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Cardiothoracic area ratio for evaluation of ejection fraction in patients

Cardiothoracic area ratio for evaluation of ejection fraction

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Abstract

Aim: The advent of digital radiology and computerized workstations renders it very easy to measure cardiothoracic ratio (CTR) and cardiothoracic area ratio (CTAR) on chest radiographs. The aim of this study was to assess whether CTAR correlates with the left ventricular ejection fraction (EF) better than CTR in healthy individuals and patients with congestive heart failure. Material and Method: The study included 156 healthy individuals and 98 heart failure patients undergoing echocardiography and digital chest radiography. The CTR was calculated in the traditional manner, and the CTAR was taken as the ratio between the pixel counts of the cardiac area and whole thoracic area. Results: The traditional CTR showed an inverse correlation with ejection fraction in both healthy individuals (r = -0.13) and heart failure patients (r = -0.19). The CTAR showed an improved correlation (r = -0.32 for healthy individuals and r = -0.37 for heart failure patients). If it is assumed that an ejection fraction of 55% or more indicates normal cardiac function, a value of 50% or less for CTAR can be taken as normal. Discussion: Digital chest radiography is widely used as a popular technique for diagnosing various thoracic and cardiac diseases. Cardiomegaly is associated with an adverse outcome in patients with heart disease. Therefore, evaluation of heart size is an important clinical variable, and changes in heart size may be used to monitor and grade cardiac disease severity. Conclusion: Our findings suggest that the CTAR correlates better with cardiac function as assessed by the ejection fraction than the traditional CTR.

Keywords

Cardiothoracic Ratio; Cardiothoracic Area Ratio; Ejection Fraction; Congestive Heart Failure; Digital Radiography

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Introduction

The evaluation of cardiac size is an important clinical parameter and can be used to monitor and rate the severity of many diseases such as changes in heart size, valve problems, hypertrophy, and heart failure [1]. There are various techniques used to determine cardiac size, such as digital chest radiography (X-ray), computed tomography (CT) and magnetic resonance imaging (MRI). Although CT or MRI produces high-resolution images, they are not suitable for every patient due to high exposure to radiation or complex procedures for examination. Moreover, cost-effectiveness performance of these techniques is poor since they are expensive diagnostic methods [2].

Congestive heart failure (CHF) is a common chronic condition with a poor prognosis in which the heart loses its ability to pump an adequate amount of blood to the body. The measurement of the ejection fraction (EF) is of great importance in terms of diagnosis, prognosis, and treatment in patients with CHF [3,4]. EF is inversely proportional to the mortality rate and is a good prognostic indicator in CHF [5,6]. Although EF can be easily measured using angiographic, radionuclide, or echocardiographic techniques, these tests are expensive and may not be readily available in all clinical services [7]. Therefore, the development of a simple, inexpensive and non-invasive technique of estimating EF correctly is of great importance.

Cardiothoracic ratio (CTR) is often used to identify cardiomegaly in digital chest radiographs [8]. Although it is criticized, it is continued to be used routinely in clinical practice [7]. CTR is calculated by dividing the maximum transverse diameter of the heart by the maximum chest diameter [9]. The values equal to or less than 0.5 are considered as "normal heart size", whereas the values greater than 0.5 are defined as "cardiomegaly"(1). The measurement of the conventional one-dimensional cardiothoracic ratio (CTR) and cardiothoracic area ratio (CTAR), also called two-dimensional cardiothoracic ratio (2D-CTR), on digital chest radiographs has become quite easy with the wide use of Picture Archiving and Communication Systems (PACS) in hospitals and recent developments in computerized workstations. CTAR is defined as the ratio between the cardiac area and the whole thoracic area [2].

