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ORIGINAL ARTICLE

Cardiothoracic ratio in postmortem computed tomography: reliability and threshold for the diagnosis of cardiomegaly

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Abstract The aim of this study was to evaluate the reliability of the cardiothoracic ratio (CTR) in postmortem computed tomography (PMCT) and to assess a CTR threshold for the diagnosis of cardiomegaly based on the weight of the heart at autopsy. PMCT data of 170 deceased human adults were retrospectively evaluated by two blinded radiologists. The CTR was measured on axial computed tomography images and the actual cardiac weight was weighed at autopsy. Inter-rater reliability, sensitivity, and specificity were calculated. Receiver operating characteristic curves were calculated to assess enlarged heart weight by CTR. The autopsy definition of cardiomegaly was based on normal values of the Zeek method (within a range of both, one or two SD) and the Smith method (within the given range). Intra-class correlation coefficients demonstrated excellent agreements (0.983) regarding CTR measurements. In 105/170 (62 %) cases the CTR in PMCT was >0.5, indicating enlarged heart weight, according to clinical references. The mean heart weight measured in autopsy was 405 ± 105 g. As a result, 114/170 (67 %) cases were interpreted as having enlarged heart weights according to the normal values of Zeek within one SD, while 97/170 (57 %) were within two SD. 100/170 (59 %) were assessed as enlarged according to Smith's normal values. The sensitivity/specificity of the 0.5 cut-off of the CTR for the diagnosis of enlarged heart weight was 78/71 % (Zeek one SD), 74/55 % (Zeek two SD), and 76/59 % (Smith), respectively. The discriminative power between normal heart weight and cardiomegaly was 79, 73, and 74 % for the Zeek (1SD/2SD) and Smith methods respectively. Changing the CTR threshold to 0.57 resulted in a minimum specificity of 95 % for all three definitions of cardiomegaly. With a CTR threshold of 0.57, cardiomegaly can be identified with a very high specificity. This may be useful if PMCT is used by forensic pathologists as a screening tool for medico-legal autopsies.

Keywords Forensic radiology · Virtopsy · Computed tomography · Heart size · Cardiomegaly · Reliability · Cardio thoracic ratio

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Introduction

The cardiothoracic ratio (CTR) is frequently used to determine cardiomegaly in plain film chest radiography (CXR) [1–3]. Although it has also been criticized [4, 5], it continues to be the routine way radiologists assess cardiomegaly. CTR is calculated by dividing the maximum transverse diameter of the heart with the maximum thoracic diameter [6]; values lower or higher than 0.5 are defined as "normal heart size" and "cardiomegaly" respectively [2, 7–9].

Several studies have assessed and adapted the CTR approach to computed tomography (CT) and these measures have been shown to correlate highly with those from CXR [10–12]. Despite this, there continue to be differing opinions regarding the clinical reliability and usefulness of the CTR in cross sectional imaging [10–12].

Unfortunately, to measure heart weight, most of these studies used other imaging modalities (e.g. ultrasound or MRI) as the reference standards, rather than autopsy. In fact, very few studies have investigated the CTR on PMCT in relation to cause of death [2], or compared the CTR on CXR with heart size measured at autopsy [4, 5].

Cardiomegaly is defined as hypertrophy of the heart (greater heart weight or ventricular thickness) or dilation (enlarged chamber size) [13]. In the medico-legal context, increased heart weight is indicative of underlying cardiovascular disease. This may include valvular diseases, cardiomyopathy, congenital heart diseases, pericardial effusions or mass lesions [8]. In cases of an assumed natural death, knowledge of underlying cardiovascular disease represents helpful information for the forensic pathologist. Therefore, a CTR technique similar to that used in the living would be desirable for predicting cardiomegaly in PMCT.

Zeek et al. [14] and Smith et al. [15] examined the autopsy heart weight of normal populations and generated normal heart weight tables for males and females, in relation to body length and weight, respectively. These results are well established and frequently used for diagnosing cardiomegaly in clinical and forensic pathology.

