 1968; Boyd, 1935).

All of these are broadly stated in the frame:

$$\mathrm{BSA} = \alpha_0 \, \mathrm{H}^{\alpha_1} * \mathrm{M}^{\alpha_2}, \quad (3)$$

where, M is mass (kg), H is height (cm). All parameter values derived from various studies gave reasonably similar results. The mean body surface area varied based on age and gender. Generally, the average BSA estimated value of an adult male is 1.9 $m^2$, while the average body surface area for an adult female is approximately 1.6 $m^2$. Furthermore, the average body surface area for younger children largely varied with age in the range of 1.07 $m^2$ and 1.14 $m^2$ between ages 10 to 16 years (IAEA, 1989).

Furthermore, BSA in relation to the body weight describes a new parameter called body surface index (BSI) which is a more precise indicator than both the BMI and the BSA. It is estimated by dividing the body weight by the calculated square root of its BSA, mathematically expressed as:

$$\mathrm{BSI} = \frac{\mathrm{WEIGHT}}{\sqrt{\mathrm{BSA}}} \quad (4)$$

Indeed, BSA and BSI, which is significantly used to perform the following clinical services; for instance BSA and BSI is used to estimate the renal clearance (RC), as RC usually divided by either BSA or BSI to gain an appreciation of the true glomerular filtration rate (GFR). In addition the cardiac index is a measure of cardiac output divided by the BSA, giving a better approximation of the effective cardiac output. BSI on the other hand, is used to estimate weight in relation to BSA. The BMI, BSA and BSI define and show the relationship between the average body size to the height and normal increases with increasing age (Ferreira & Duarte, 2014).

## III. METHODOLOGY

The retrospective study was undertaken across the country. It include patients who had chest X-ray for other studies rather than heart studies were selected. In total, 1000 X-ray reports that met the selection criterion were selected. The selection criteria include; the fact that the study was reported as being technically adequate and qualitative and quantitative data were present to enable the measurement of **Cardiac Width and Thoracic Width**. The chest radiograph (posterior-anterior or anterior-posterior) where the cardiothoracic ratio is calculable will identified and included as the final subset for analysis. In addition the height and weight of those who qualified for study were also recorded and use to estimate body mass index, body surface area and body surface index.

All posterior-anterior and anterior-posterior films, regardless of depth of inspiration, were included. Patients with severe consolidation or pleural effusions where the cardiac silhouette, which is indistinct, were excluded. To obtain accurate measurement, a vertical line was drawn on the radiograph through the midpoint of the spine from the sternum to the diaphragm. The maximum transverse diameter of the heart were obtained by adding the widest distance of the right heart border from the midline and the left heart border to the midline (cardiac diameter). This value was then divided by the maximum transverse diameter of the thorax (the thoracic diameter) to give the cardiothoracic ratio. In other words, Cardiac size was measured by drawing vertical parallel lines down the most lateral points on each side of the heart, and measuring between them as shown by yellow line in figure 1. Whiles, thoracic width is measured by drawing vertical parallel lines down the inner aspect of the widest points of the rib cage, and measuring between them as shown in figure 1 with blue line.

Hence, the cardio-thoracic ratio was calculated as the cardiac Width divided by the thoracic width as shown in equation 5.

$$\mathbf{CTR} = \frac{\textbf{Cardiac Width}}{\textbf{Thoracic Width}} \quad (5)$$

Here the CTR is approximately 15: 33 (cm) and is therefore within the normal limit of 50%.

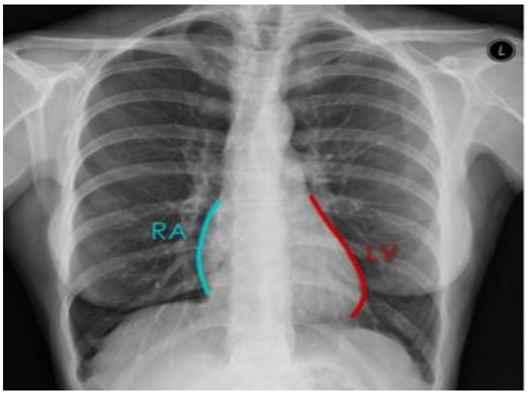


**Figure 3:** Normal heart walls

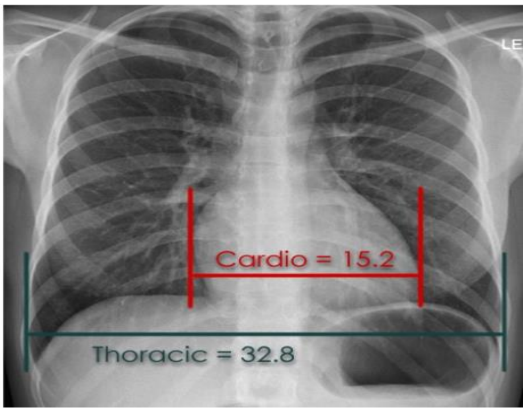


**Figure 4:** Normal cardiac contours

The left heart contour (red line) consists of the left lateral border of the Left Ventricle (LV). The right heart contour is the right lateral border of the Right Atrium (RA).