Although there are more published articles about CTR, there are only two study reporting on CTAR [2,10]. The report by Hasan et al. [2] is a methodological study that allowed a successful measurement of CTAR by using an automatic segmentation technique on digital chest radiograph images. Whereas in the study by Browne et al. [10], CTAR was calculated by making a drawing on the digital PA chest radiographs with the help of mouse and the correlation between the ejection fraction and CTAR was examined in individuals with various cardiac diseases, however, healthy subjects were not included in the study. An anatomical mistake has been made in both studies during the determination of the upper border of the heart, and the major vessels originating from the heart were also included within the borders of the heart [2,10]. Therefore, the anatomical borders of the heart were tried to be determined more accurately in this study. The aim of this study was to evaluate the cardiac size in healthy individuals using CTAR and to assess whether CTAR correlates with the left ventricular EF better than CTR in healthy individuals and patients with congestive heart failure.

Material and Method

The study was approved by the local ethics committee (14-KAEK-62) and written informed consents were obtained from all participants. One hundred and fifty-six patients with congestive heart failure and 98 healthy individuals aged between 30-89 years, who were admitted to Cardiology Polyclinic, were included in this prospective study. Obese and weak patients were not included in the study. The images of the participants, who underwent telecardiography, were obtained from the PACS system and analyzed in the digital environment by converting them into JPEG format using Image J program. Moreover, echocardiography reports and clinical information of all participants were recorded on the study form and archived.

CTR was calculated as the ratio between the maximum cardiac transverse diameter and the maximum chest diameter (Figure 1A). The borders of the heart and thoracic cavity were drawn

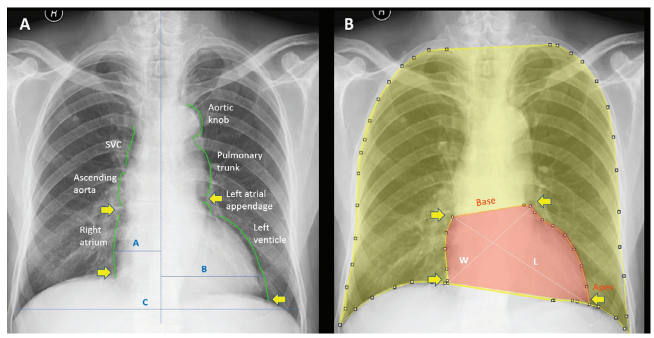

Figure 1. Radiological measures of CTR and CTAR. (A) CTR was calculated as the ratio between the maximum cardiac transverse diameter and the maximum chest diameter (A+B/C). (B) The borders of the heart and thoracic cavity were drawn with the help of a mouse, and CTAR was obtained by dividing the number of pixels in the cardiac area by the number of pixels in the thoracic area.

on the telecardiographic images with the help of mouse. The lower cardiac borders were determined by drawing a line from the right cardiophrenic angle to the line of the intersection of the left cardiac border and the left hemidiaphragm, the upper borders were determined by drawing a line from the upper pole (uppermost point) of the auricle to the upper pole of the right atrium. The right and left borders of the heart were used while determining the lateral borders of the heart. The right side of the heart was formed by the right atrium, while the left side of the heart was formed by the left auricle and left ventricle on the telecardiography (Figure 1B). The lateral borders of the thorax were determined by drawing a line from the inner parts of the costae, and the lower border of the thorax was determined by drawing a line along the diaphragm, and the upper border of the thorax was determined by drawing a straight line from the junction point of the inner edge of the 1st costa and the lower edge of the 2nd costa to the same junction point on the opposite side (Figure 1B). The line determining the upper border of the thorax also matched up with the 1st thoracic vertebra level. The cardiac and thoracic areas were calculated as the count of pixels. CTAR was obtained by dividing the number of pixels in the cardiac area by the number of pixels in the thoracic area.