The aim of this study was to evaluate the diagnostic reliability of the cardiothoracic ratio (CTR) in postmortem computed tomography (PMCT), in terms of sensitivity and specificity, with respect to heart weight as defined by pathology references.

Materials and methods

Study sample

The study was approved by our institutional review board and the public prosecution department.

PMCT datasets of 250 deceased individuals were retrospectively evaluated in this study. As the combination of postmortem imaging and autopsy is the standard procedure in our department following the Virtopsy approach [16], datasets were accessed from our own archives. Consecutive cases were collected between 2010 and 2012, as defined by the installation of a new CT scanner.

Inclusion criteria were: age over 18 years and heart weight measured at autopsy. Exclusion criteria were: advanced decomposition [17], deformations of the thorax, massive blood loss (e.g. hematothorax, aortic rupture, pericardial tamponade), and trauma to the chest, heart or the aorta. After consideration of the exclusion criteria, the final study population consisted of 170 cases. Table 1 shows the subject demographics of the final study population.

Table 1 Study population demographics

Study population demographics	
Total number of subjects	170
Mean age ± SD (years)	44.5 ± 16.5
Gender (*n*)	Female (51); Male (119)
Mean body weight ± SD (kg)	79.42 kg (18.162)
Mean height ± SD (cm)	175.5 cm (8.647)
Cause of death (n)	
Cardiovascular failure	62
Trauma	15
Metabolic disease	4
Respiratory disease	1
Asphyxia	71
Infection	6
Other/unknown	11

CT data acquisition and image reconstruction

Image acquisition was performed on a 128-slice Somatom Definition Flash Dual Source CT scanner (Siemens Healthcare, Forchheim, Germany). All scans were routinely performed after the arrival of the deceased in our department and prior to autopsy, with the following parameters: 120 kV, 350–1,000 mAs dependent on automatic exposure control with tube current-time modulation (CareDose4D, Siemens Healthcare, Forchheim, Germany), 128 × 0.6 mm collimation, 0.5 s rotation, and 0.6 pitch. Image reconstruction was carried out using a soft tissue convolution kernel (B30) with a slice thickness of 1 mm and an increment of 0.5 mm.

Data analysis

Image analysis was carried out by a radiologist (XY—blinded for review) with 5 years of experience in CT using a Sectra Workstation IDS7 (Version 14.3.5.136, Sectra, Linkoping, Sweden). In order to determine the inter-reader reliability a second reader (XX—blinded for review- with 5 years of experience in CT) evaluated the first 70 cases and intra-class correlation coefficients (ICCs) were calculated.

In both cases, linear measurements were taken in an adapted way according to the method of Ungerleider and Gubner [6] as described in several previous CT studies [10–12]. All measurements were performed on axial slices using the

