World Journal of Cardiovascular Surgery, 2014, 4, 69-76
Published Online April 2014 in SciRes. http://www.scirp.org/journal/wjcs
http://dx.doi.org/10.4236/wjcs.2014.44011

Four Chamber Normative Data for Computed Tomography Angiography in the Axial Plane

Weston Whittington MD*, Akil Loli MD, Richard Gerkin MD, Kenneth Desser MD

Banner Good Samaritan Medical Center, Phoenix, USA
Email: *westonww@hotmail.com

Received 10 March 2014; revised 10 April 2014; accepted 19 April 2014

Abstract

Background: Computed Tomography Angiography (CTA) is a new and promising type of imaging to evaluate cardiac structure and function. Although it does require injection of contrast material and some radiation exposure, it is much less invasive than conventional catheter based on angiography. It has been already shown to correlate well with echocardiography images, but normative values have yet to be established. Objectives: To publish the first known data on CTA measurements for all four chambers of the heart. Methods: We conducted a retrospective chart review study of around 3000 patients over a three-year period (2006-2008) from a private cardiology practice in Phoenix, Arizona. Patients were screened for any preexisting conditions that might contribute to abnormal cardiac structures. A "normal" population of 226 patients' CTA's was reviewed and 29 different measurements were taken cardiac anatomy. Patients were then categorized based on sex and BMI and the cardiac measurements were compared. Results: The values obtained were similar to already established normal measurement values from echocardiography. There was good correlation between body mass index (BMI) and the sexes. Conclusion: This study serves to establish normative data for cardiac CTA while also proves to show good correlation with already established normative values for echocardiography and justifies these CTA measurements as an alternative means of cardiac evaluation. Further study regarding the variations between data for specific measurements will be addressed in future studies.

Keywords

Cardiac CT, Computed Tomography, Normative, Data

*Corresponding author.

How to cite this paper: Whittington, W., Loli, A., Gerkin, R. and Desser, K. (2014) Four Chamber Normative Data for Computed Tomography Angiography in the Axial Plane. *World Journal of Cardiovascular Surgery*, **4**, 69-76.
http://dx.doi.org/10.4236/wjcs.2014.44011

1. Introduction

Over the last half-century, the diagnosis and treatment of atherosclerotic heart disease have advanced exponentially. However, despite all the technological advances, Coronary Artery Disease (CAD) remains the number one cause of morbidity and mortality in developed nations worldwide. Eighty million Americans alone have some forms of cardiac disease, 16.8 million with coronary heart disease, leading to an estimated total cost in 2008 of $475.3 billion [1]. The greatest challenge in treating CAD is in detecting it at a stage early enough to intervene before it causes irreversible damage to heart muscle. Computed Tomography Angiography (CTA) scans are a relatively new, yet largely untested, addition to the array of cardiac imaging techniques available. The accuracy and three-dimensional reconstruction provide unique diagnostic advantages over other modalities.

The correlations in measurements between Echocardiogram and CTA evaluation of cardiac volumes are excellent when comparing LVEDV, LVESV and LVEF ($r = 0.92$, $r = 0.93$, $r = 0.80$), respectively [2]. The imaging has also begun to be used to identify cardiac anomalies, pulmonary vein structure prior to electrophysiology studies, pericardial disease and even vein graft patency [3]. However, one aspect of the scan seems to have largely been ignored: the standardization of cardiac structure measurements.

After a review of the literature we could not find any studies that encompassed the entire heart and its structures in a cardiac disease free population. Therefore, the purpose of our study is to evaluate a population free of cardiac disease, using a single scanner, to establish right and left heart structure measurements using CTA. We also explored the effect of gender on the size of these structures.