Individuals with technically inadequate telecardiography (thoracic wall or spinal deformity, inadequate inspiration, inability to determine heart borders due to the massive effusion or severe atelectasis, incompletely erect radiograph, mediastinal de-

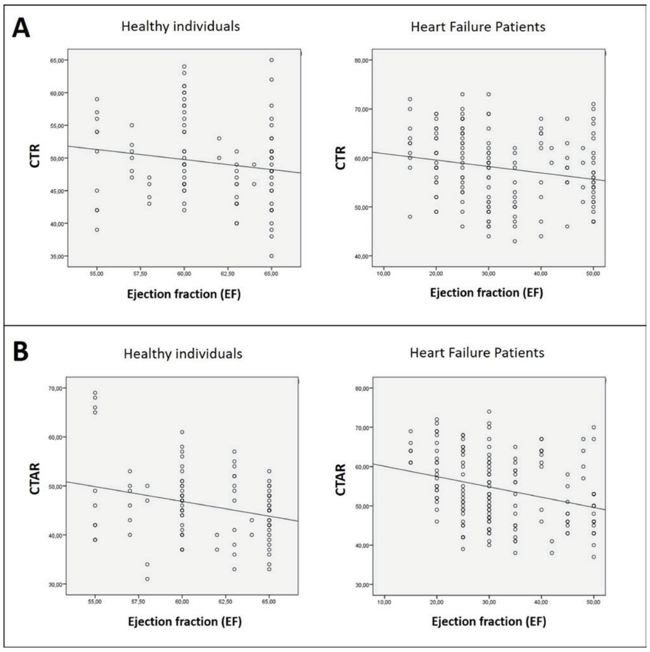

Figure 2. Distribution of three parameters, CTR, CTAR, and EF, for digital chest radiographs. (A) Correlation between the CTR and EF, and (B) correlation between the CTAR and EF unhealthy individuals and patients with congestive heart failure.

viation, and significant rotation) have been excluded from the study. Moreover, pulmonary diseases that may alter the total lung capacity (such as COPD and cystic fibrosis) and skeletal diseases that may alter the shape and size of the thoracic cage (such as scoliosis and ankylosing spondylitis) were included in the exclusion criteria. While setting up the control group, patients with heart failure and healthy individuals within the same age range but without any clinical finding in terms of heart failure were selected.

Echocardiographic evaluation was performed in the left lateral position. Parasternal long and short axis and apical 4-chamber images were acquired. Echocardiographic examinations of all patients were performed by the same cardiologist. Echocardiographic measurements were made according to the criteria recommended by the American Society of Echocardiography. Patients were subjected to M-mode and 2D echocardiographic evaluations, respectively. Left ventricular systolic and diastolic diameters were measured at the end of systole and diastole, and left ventricular ejection fraction (LVEF) was calculated according to the modified Simpson's rule.

IBM-SPSS 20 program was used in the statistical analysis of the data. The homogeneity of variances was evaluated by the Levene test, and the compatibility of the data with normal distribution was evaluated by the Kolmogorov-Smirnov test. The data was demonstrated as mean ± standard deviation (SD). Independent-samples t-test was used to compare the means of the two groups. The correlation between CTR, CTAR, and EF was analyzed by the Pearson's test. $P<0.05$ was considered statistically significant.

Results

A total of 331 participants were enrolled in this study between April 2016 and June 2017. Of the total population, 18 participants were excluded from this analysis based on the presence of other heart diseases (e.g. valvular disease) and lung diseases (e.g. emphysema and chronic bronchitis). An additional 59 participants were excluded based on the partially lost data and technically inadequate chest X-ray. Finally, a total of 254 participants (156 patients with congestive heart failure and 98 healthy individuals) were included in the study.

Distribution of the study groups by gender are shown in Table 1. The mean age of patients with congestive heart failure was 68 years, whereas the mean age was 66 years in the healthy group. There was no significant difference between the healthy and patient groups and between both genders in terms of age. The mean CTR among the healthy individuals was 48% for males, and 50% for females (Table 1). CTR values were higher in patients with congestive heart failure as expected ($p<0.01$). The mean CTR for entire heart failure patients was 60%, and for male and female patients was 57% and 62% respectively.

The mean CTAR was 50% in healthy individuals, compared with 55% in patients with congestive heart failure (Table 1). Females had higher CTAR values in both healthy individuals and heart failure patients. The mean CTAR was 45% for males and 55% for females in healthy individuals ($p<0.01$); whereas the mean CTAR for male and female heart failure patients was 51% and 60% respectively ($p<0.05$).

