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Original Article

Main anatomical sizes of the cardiac chambers and great vessels by dual-source cardiac computed tomography

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Abbreviations
CT: computed tomography
LV: left ventricle
RV: right ventricle

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ABSTRACT

Introduction: Technological advances in computed tomography have made it possible to assess small, mobile structures such as the coronary arteries and the rest of the heart. Cardiac tomography provides anatomical and functional information.
Objectives: To identify the values of the main anatomical sizes of the cardiac chambers and great vessels, and compare them with the reference values.
Methods: An analytical research and development study was conducted with a population of 325 normotensive, non-obese patients without cardiopulmonary or great vessel structural disease, arrhythmia or significant coronary artery disease. One hundred patients were selected by simple random probability sampling, who underwent dual-source cardiac computed tomography at the Cardiocentro Ernesto Che Guevara, Santa Clara, Cuba.
Results: Left and right ventricular measurements showed differences when compared with most reference values. Aortic diameters increased with age. They were higher in men and were different from the reference values except for the short-axis diameter of the aortic root in end-diastole and short-axis diameter of the descending aorta in end-systole. The pulmonary artery showed significant differences in relation to the reference values.
Conclusions: Measurements of cardiac chambers and great vessels by tomographic techniques are necessary in certain population groups to achieve adequate standardization due to their great variability in relation to different variables. The significant difference with the reference values indicates the need for multicenter studies with larger populations to achieve homogeneity.
Keywords: Multidetector computed tomography, Computed tomography angiography, Coronary arteries, Heart chambers, Reference values

Principales medidas anatómicas de las cavidades cardíacas y grandes vasos por tomografía computarizada cardíaca de doble fuente

RESUMEN

Introducción: Los avances tecnológicos en tomografía computarizada han hecho posible la evaluación de estructuras pequeñas y móviles, como las arterias coronarias y el resto del corazón. La tomografía cardíaca aporta información anatómica y funcional.
Objetivo: Identificar los valores de las principales medidas anatómicas de las cavidades cardíacas y los grandes vasos, y compararlos con los valores de refe-

Authors' contribution
MENL and RAIA: Conception and design of the research; collection, analysis and interpretation of data, and drafting of the manuscript.
MPD: Conception and design of the research, and assistance in writing the manuscript.
All authors critically reviewed the manuscript and approved the final report.

rencia utilizados.
Método: Se realizó un estudio analítico de investigación y desarrollo con un universo de 325 pacientes normotensos, no obesos, sin enfermedad estructural cardiopulmonar o de grandes vasos, arritmia o enfermedad coronaria significativa, de donde se seleccionaron 100 pacientes por muestreo probabilístico aleatorio simple, a quienes se les realizó tomografía computarizada cardíaca de doble fuente en el Cardiocentro Ernesto Che Guevara, Santa Clara, Cuba.
Resultados: Las mediciones ventriculares izquierda y derecha mostraron diferencias con la mayoría de los valores referenciales. Los diámetros de la aorta, aumentaron con la edad, fueron superiores en los hombres y difieren de los valores de referencia con excepción del medido en eje corto de la raíz aórtica en telediástole, y el diámetro en eje corto de la aorta descendente en telesístole. La arteria pulmonar mostró diferencias significativas con relación a los valores de referencia.
Conclusiones: Las mediciones de las cavidades cardíacas y los grandes vasos basados en las técnicas tomográficas constituyen una necesidad en determinados grupos poblacionales para lograr una estandarización adecuada debido a su gran variabilidad en relación a distintas variables. La diferencia significativa con los valores de referencia indica le necesidad de estudios multicéntricos con poblaciones mayores para lograr su homogeneidad.
Palabras clave: Tomografía computarizada multidetector, Angiografía por tomografía computarizada, Arterias coronarias, Cavidades cardíacas, Valores de referencia

INTRODUCTION

On November 8, 1895, Wilhelm Conrad Roentgen discovered X-rays in his laboratory (Wurzburg, Germany). This discovery allowed the internal visualization of the human body and years later the diagnosis of various diseases[1].