The heart size will be assessed on the entire chest X-ray collected. If the CTR is less than 50% on either a Posterior - Anterior (PA) or an Anterior - Posterior (AP) view, then the heart size is within normal limits. However, a PA view will be used for confirmatory analysis, as it is required to confidently diagnose cardiac enlargement. Note; the AP view will exaggerate the heart size due to magnification. If the heart contours are of the upper lobe of the left lung - wraps over the left ventricle, and so loss of definition of the left heart border may be related to disease in this area of lung. On the right, the middle lobe is located adjacent to the right atrium, and therefore loss of definition of the right heart border may be due to increased density caused by disease in this lung lobe.

The body mass index was estimated mathematically using the ratio of the body weight to the height square. Define mathematically as

$$\mathrm{BSI} = \frac{\mathrm{WEIGHT}}{Height^2} \quad (6)$$

$$\mathrm{BSA} = 0.007184\ \mathrm{H}^{0.735_1} * \mathrm{M}^{0.425_2}, \quad (7)$$

where, M is mass (kg), H is height (cm). All parameter values derived from various studies gave reasonably similar results. The mean body surface area varied based on age and gender. The BSI was also estimated by dividing the body weight by the calculated square root of its BSA, mathematically expressed as:

$$\mathrm{BSI} = \frac{\mathrm{WEIGHT}}{\sqrt{\mathrm{BSA}}} \quad (8)$$

## IV. STATISTICAL ANALYSIS

The median of CTR value of 0.5 were used to split patients into two groups. Here, measured CTR of ≤ 0.49 will be considered, while those with a CTR > 0.50 will then be excluded. Age-adjusted tests of linear trend will be applied to continuous variables using the analysis of variance whereas differences in proportions were assessed by Minitab statistical tests when examining baseline data across CTR groups.

## V. RESULTS AND DISCUSSION

### RESULTS

**Table 1 :** Variation of CTR with BMI, BSA, BSI and body parameters

| Gender | Age-Groups | SAMPLE | CTR | BMI | BSA | BSI |
|---|---|---|---|---|---|---|
| (M) | 10-19 | 151 | 0.45 | 25.48 | 2.02 | 39.93 |
| | 20-29 | 365 | 0.44 | 25.51 | 2.04 | 40.09 |
| | 30-39 | 291 | 0.45 | 25.66 | 2.06 | 40.21 |
| | 40-49 | 115 | 0.47 | 24.45 | 1.99 | 38.25 |
| | 50-59 | 46 | 0.48 | 23.31 | 1.83 | 37.35 |
| | 60-80 | 30 | 0.48 | 22.23 | 1.77 | 36.15 |
| | Total | 998 | 0.45 | 25.19 | 2.02 | 39.81 |
| Female (F) | 10-19 | 159 | 0.45 | 22.04 | 1.71 | 37.09 |
| | 20-29 | 357 | 0.46 | 22.13 | 1.73 | 38.01 |
| | 30-39 | 260 | 0.47 | 22.18 | 1.74 | 38.88 |
| | 40-49 | 114 | 0.48 | 21.63 | 1.63 | 36.81 |
| | 50-59 | 44 | 0.49 | 21.14 | 1.59 | 35.68 |
| | 60-80 | 57 | 0.52 | 20.19 | 1.49 | 34.97 |
| | Total | 991 | 0.47 | 21.91 | 1.69 | 36.58 |
| M/F | 10-19 | 330 | 0.45 | 23.76 | 1.87 | 38.51 |
| | 20-29 | 722 | 0.45 | 23.82 | 1.89 | 39.05 |
| | 30-39 | 551 | 0.46 | 23.92 | 1.90 | 39.55 |
| | 40-49 | 209 | 0.47 | 23.04 | 1.81 | 37.53 |
| | 50-59 | 90 | 0.49 | 22.23 | 1.71 | 36.52 |
| | 60-80 | 87 | 0.51 | 22.23 | 1.77 | 35.56 |
| | Total | 998 | 0.45 | 23.55 | 1.86 | 38.20 |