Table 1. Average value (and standart deviation) of age, CTR, CTAR and EF for healthy individuals and patients with congestive heart failure.

	Healthy individuals			Heart failure patients		
	Male (n=46)	Female (n=52)	Total (n=98)	Male (n=80)	Female (n=76)	Total (n=156)
Age (years)	65±12	66±11	66±12	69±11	67±10	68±11
CTR (%)	48±6	50±7	49±7	57±7	62±8	60±8
CTAR (%)	45±7*	55±9	50±8	51±5*	60±9	55±7
EF (%)	63±3	60±2	62±3	32±10	33±9	33±10

CTR = cardio thoracic ratio; CTAR = cardio thoracic area ratio; EF = ejection fraction.
*p<0.01 compared with female.

The mean EF among the healthy individuals was 63% for males, and 60% for females (Table 1). EF was not lower than 55% in all healthy individuals. The mean EF for patients with congestive heart failure was 33%. EF values were similar for male and female heart failure patients and the mean EF was 32% for males and 33% for females.

The value for CTAR might be used as an indicator of normal cardiac function. Assuming that an ejection fraction of 55% or more indicates normal cardiac function, a value of 50% or less for CTAR can be considered as normal. The sensitivity and specificity of a CTAR higher than 50% for prediction of the heart failure were 67% and 84% respectively. Conversely, sensitivity and specificity values for CTR were 36% and 61% respectively.

Correlation and regression analysis were used to examine the data set for an association between the EF, CTR, and CTAR. For the entire cohort, the correlation between the CTR and left ventricular EF was inverse and somewhat limited ($r = -0.13$for healthy individuals, and $r= -0.19$ for heart failure patients)

(Figure 2A). The inverse correlation between the CTAR and EF was improved (r = -0.32 for healthy individuals and r = -0.37for heart failure patients) (Figure 2B).These correlation coefficients were of high statistical significance (p<0.01). In the patients with congestive heart failure, a regression equation for the prediction of EF from the CTAR was derived as EF= (-33.5xCTAR) +51.2.

Discussion

Digital chest radiography is widely used as a popular technique for diagnosing various thoracic and cardiac diseases. The main reasons for being a popular diagnostic tool are that it is a cheap, practical and quick technique [2]. Although digital chest radiography is used as a more common and indispensable technique in clinical practice, studies evaluating cardiac and thoracic anomalies with direct radiographs remained limited in number [7]. Much more studies have been conducted on MRI and CT images. Since the patient lies in the supine position during MRI and CT scans, the results obtained from the studies using these techniques are not applicable to a standing person who exhibits gravitational effects [7]. Therefore, the studies using chest radiographs in standing position are still important in nowadays.

Cardiomegaly is associated with an adverse outcome in patients with heart disease [11]. Therefore, evaluation of heart size is an important clinical variable, and changes in heart size may be used to monitor and grade cardiac disease severity [1]. Posteroanterior (PA) chest radiograph has been known as a popular method to diagnose different heart-related diseases. The size of the heart can be estimated from a PA chest radiograph by the CTR. Clinicians continue to use the CTR because a quick decision is required under urgent situations, especially in the emergency department [12].

The upper limit for CTR measurement is generally considered to be 50% but different studies suggest different cut-off points for CTR [13]. Additionally, studies showed that the same CTR values are not suitable for detecting cardiomegaly for all age groups [14]. Therefore, CTR sometimes leads to the vagueness among normal and abnormal hearts causing difficulty in diagnosis. Due to the limitation of CTR, some researchers introduce a new index to evaluate the cardiac hypertrophy, the cardiothoracic area ratio (CTAR), which is computed by dividing the area of heart region by the area of thorax region [2]. The findings of our study show that the CTAR can be used effectively for evaluating the cardiac hypertrophy. CTAR also achieves the higher discrimination power than the traditional CTR in identifying hypertrophied hearts and diagnosis of the congestive heart failure.