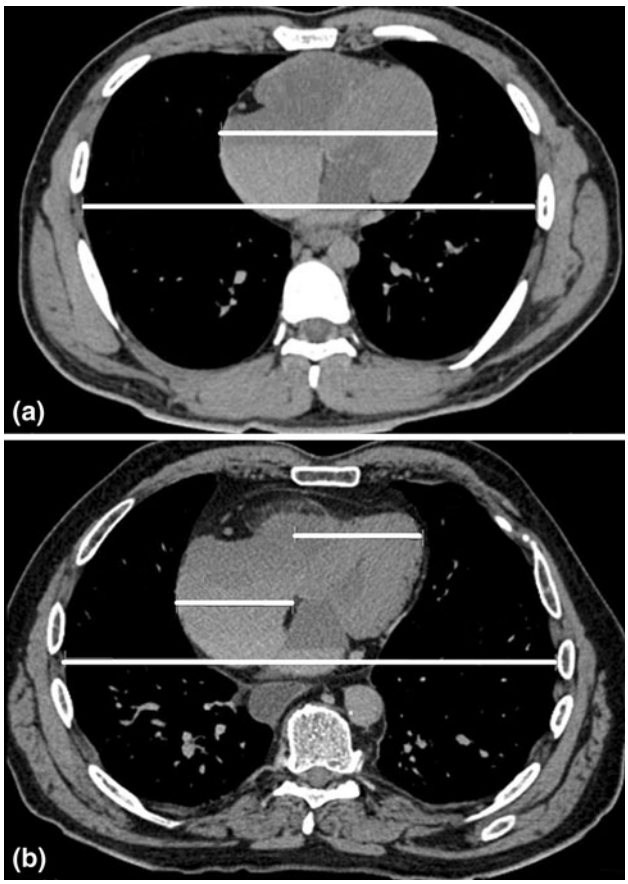

Fig. 1 Axial CT images of the thorax. *Lines* were drawn for the maximum thoracic diameter and for the maximum cardiac diameter in transverse direction (**a**). In cases where the maximum diameter of the heart was not assessable with one measurement (**b**), *lines* were divided according to the method of Ungerleider and Gubner [6]. *Line* placement was not necessarily in the same level of the axial slices

workstation caliper tool. Figure 1 depicts the lines defining the maximum diameter of the thorax as well as the maximum diameter of the heart, each in left-right direction. Line placement was not necessarily in the same level of the axial slices. Both readers were briefly instructed in this technique of image analysis. Initially, a CTR ≤ 0.5 was considered normal, whereas a CTR > 0.5 represented cardiomegaly.

Autopsy

Heart weight (in grams) was measured and recorded in all cases at the time of autopsy. Autopsies were performed following the harmonized European guidelines for medicolegal autopsies [18, 19] by two forensic pathologists, at least one of whom was board certified. Using the normal values defined by Zeek et al. [14] and Smith [15], cardiomegaly was defined as a heart weight above one, or two, standard deviations (SD) for the Zeek values, or above the range of average heart weights given by Smith.

Table 2 Results for heart weight, CTR, and diagnosis of cardiomegaly

	Female ($n = 51$)	Male ($n = 119$)
Mean heart weight (±SD)	337,65 g (80.04)	434.56 (101.98)
Mean CTR (±SD)	0.5052 (0.08)	0.5166 (0.06)
Cardiomegaly defined by CTR > 0.5 (%)	27/51 (53 %)	78/119 (66 %)
Cardiomegaly defined by Zeek ± 1 SD (%)	31/51 (61 %)	83/119 (70 %)
Cardiomegaly defined by Zeek ± 2 SD (%)	22/51 (43 %)	75/119 (63 %)
Cardiomegaly defined by Smith (%)	26/51 (51 %)	74/119 (62 %)

Statistical analysis

Continuous variables were expressed as mean ± SD and categorical variables as frequencies and percentages.

Inter-reader agreements regarding CTR measurements were analyzed by using ICC. According to Landis and Koch [20], ICC values of 0.81–1.00 indicate excellent agreement.

The diagnostic performance of the CTR for determining cardiomegaly as defined by autopsy heart weight and normal values by Zeek (one and two SD) and Smith was assessed on a per subject level and expressed as sensitivity and specificity with their corresponding 95 % confidence intervals (CI). Receiver operating characteristics (ROC) with discriminative power analysis were used to describe cardiomegaly by means of CTR. Point estimates, 95 % CI, and areas under the ROC curve (AUC) were calculated.

Statistical analysis was performed using IBM SPSS statistics software (release 20.0, Chicago, IL, USA). A p value of <0.05 was used to denote statistical significance.

Results

Autopsy

Mean heart weight was 405.5 ± 105.6 g with a range of 180–840 g. According to Zeek et al. [14], 114/170 (67 %) cases had enlarged heart weights within one SD and 97/170 (57 %) cases within two SD. According to the normal values given by Smith et al. [15], 100/170 (59 %) cases showed heart enlargement (Table 2).