## VI. DISCUSSION

The cardiothoracic ratio is the maximum dimension of the heart divided by the thoracic cavity width at the diaphragm on a standard posteroanterior chest film. It can serve as an index of cardiac size during screening of a specific population for cardiovascular diseases. Clinically, these measured values are require to serve a base line data for proper assessment of cardiovascular diseases. Generally, a cardiothoracic ratio of 0.6 is normal in newborns, whereas 0.45 is normal in older children and adolescents. For clinical application, a measured CTR can confirm the location of endotracheal tubes, catheters within the circulatory system, and enteral feeding and drainage tubes.

Furthermore, it is of interest to note that clinical echocardiography is a general standard means of assessing cardiac structure and function. With chest wall abnormalities, imaging may not be adequate. Better image resolution can be obtained with transesophageal imaging, but requires very heavy sedation or general anesthesia. The echocardiogram provides comprehensive information about the patient's overall anatomy and function and is vital to the assessment of the critically ill patient. It is not routinely used as a tool for daily examination.

The cardiothoracic ratio (CTR) was also noted to increase gradually with age in this study. The gradual increase in CTR up to age 50 years is believed to be due to gradual increase in TCD. The reduction in the TTD also comes into play in the elderly leading to additional increase in CTR. The mean CTR of the study population were 45.9% +0.2, 46.7% +0.3 and 45.2% +0.2 for the general population, females and males respectively. A study showed that 2.5% had a CTR greater than 0.5. This result compared favourably with a similar study in Ghana where the mean CTR values were 45.7% ± 0.03 for males, 46.7% ± 0.04 for females and 46.3% ± 0.03 for both males and females.

The 95% confidence interval for the mean CTR for all males and females less than 60 years was found to be less than 0.5. This trend is similar to what has been noted in other local studies. Elderly females on the other hand had a figure greater than 0.5. A similar trend was noted in a longitudinal study on changes of CTR in women which showed that about 20% of elderly women will have a CTR greater than 0.5. This was attributed to the fact that the reduction in TTD with age was more pronounced in elderly women.

Various studies have shown that though the cardiothoracic ratio is a very useful basic tool for the evaluation of heart size, it fares poorly when it comes to evaluation of both the size of the heart and the sizes of its chambers. A study, which compared the sensitivity and specificity of cardiothoracic ratio, noted that cardiothoracic ratio had a fairly high sensitivity (85 to 90%) but low specificity (14 to 17%) when used to determine whether the heart is enlarged or not. Echocardiography is therefore the modality to go for when a more objective numerical estimation of the cardiac size (and the sizes of its chambers) is needed because of its high sensitivity and specificity.

The study recommends that because it is easy and cheap to measure the CTR by the chest X-ray for any patient, it can be regarded as a preliminary measure to the size of the heart, especially in the numerous settings where X-ray remains the only available diagnostic facility but the echocardiographic measurement remains the more accurate.

Furthermore, it is important to estimate the heart size with the body size. Since the hearts function depends on the body size and its function is directly link with the body size. The BSI is the most accurate body size estimate even though the BSA and the BMI are commonly being use. The BMI, BSA and BSI define and show the relationship between the average body size to the height and normal increases with increasing age (Ferreira & Duarte, 2014). The measured average male weight and height were 80.83 kg and 178.62 cm respectively. In addition, the average male BMI, BSA and BSI were 25.19±1.4 kg/m², 2.02±0.09 m² and 39.81 kg/m² respectively. The female measurements were 61.87 kg, 167.11 cm, 21.91±0.15 kg/m², 1.69±0.12 m² and 36.58 kg/m² for weight, height, BMI, BSA and BSI respectively. The relationship between organ volume and body parameters is used to study the progressive development of the human body in relation to organ development. The relationship between body parameters and organs volume was analysed using major axis regression analysis with Minitab statistical application tools as applied to any two or more unknown relationship.

Indeed, BSA and BSI, which is significantly used to perform the following clinical services; for instance BSA and BSI is used to estimate the renal clearance (RC), as RC usually divided by either BSA or BSI to gain an appreciation of the true glomerular filtration rate (GFR). In addition the cardiac index is a measure of cardiac output divided by the BSA, giving a better approximation of the effective cardiac output. BSI on the other hand, is used to estimate weight in relation to BSA.