The spectacular progression of X-rays led to the emergence of computed tomography (CT). In the second half of the 1980s, sequential CT gave way to helical CT. When this technique was thought to have reached its final stage, as other methods such as magnetic resonance imaging had emerged, Kalender *et al.*[2] revolutionized CT with the spiral acquisition model, which considerably reduced temporal resolution and gradually improved spatial resolution; all of which was achieved by moving from single-row to two-row detectors. Shortly after that, 4-, 16-, 32-, 40-, 64-, 128-, 256-, and 320-frame-per-rotation models came on the scene[2,3]. Dual-Source CT is another technological milestone that allows a special acquisition method[4-7], similar to the equipment used in this study and described below.

Groundbreaking advances in CT have made it possible to assess small and mobile structures, such as the coronary arteries and the rest of the heart. Coronary CT provides anatomical and functional information, and allows for the diagnosis of congenital and acquired diseases[8]. Currently, CT scanning does not require high doses of radiation and intravenous contrast, greatly reducing complications and contraindications.

It is possible to evaluate the heart and coronary arteries by synchronizing CT imaging with the patient's electrocardiogram. Here lies the difference between coronary CT and CT of any other part of the body. The heart, as a beating, constantly moving organ with small structures, poses a challenge for imaging assessment[8-10].

Measurements of cardiac structures based on tomographic techniques vary in certain population groups, depending on some variables, such as age, skin color and sex, among others. Therefore, our research aimed to identify the values of the main anatomical measurements of the cardiac chambers and great vessels, and compare them with the reference values applied to this purpose.

METHOD

A comparative analytical, research and development study was conducted in non-obese, normotensive patients, without structural cardiopulmonary or great vessel structural disease, arrhythmia or significant coronary disease, from the provinces of Cienfuegos, Sancti Spíritus, Villa Clara, Ciego de Ávila and Camagüey, who underwent dual-source cardiac CT at the

Cardiocentro Ernesto Che Guevara, Santa Clara, Cuba, from November 2016 to January 2019.

The study population consisted of 325 patients with the aforementioned characteristics and the sample was made up of 100 patients selected by simple random probability sampling.

Computed Tomography Scanner system

The Cardiac and Vascular CT-Imaging Department of the *Cardiocentro Ernesto Che Guevara*, where our study was conducted features a Somaton Definition system (Siemens, Germany) equipped with two X-ray tubes and two corresponding detectors mounted on a single gantry with an angular offset of 90°. With respect to cardiac imaging capabilities, this scanner system offers a high temporal resolution of 83 ms in a mono-segment reconstruction mode. The temporal resolution is independent of the heart rate, which is a major difference from single-source CT systems reliant on multi-segment reconstruction techniques.

SIEMENS image acquisition protocols use ULTRAVIST 370 low-density iodinated contrast agent by using a state-of-the-art ULRISCH Contrast Injector and ECG-triggered high-pitch protocols, using an automatic tube current modulation, thus achieving minimal radiation doses. The image acquisition is synchronized to the R-R interval, which depends on the patient's heart rate.

Angiographic analysis

Measurements were performed by means of multiplanar reconstructions in the short and long axes and in two-, three- and four-chamber views. Additionally, perpendicular cardiac planes of the main pulmonary artery and aorta in axial views were used. For functional or dynamic evaluation of the ventricle and great vessels, we performed the analysis in the two stages of the cardiac cycle, systole and diastole, using volumetric reconstructions for anatomical localization.

In our study, the analysis of the anatomical features of the heart and great vessels was based on the interpretation of images from standard cardiac planes. We used the same nomenclature as the other noninvasive cardiac imaging modalities and recommendations of the expert consensus on coronary angiography CT[11].