Inter-observer agreement

Measurements for both readers were significantly correlated ($p < 0.001$). ICCs demonstrated excellent inter-

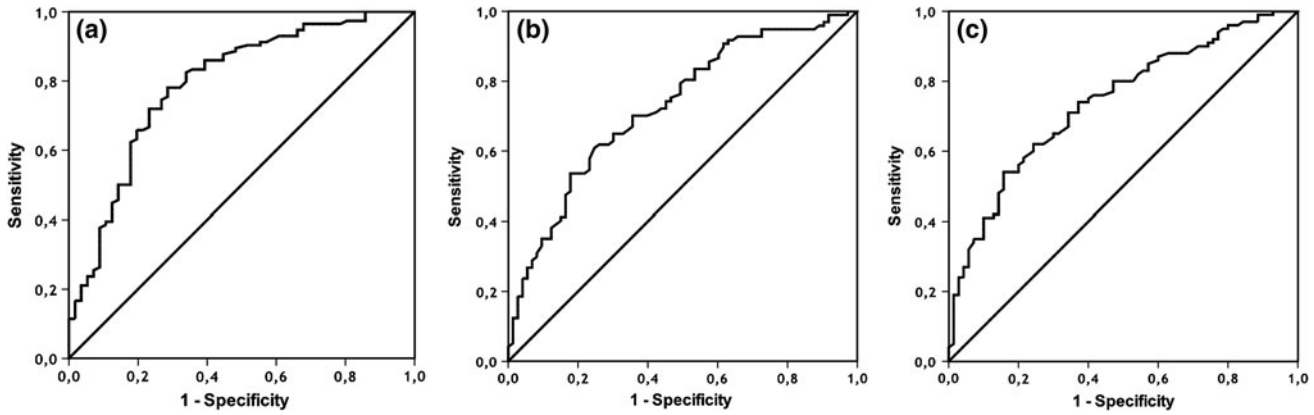

Fig. 2 ROC analysis for Zeek one SD (**a**), two SD (**b**), and Smith (**c**)

observer agreements regarding CTR measurements (ICC = 0.983).

PMCT analysis

The mean CTR was 0.513 ± 0.07 with a range of 0.28–0.69. A CTR above 0.5 (indicating cardiomegaly) was observed in 105/170 (62 %) of the cases.

The 0.5 CTR threshold showed a sensitivity of 78 % (95 % CI, 0.694–0.853) and a specificity of 71 % (95 % CI, 0.578–0.827) for detecting enlarged heart weight according to Zeek within one SD. Within two SD, sensitivity was 74 % (95 % CI, 0.644–0.826) and specificity 55 % (95 % CI, 0.427–0.665). For the Smith normal value, sensitivity, and specificity were 76 % (95 % CI, 0664–0.839) and 59 % (95 % CI, 0.462–0.702), respectively.

ROC analysis of CTR revealed a significant ($p < 0.0001$) discriminative power to differentiate between cardiomegaly and normal heart weight for both the Zeek and Smith normal values.

The area under the ROC curve was 0.79 (95 % CI 0.716, 0.865) for one SD Zeek and 0.728 (95 % CI 0.652, 0.804) for two SD Zeek normal values (Fig. 2a, b).

The area under the ROC curve for the Smith normal values was 0.738 (95 % CI 0.664, 0.812) (Fig. 2c).

Changing the CTR cut-off value from 0.50 to 0.57 results in a specificity of 95 % for diagnosing cardiomegaly using the Zeek method (one SD and two SD), and 96 % using Smith normal values. At the cost of the higher specificity, the sensitivity decreased to 24 % for Zeek one SD, 27 % for Zeek two SD and 27 % for Smith.