**Regression Analysis: CTR versus BMI**

**Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.02 | 82.44% | 89.93% | 81.94% |

**Regression Equation**

$$CTR = 0.7095 - 0.01040\ BMI \tag{9}$$

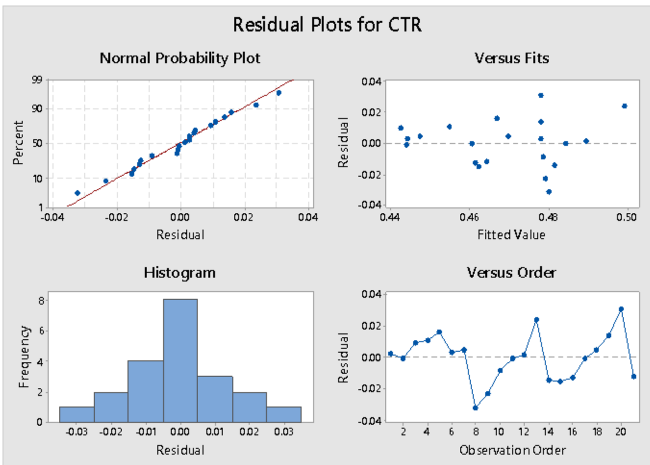


**Figure 5 :** A modeled relationship between CTR and BMI

**Regression Analysis: CTR versus BSA**

**Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.02 | 90.77% | 88.17% | 90.32% |

### Regression Equation

$$CTR = 0.6514 - 0.1006\ BSA \quad (10)$$

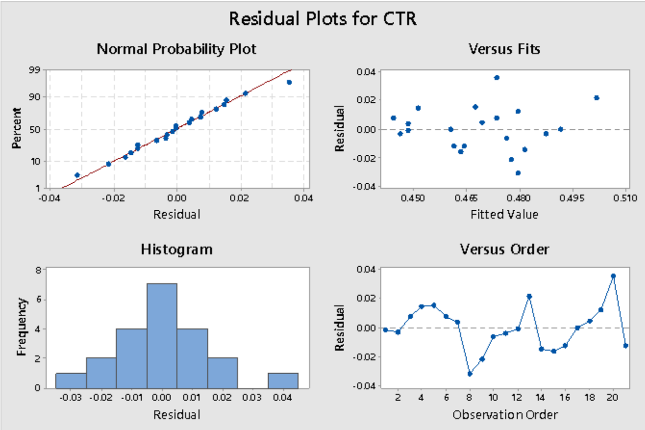


**Figure 6 :** A modeled relationship between CTR and BSA

### Regression Analysis: CTR versus BSI

### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.01 | 99.79% | 98.20% | 92.53% |

### Regression Equation

$$CTR = 0.9038 - 0.01149\ BSI \quad (11)$$

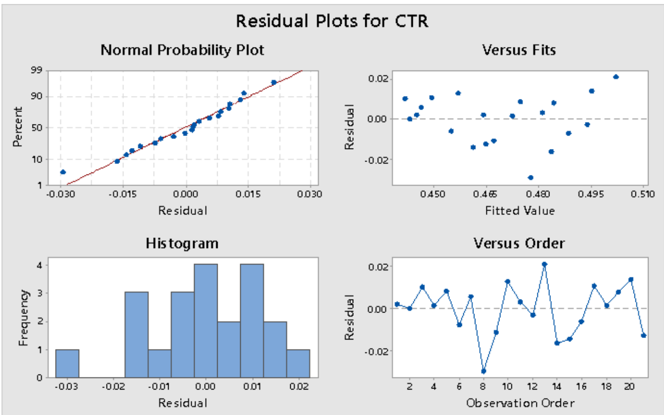


**Figure 7 :** A modeled relationship between CTR and BSI

## VII. CONCLUSION

This study has been able to establish 0.46 as the mean CTR values for Ghanaians. It has also shown the relationship between age and client's cardiothoracic ratio, transverse cardiac diameter and transverse thoracic diameter. These figures compare favourably with findings of a similar study in Nigeria, a neighbouring country in the West African sub region with similar ethnic and social structures like Ghana (as has been shown in table 1). The values will be very valuable in screening Ghanaians for cardiomegaly.

Additionally, the data also shows an average predictive relationship between CRT and BSI to be 92.53%, CRT and BSA to be 90.32 and CTR and BMI to be 81.94%. This shows that BSI is a better body parametric indicator to predict CTR than any other body parameter. Hence the BSI should be use for clinical application to predict CTR stead of BSA or BMI.

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