Statistical analysis

The SPSS Version 15.0 statistical program was used for data processing and inference tests for quantitative variables were performed using Student's t-tests and ANOVA (Analysis Of VAriance). Results were compared with the hypothetical values used as international references by using Student's t-test for one sample.

RESULTS

The **figure** shows the distribution of patients according to age and sex, where the age group between 40 and 60 years and female sex predominated, both with equal frequency (55%).

Both ventricular measurements in the study population differed significantly from the reference values (**Table 1**), except the septal-lateral diameter of the right ventricle

Mean values of the thoracic aorta, measured in short axis, according to sex, showed higher values for men in all measurements (**Table 2**). A significant difference was found in the end-diastolic diameter, aortic root area and end-systolic diameters of the ascending and descending aorta. When these variables were compared between both sexes, all showed significant differences with the reference values, except for the end-diastolic diameters of the aortic root and end-systolic diameters of the descending aorta in female sex (**Table 3**).

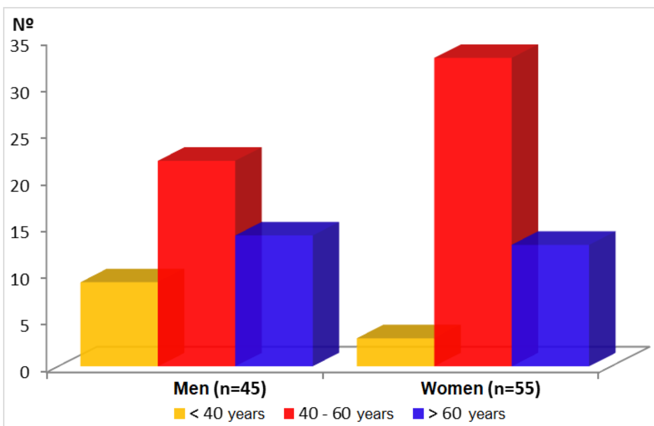

Figure. Distribution of patients according to sex and age groups.

Table 1. Left and right ventricular values compared with reference values.

Short-axis measurements (mm)	Mean	95% confidence interval		Reference value	t	p
LV ejection fraction	60.88	58.89	62.87	63.8	-2.909	0.040
LV end-diastolic volume	122.49	116.62	128.36	143.6	-7.136	<0.0001
LV end-systolic volume	49.19	45.89	52.49	52.6	-2.052	0.043
LV wall thickness	10.17	9.80	10.53	7.3	15.39	<0.0001
RV wall thickness	3.59	3.37	3.81	2.4	10.54	<0.0001
LV septal-lateral diameter	43.77	42.60	44.94	47.4	-1.37	<0.0001
RV septal-lateral diameter	38.05	36.87	39.23	37	1.76	0.081
LV anteroinferior diameter	53.03	51.64	54.42	57.7	-6.65	<0.0001
RV anteroinferior diameter	50.89	48.36	53.42	72.6	-17	<0.0001
LV annular apical diameter	74.65	72.89	76.41	87.6	-14.56	<0.0001
RV annular apical diameter	67.46	65.80	69.12	77.7	-12.25	<0.0001

LV, left ventricle; RV, right ventricle

Table 2. Mean aortic values according to sex.

Short-axis measurements (mm)	Male	Female	Total	t	p
ED diameter of Ao root	32.51	29.62	30.92	3.93	<0.0001
ED area of Ao root (mm^2)	93.27	75.45	83.47	5.06	<0.0001
ED diameter of ascending Ao	30.49	29.22	29.79	1.53	0.13
ES diameter of ascending Ao	31.84	30.24	30.96	2.07	0.04
ED diameter of descending Ao	23.27	22.13	22.64	1.44	0.15
ES diameter of descending Ao	24.04	21.55	22.67	4.86	<0.0001

Ao, aorta; ED, end-diastolic; ES, end-systolic

Table 3. Comparison of aortic values, according to sex, with reference values.