2. Methods

This study is a retrospective review of 3000 patients over a three-year period by electronic medical record review at a private cardiology office in central Phoenix, AZ. The practice consists of ten physicians, five nurse practitioners and one physician assistant with nearly 40,000 patient visits annually. The population screened for this study underwent CTA between 1/3/06 and 12/30/08. Reasons for referral included chest pain, coronary artery anatomy evaluations, cardiac chamber size measurement and coronary artery calcium scoring. This initial population was then screened via electronic chart for documented evidence of heart disease that may affect cardiac structure. About 10% of the total population reviewed qualified. Exclusion criteria were obtained from a physician generated problem list available on chart review and included:

1. Diabetes Mellitus (type I or II).
2. Conditions affecting cardiac structure:

- History of Stage One Hypertension (140/90) or greater.
- History of CAD (myocardial infarction, coronary angioplasty or stenting, coronary artery bypass grafting).
- History of any congenital heart abnormalities (either corrected or not).
- Atrial or ventricular hypertrophy.
- Left ventricular ejection fraction less than 40%.
- History of documented pulmonary hypertension (>25 mm Hg).
- History of valvular disease of any valve, including regurgitation, prolapse and stenosis as previously diagnosed by a physician (excluding "trivial" or "mild" diagnoses).
- Previous documentation of cardiomyopathy (dilated, restrictive, hypertrophic).

3. Lack of data, including:

- Undocumented BMI measurements

Or recent CTA evidence of:

- Agatston calcium score greater than 0 (as calculated on original cardiologist reading of CTA).
- Inadequate visualization of right heart structures (as determined by certified CTA reader).

After all exclusion criteria were reviewed, the final population consisted of 83 males and 143 females. Not all measurements could be obtained for all patients.

The study gained approval through the Institutional Review Board at Banner Good Samaritan Medical Center. All CTA's were performed on the same GE Lightspeed VCT single-source, 64-slice CT system. Scanning parameters were consistent through all scans as follows: tube current-time product 700 - 750 mAs, tube voltage 100 - 120 kV, slice acquisition 64 × 0.6 mm by means of a z-flying focal spot, gantry rotation time 330 ms, pitch 0.2 - 0.22 (depending on HR), reconstructed slice thickness 0.625 mm, using mediastinal windows and a standard kernel.

All images were acquired during maximal breath hold on third breath of hyperventilation sequence, in supine position with hands over head. Beta blockade medication was given for heart rates greater than 65 bpm. Pt would take 50 mg metoprolol two hours prior to scan if resting HR was 65 - 75 bpm, 100 mg metoprolol if HR greater than 75 bpm. An additional dose could be administered at time of scan if HR was still elevated.

Prior to scan each patient had a 20-gauge IV catheter placed in the right antecubital fossa (unless placement contraindicated) and a test saline injection of 10 ml normal saline at 5 ml/sec was performed. EKG leads (Ivy Biomedical Systems) were then placed on the torso for monitoring and gating. Patients were then placed supine on the scanning bed with their hands above their head.

All patients underwent identical imaging protocol, which consisted of five total parts: two scout images, calcium scoring, timing scan and angiogram imaging. Two scout images were taken in the antero-posterior and lateral angles. A calcium score was then calculated off these scout images. Next, a timing injection of 20 ml Isoview 370 contrast material (Bracco Diagnostics Inc. Stead, NV) followed by 20 ml of normal saline at 5 ml/sec by a Stellant dual saline/contrast injector system (2 - 200 ml syringes, 1 - 60 inch T-connector and primer tube, 2 spikes) was administered. A time curve was then calculated for optimal contrast media in the left heart, typically 25 - 30 seconds after injection. Bolus injection of 80 ml of contrast at 5 ml/sec followed by 15 ml of contrast at 3 ml/sec pushed by 50 ml normal saline at 5 ml/sec was then initiated. Automatic timing of the CTA scan was begun in conjunction with the injection protocol. Scanning was performed in the cranio-caudal direction, beginning 2 - 3 cm above the aortic arch to the base of heart. ECG-gated tube pulsing was used for radiation dose reduction in all patients and adapted according to heart rate. Images were recorded, stored and reconstructed via GE AW workstation and software package.