Most of CHF cases are associated with chamber dilation due to acquired left ventricular systolic dysfunction , and patients with CHF generally have a larger CTR [15] . Additionally, left ventricular systolic function decreases in most patients with CHF [16] . Thus, clinicians have extrapolated that the chest roentgenogram can be used to predict systolic function in patients with CHF [7]. In this context, one would expect an association between CTR and EF. But early studies have shown a weak or inconsistent relationship between CTR and left ventricular function [6,7,17-19].

The results we obtained from this study, in which we evaluated the correlation between EF and CTR in patients with congestive heart failure, were consistent with previous studies. A weak negative correlation was found between CTR and EF in a study by Philibin et al. [7] conducted on 7476 patients with congestive heart failure and it was indicated that CTR cannot reliably be used to calculate left ventricular EF in patients with congestive heart failure. Again, a negative but a slightly better correlation was reported in a study by Cohn et al. [6], in which the correlation between CTR and EF was evaluated in 584 male patients. Such a difference may be due to the fact that only male patients were included in the study of Cohn et al. [6] and that there were patients with more severe congestive heart failure than in other studies. In our study, a weak correlation was found between CTR and EF, and it was understood that CTR could not be a good parameter in predicting left ventricular EF in the light of the results obtained from our study.

There are also similar reports in terms of the correlation between CTR and EF in studies conducted on individuals with congestive heart failure as well as other diseases. Rose and Stolberg [19] reported a weak negative correlation between CTR and angiographic EF in 256 patients underwent cardiac catheterization. Righetti et al. [18] found that serial changes in roentgenographic heart size following cardiac surgery correlated with the pericardial fluid but not left ventricular function. In a study by Bertolet et al. [17], conducted on alcohol abusers, only 8 of 29 patients with asymptomatic left ventricular systolic dysfunction identified by echocardiography were reported to have cardiomegaly on chest radiography.

A possible explanation for the weak relationship between CTR and EF is the variable distortion of right atrial and ventricular morphological characteristics among patients with CHF [7]. In the classic one-dimensional CTR, only the width is assessed for the heart size, and the entire growth of the heart, including the right side of the heart, is regarded as only one dimension. But, on a chest film, the heart size is seen as a two-dimensional structure. Therefore, we hypothesize that the two-dimensional CTR (also called CTAR) measured from the chest roentgenogram has better correlation with left vent ventricular EF than the one-dimensional CTR. Consistent with our opinion, we have shown that CTAR has better performance for the diagnosis of the CHF.

In the CTAR, heart area is measured, and the heart is evaluated as two-dimensional [2]. Thus, this measurement method shows an improved correlation with cardiac function compared with the traditional one-dimensional CTR (r = -0.19 vs. r = -0.37) in this study. A minor enhancement of data yield from the chest radiograph would be significant because it is still the most common investigation performed in the clinical practice. Therefore, findings from our study are of great importance for the evaluation of CHF and for the determination of cardiomegaly.

Study limitations

The main limitation of our study was the limited numbers of patients, so further studies with larger number of patients are needed. Another limitation was that heart failure was not divided into subtypes.

Conclusion

The correlation between CTAR and left ventricular EF was evaluated for the first time in patients with congestive heart failure and a significant negative correlation was found between CTAR and EF. When compared to CTR, CTAR shows an improved correlation with left ventricular EF in healthy individuals and heart failure patients. Additionally, CTAR values in normal individuals were determined as 45% for males and 55% for women. We believe that the radiographic assessment of the heart cannot replace EF measurement by echocardiographic means, but the CTAR can be of help to clinicians in the assessment of the heart on digital chest radiographs.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest

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References

1. Baron MS, Vitek JL, Bakay RA, Green J, McDonald WM, Steven AC, et al. Treatment of advanced Parkinson's disease by unilateral posterior GPi pallidotomy: 4-year results of a pilot study. Movement disorders: official journal of the Movement Disorder Society.2000; 15(2): 230-7.
2. Hasan MA, Lee S-L, Kim D-H, Lim M-K. Automatic evaluation of cardiac hypertrophy using cardiothoracic area ratio in chest radiograph images. Computer methods and programs in biomedicine.2012; 105(2): 95-108.
3. Bonow RO, Udelson JE. Left ventricular diastolic dysfunction as a cause of congestive heart failure: mechanisms and management. Annals of internal medicine. 1992; 117(6): 502-10.
4. Williams JF, Bristow MR, Fowler MB, Francis GS, Garsonjr A, Gersh BJ, et al. Guidelines for the evaluation and management of heart failure: report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Evaluation and Management of Heart Failure). Circulation.1995; 92(9): 2764-784.
5. Cintron G, Johnson G, Francis G, Cobb F, Cohn JN. Prognostic significance of serial changes in left ventricular ejection fraction in patients with congestive heart failure. The V-HeFT VA Cooperative Studies Group. Circulation. 1993; 87(6 Suppl.): S17-23.
6. Cohn JN, Johnson GR, Shabetai R, Loeb H, Tristani F, Rector T, et al. Ejection fraction, peak exercise oxygen consumption, cardiothoracic ratio, ventricular arrhythmias, and plasma norepinephrine as determinants of prognosis in heart failure. The V-HeFT VA Cooperative Studies Group. Circulation.1993; 87(6 Suppl.): SI5-16.
7. Philbin EF, Garg R, Danisa K, Denny M, gosselin G, Hassapoyannes C, et al. The relationship between cardiothoracic ratio and left ventricular ejection fraction in congestive heart failure. Archives of internal medicine. 1998; 158(5): 501-6.
8. Nakamori N, Doi K, Macmahon H, Sasaki Y, Montner S. Effect of heart-size parameters computed from digital chest radiographs on detection of cardiomegaly. Potential usefulness for computer-aided diagnosis. Investigative radiology. 1991; 26(6): 546-50.
9. Danzer CS. The cardiothoracic ratio: an index of cardiac enlargement. The American Journal of the Medical Sciences (1827-1924). 1919; 157(4): 513.
10. Browne RF, O'Reilly G, McInerney D. Extraction of the two-dimensional cardiothoracic ratio from digital PA chest radiographs: correlation with cardiac function and the traditional cardiothoracic ratio. Journal of digital imaging. 2004; 17(2): 120-3.
11. Wong M, Johnson G, Shabetai R, Hughes V, Bhat G, Lopez B, et al. Echocardiographic variables as prognostic indicators and therapeutic monitors in chronic congestive heart failure. Veterans Affairs cooperative studies V-HeFT I and II. V-HeFT VA Cooperative Studies Group. Circulation. 1993; 87(6 Suppl.): S65-70.
12. Chon SB, Oh WS, Cho JH, Kim SS, Lee S-J. Calculation of the cardiothoracic ratio from portable anteroposterior chest radiography. Journal of Korean medical science.2011; 26(11): 1446-53.
13. Raphael MJ. The Normal Heart methods of Examination. Textbook of Radiology and Imaging. 1998:562-5.
14. Brakohiapa EKK, Botwe BO, Sarkodie BD, Ofori EK, Coleman J. Radiographic determination of cardiomegaly using cardiothoracic ratio and transverse cardiac diameter: can one size fit all? Part one. The Pan African medical journal. 2017; 27.
15. Sharpe N. Cardiac remodeling in congestive heart failure. In: Congestive heart failure. Springer; 1994: 83-94.
16. Parmley WW. Pathophysiology and current therapy of congestive heart failure. Journal of the American College of Cardiology.1989; 13(4): 771-85.
17. Bertolet BD, Freund G, Martin CA, Perchalski DL, Williams CM, Pepine CJ. Unrecognized left ventricular dysfunction in an apparently healthy alcohol abuse population. Drug &Alcohol Dependence.1991; 28(2): 113-19.
18. Righetti A, Crawford MH, O'Rourke RA, Daily PO, Ross Jr J. Echocardiographic and roentgenographic determination of left ventricular size after coronary arterial bypass graft surgery. Chest.1977; 72(4): 455-58.
19. Rose CP, Stolberg HO. The limited utility of the plain chest film in the assessment of left ventricular structure and function. Investigative radiology.1982; 17(2): 139-44.

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