Measurements in short axis (mm)	Mean	95% confidence interval		Reference value	t	p
Female						
ED diameter of Ao root	29.62	28.80	30.44	29	1.51	0.137
ED area of Ao root (mm^2)	75.45	71.89	79.02	69	3.63	0.010
ED diameter of ascending Ao	29.22	28.25	30.18	28	2.53	0.014
ES diameter of ascending Ao	30.24	29.26	31.21	29	2.54	0.014
ED diameter of descending Ao	22.13	20.94	23.31	20	3.59	0.010
ES diameter of descending Ao	21.55	20.86	22.23	22	-1.34	0.187
Male						
ED diameter of Ao root	32.51	31.28	33.74	32	0.87	0.009
ED area of Ao root (mm^2)	93.27	87.15	99.38	85	2.72	<0.0001
ED diameter of ascending Ao	30.49	29.07	31.90	28	3.54	0.001
ES diameter of ascending Ao	31.84	30.59	33.10	30	2.96	0.005
ED diameter of descending Ao	23.27	22.28	24.25	22	2.58	0.013
ES diameter of descending Ao	24.04	23.26	24.83	23	2.69	0.010

Ao, aorta; ED, end-diastolic; ES, end-systolic

Table 4 shows the mean values of the different aortic segments measured, according to the three age groups, where we can appreciate their increase as age advances, with significant differences in the diameters of the ascending (p=0.009) and descending aorta (p<0.0001), more evident with respect to the group younger than 40 years; however, when comparing these results with the reference values in this age group, no significant differences were found, while there were significant differences in the 40−60 age group, specifically in the mean values of the ascending (p=0.01) and descending (p<0.0001) aortic diameters. Similarly, significant differences were found with respect to the reference values in three of the four variables analyzed in patients over 60 years of age: diameter (p=0.03) and area (p=0.01) of

Table 4. Mean aortic values according to age groups, compared to reference values.

Short-axis end-diastolic measurements (mm)	Mean	95% confidence interval		Reference value	t	p
Under 40 years of age						
Diameter of Ao root	30.06	28.30	31.82	31	-1.13	0.273
Area of Ao root (mm²)	76.33	68.15	84.52	78	-0.43	0.673
Diameter of ascending Ao*	27.33	25.56	29.11	26	1.58	0.131
Diameter of descending Ao**	19.39	18.23	20.55	20	1.11	0.28
40 - 60 years						
Diameter of Ao root	30.53	29.49	31.57	31	-0.91	0.36
Area of Ao root (mm²)	83.89	78.97	88.82	80	1.58	0.12
Diameter of ascending Ao*	29.95	28.83	31.06	28	3.48	0.01
Diameter of descending Ao**	23.24	22.09	24.38	20	5.65	<0.0001
Older than 60 years						
Diameter of Ao root	32.30	30.83	33.76	30	3.22	0.03
Area of Ao root (mm²)	87.37	79.01	95.73	76	2.79	0.01
Diameter of ascending Ao*	31.11	29.55	32.67	31	0.146	0.88
Diameter of descending Ao**	23.59	22.37	24.81	22	2.68	0.01

Ao, aorta
* p=0.009 when comparing between age groups
** p<0.0001 when comparing between age groups

Table 5. Mean values of pulmonary artery and superior vena cava compared to reference values.

Vessels	Mean	95% confidence interval		Reference value	t	p
Pulmonary artery						
Short-axis diameter	28.09	27.36	28.82	25	8.41	<0.0001
Anteroposterior diameter	27.90	27.23	28.57	26	5.6	<0.0001
Lateral diameter	26.44	25.66	27.22	24	6.1	<0.0001
Aorta-PA ratio in short axis	1.13	1.10	1.15	0.9	17.4	<0.0001
Superior vena cava						
Short-axis	15.2	14.72	15.68	17	-7.43	<0.0001
Long-axis	21.18	20.64	21.72	21	0.6	0.511
Area by planimetry	27.6	26.24	28.96	27	0.87	0.381

PA, pulmonary artery

the aortic root and diameter of the descending aorta ($p=0.01$).