3. CTA Data Analysis

Each patient's scan was reviewed by a single physician, under a consistent method of views and diameters. All measurements were taken in the axial plane for consistency in measurement. Cardiac structures and volumes measured include:

- aortic root, axial view just above aortic valve
- ascending aorta, axial view, 2 cm below arch
- left main coronary artery at the ostium, axial view
- left anterior descending artery at the ostium, axial view
- circumflex artery at the ostium, axial view
- right coronary artery at the ostium, axial view
- pulmonary artery at the valve cusp, axial view superior to pulmonic valve
- right main pulmonary artery at bifurcation, axial view
- left main pulmonary artery at bifurcation, axis adjusted for axial section
- superior vena cava, axial view 2 cm above right atrium
- inferior vena cava, axial view 2 cm below right atrium
- coronary sinus, axial view at ostium
- left atrium length measurement (mitral valve to apex), axial view
- left atrium width(lateral wall to lateral wall), axial view
- right upper pulmonary vein at ostium, axial view
- right lower pulmonary vein at ostium, axial view
- left upper pulmonary vein at ostium, axial view
- left lower pulmonary vein at ostium, axial view
- left atrial appendage width at ostium, axial view
- left atrial appendage length, axial view
- left ventricular wall thickness, axial view, mid ventricle
- left ventricular base, axial view, sub-valvular level
- left ventricular papillary muscle, mid muscle belly width
- left ventricular length, axial view
- right atrial base (lateral wall to lateral wall), axial view
- right atrial length (tricuspid valve to posterior wall), axial view
- right ventricle base, axial view

- right ventricular length, axial view
- anterio-posterior diameter (sternum to vertebral body).

Independent variables such as age, sex and BMI were also collected. Although not the typical axis for all measurements when compared to echocardiogram, the mean values of left atrial and left ventricular chamber size were consistent with standard echocardiogram values [4].

Descriptive statistics were used. Continuous variables were reported as means and standard deviations. Categorical variables were reported as percentages. Independent t-tests were used for testing differences in structure sizes by gender. A two-tailed $p < 0.05$ was considered significant. SPSS 16.0 (SPSS, Inc., Chicago, IL) was used for the analysis.

4. Results

Not all measurements could be obtained on all patients due to poor quality of the structure being measured or incomplete inclusion of the structure within the scanning window. Significant differences were found between sexes in all structures except SVC, coronary sinus, left atrial length, atrial appendage at ostium and atrial appendage length.

The following **Table 1**, **Table 2**, **Table 3**, **Table 4**, and **Table 5** display the mean and standard deviation, as well as the p value for difference between genders for the measured cardiac structures. Structures have been divided into groups by anatomical location and proximity.

5. Discussion

Other imaging techniques for assessment of cardiac structure and function, such as echocardiography (Echo) and magnetic resonance imaging (MRI), have been performed for years with both predictability and reliability. Echo, either transthoracic or transesophageal, has been a widely utilized and accepted modality for non-invasive evaluation of cardiac structures with a sensitivity and specificity for end diastolic volume of 80% and 88% respectively with a predictive accuracy of 86% [5]. However, echo measurements are often limited by a patient's body

Table 1. Means, SD and p values for right-sided heart structures by gender.

Female	Right Sided Structures	Male	p
X = 17.2 Sd = 2.89 N = 143	SVC	X = 18.0 Sd = 2.98 N = 83	0.070
X = 23.3 Sd = 3.13 N = 143	IVC	X = 24.8 Sd = 3.68 N = 82	0.001
X = 49.0 Sd = 6.21 N = 137	Right Atrial Base	X = 53.2 Sd = 7.64 N = 82	<0.001
X = 36.9 Sd = 4.89 N = 138	Right Atrial Length	X = 39.2 Sd = 7.66 N = 82	0.007
X = 41.8 Sd = 5.24 N = 140	Right Ventricular Base	X = 48.8 Sd = 6.30 N = 82	<0.001
X = 72.0 Sd = 9.04 N = 140	Right Ventricular Length	X = 81.6 Sd = 10.70 N = 82	<0.001
X = 27.0 Sd = 3.56 N = 141	Pulmonary Artery @ Valve	X = 30.4 Sd = 3.89 N = 82	<0.001
X = 17.8 Sd = 2.31 N = 136	Right Main Pulmonary Artery	X = 19.3 Sd = 2.42 N = 82	<0.001
X = 18.4 Sd = 2.55 N = 110	Left Main Pulmonary Artery	X = 19.8 Sd = 2.55 N = 68	0.001

Table 2. Means, SD and p values for Pulmonary Veins by gender.