Changing the cut-off value to 0.45 results in a 95 % specificity for ruling out cardiomegaly by CTR for Zeek (one SD and two SD), and a specificity of 92 % for Smith normal values. This decreased the sensitivity to 34 % for Zeek one SD, 27 % for Zeek two SD, and 24 % for Smith normal values.

Discussion

Our study evaluates the reliability of the CTR in postmortem CT for the diagnosis of cardiomegaly. Cardiomegaly reflects a remarkable pathologic finding and plays a key role in clinical as well as forensic medicine for the diagnostic workup of patients and the resolution of medico legal cases, respectively.

The rapidly evolution of postmortem imaging [21, 22] requires evidence-based medicine and the validation of radiological methods and techniques used in the living to postmortem applications.

The high inter-reader reliability for the CTR in this study suggests that linear measurements on axial CT scans are a simple and effective means of assessing cardiomegaly postmortem. This stands in agreement with the technical approach of other studies and supports the use of this method for quantifying the diameter of the thorax and heart on CT images [10–12].

Using a 0.5 cut off value for differentiating normal heart weight from cardiomegaly, the discriminative power of the CTR as approached herein was 73–79 % depending on the normal value table used. Increasing the CTR cut off value to 0.57 significantly increased the specificity and the AUR and improved the ability to diagnose cardiomegaly in CT. This is also in line with two previous studies that measured heart size in anterior-posterior chest radiography in supine patients using a CTR cut-off value of 0.55–0.58 [23, 24].

Other studies have shown moderate correlations between the CTR in CT and specific heart properties such as left ventricular hypertrophy or heart function [10–12]. However, as these can be assessed by CT with other methods [25], it was not the aim of this study to demonstrate individual chamber pathologies.

More and more forensic institutes are implementing PMCT as part of their daily workload [21]. In a majority of them, PMCT is being used as a screening tool to rule out

specific causes of death and potentially reduce the number of forensic autopsies [26]. However, if PMCT is going to be used for such applications, a high specificity is needed. By setting a cutoff value of 0.57 for the PMCT CTR, the number of false positives is significantly restricted and a diagnosis of cardiomegaly on PMCT will also be found at autopsy. The results of our study indicate that the CTR in PMCT is a simple and efficient measurement for the gross assessment of heart size in deceased individuals.

Several limitations of this study deserve comment. First, the heart size, as assessed in imaging as well as in autopsy, might change after death [27]. This may be due to decomposition or other postmortem processes. The same might apply to the assessment of heart weight. Therefore, the results from CTR calculations may not necessarily represent the actual heart properties of the patient while alive. The correlation between ante- and postmortem heart size was not an issue of this study, however it deserves further studies. Secondly, using other reference values than those proposed by Zeek and Smith for the normal heart weight might result in different cut-off values from those calculated in our study. We used these values as they are considered standard references in the literature. Third, the study sample represents a specific demographic (forensic pathology cases) and may not correspond to the general population. This may explain the relatively high number of 57–67 % of cases with enlarged heart weight derived from autopsy in our study. Nevertheless, as they consist mainly of cardiovascular deaths, our cases should be similar to those at a non-forensic pathological department. Finally, axial measurements may not clearly show the widest diameter of both the heart and the thoracic cavity. While this could result in measurement error, the inter-reader correlation coefficient showed a high level of measurement repeatability and suggests that this is not a major problem in this study. Further studies might be necessary to assess other techniques for measuring the CTR, such as those based on defined anatomical levels, to achieve a higher consistency and reproducibility.

Key points

1. Postmortem CT measurements of the cardio thoracic ratio (CTR) are reproducible with a high inter-reader agreement (ICC, 0.983).
2. With an optimized, calculated cut-off for the CTR (0.57) the specificity for diagnosing cardiomegaly in CT was 95 %.
3. Our results suggest that the CTR calculated from axial CT slices might be a reliable and helpful tool to identify cardiomegaly postmortem.
4. This might influence the procedures and methods used in legal cases and might reduce the number of autopsies that are performed.

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