All mean values obtained for the pulmonary artery were significantly different ($p<0.0001$) from the reference values (**Table 5**). A significant difference was found only in the mean value of the minor axis of the vena cava ($p<0.0001$).

DISCUSSION

The first commercially available CT scanner was created by British engineer Godfrey Hounsfield[4] of EMI Laboratories in 1972 (Nobel Prize in Medicine in 1979); with Allan C. Cormack, a physicist from Cape Town, who developed a mathematical basis, based on Radon's modifications, published in 1917 for reconstruction of cross-sectional images of transmission measurements[12]. The first CT scanners, now known as computed axial tomography scanners, were limited to cranial imaging until they were produced for whole-body scanning in 1975. Mechanical CT was insufficient for imaging-moving organs; therefore, in the late 1970s, a quick CT system without rotating gantry, devoted to imaging the heart, was developed; followed by multi-slice technology of rotating sources simultaneously with beam source[13,14]. The early 1990s saw the introduction of the first helical CT scanner into clinical practice, allowing for rapid coverage of large sections of the body, which was particularly useful for angiographic and cardiac CT applications, thanks to its temporal and spatial resolution, facilitating high-quality imaging of moving and beating organs, such as the heart and great vessels[13,14].

The advances in image acquisition were followed by the development of software for reconstructions in the post-processing department, where they are analyzed to reach diagnostic conclusions. In addition to all this, injection and acquisition protocols with the use of low radiation doses, synchronized to the patient's electrocardiogram with submillimeter reconstructions, facilitate the visualization of anatomical details with greater consistency, especially in the heart and vessels of the thorax and mediastinum. This is achieved by the improved spatial and temporal resolution and volumetric acquisition of the dual-source CT, offering a high temporal resolution of 83 ms, using detectors with 64 rows collimated 0.625-mm thickness, with a total z-coverage of 40 mm volume/longitudinal axis of the body at each 360-degree rotation[8-10,15-17].

Lin *et al.*[18] conducted an investigation quite similar to ours with a similar number and characteristics in terms of the patients studied. Generally, measurements and volumes of both ventricles slightly differ from our results and some of them present significant statistical differences.

These authors established specific values, according to age and sex, for the size, function and mass of all cardiac chambers in adults without cardiovascular disease, hypertension or obesity; and propose these data to be used as reference for future multidetector CT studies. For their part, Stojanovska *et al.*[19] normalized the reference range for volume, function and mass of both ventricles, according to age, sex and body surface area, and observed statistically significant differences between men and women in both left ventricular mass and right ventricular volume ($p < 0.0001$). Additionally, age and sex were associated with significant differences in right ventricular end-diastolic volume ($p=0.027$) and left ventricular ejection fraction ($p=0.03$). Similar results have been found by other authors[20-22].

Thoracic aorta values were significantly higher in male patients, which is justified by the difference in body surface area. However, these parameters had a less significant difference from the reference pattern, probably related to the lower variability of the aortic diameters of these segments with respect to body surface area. When we analyzed these same variables according to the three age groups we could observe that the variation in the aortic diameters of any segment studied increases proportionally with age, and a significant difference were found for the diameters of the ascending and descending aorta. These results also coincide with another study by Lin *et al.*[23].

Values for each parameter of the pulmonary artery and superior vena cava showed significant differences compared with the reference standards, but are similar to those found by Edwards *et al.*[24] and to those described by Sonavane *et al.*[25], respectively.

CONCLUSIONS

Measurements of cardiac chambers and great vessels based on dual-source multi-slice CT are required in certain population groups to achieve adequate standardization due to their great variability in relation to different variables, such as skin color (or race), age and sex, among other variables. Its significant differences with the reference values and with-in the same population group indicate that multicenter studies should be conducted with larger populations to achieve adequate homogeneity of these measurements.

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