Female	Pulmonary Veins	Male	p
X = 11.5 Sd = 2.03 N = 141	Left Upper Pulmonary Vein	X = 12.6 Sd = 2.23 N = 81	<0.001
X = 10.6 Sd = 2.46 N = 141	Left Lower Pulmonary Vein	X = 11.6 Sd = 2.37 N = 81	0.004
X = 13.1 Sd = 2.27 N = 142	Right Upper Pulmonary Vein	X = 13.8 Sd = 2.32 N = 83	0.034
X = 13.9 Sd = 2.12 N = 142	Right Lower Pulmonary Vein	X = 14.7 Sd = 2.51 N = 83	0.013

Table 3. Means, SD and p values for Coronary Sinus and AP Diameter by gender.

Female	Miscellaneous structures	Male	P
X = 8.52 Sd = 2.38 N = 142	Coronary Sinus	X = 8.7 Sd = 3.13 N = 82	0.592
X = 114.6 Sd = 14.23 N = 142	AP Diameter	X = 132.3 Sd = 18.86 N = 83	<0.001

Table 4. Means, SD and p values for left sided structures by gender.

Female	Left Sided Structures	Male	P
X = 33.1 Sd = 4.44 N = 142	Left Atrium Width	X = 34.9 Sd = 5.16 N = 83	0.008
X = 49.7 Sd = 8.30 N = 142	Left Atrium Length	X = 51.9 Sd = 9.66 N = 83	0.074
X = 16.0 Sd = 3.50 N = 142	Left Atrial Appendage at Ostium	X = 15.9 Sd = 3.66 N = 83	0.859
X = 37.0 Sd = 6.98 N = 142	Left Atrial Appendage Length	X = 37.4 Sd = 8.46 N = 83	0.706
X = 41.9 Sd = 4.96 N = 142	Left Ventricle Width	X = 44.4 Sd = 6.24 N = 83	0.001
X = 63.6 Sd = 9.02 N = 142	Left Ventricle Length	X = 73.3 Sd = 10.53 N = 83	<0.001
X = 25.2 Sd = 6.46 N = 140	Left Ventricle Papillary Muscle	X = 27.2 Sd = 6.83 N = 83	0.033
X = 7.6 Sd = 1.52 N = 142	Left Ventricle Wall	X = 9.0 Sd = 1.25 N = 83	<0.001

Table 5. Means, SD and p values for coronary artery structures by gender.

Female	Coronary Arteries	Male	P
X = 29.2 Sd = 3.29 N = 142	Aortic Root	X = 33.8 Sd = 3.57 N = 83	<0.001
X = 28.6 Sd = 4.35 N = 142	Ascending Aorta	X = 29.8 Sd = 3.58 N = 83	0.027
X = 3.2 Sd = 0.77 N = 126	Right Coronary Artery	X = 3.9 Sd = 0.80 N = 82	<0.001
X = 4.08 Sd = 0.98 N = 132	Left Main	X = 4.8 Sd = 1.12 N = 82	<0.001
X = 3.1 Sd = 0.53 N = 134	Left Anterior Decending	X = 3.7 Sd = 0.66 N = 82	<0.001
X = 2.8 Sd = 0.56 N = 120	Circumflex	X = 3.24 Sd = 0.63 N = 75	<0.001

habitus, which can make right heart structures indistinguishable. Cardiac MRI has been accepted as the reference standard for accuracy in assessing cardiac structures. Although a much faster test, the CTA has a predilection for underestimating the ejection fraction and end-diastolic volumes while overestimating end-systolic volumes when compared to cardiac MRI, but the two methods are highly correlative in the remainder of their measurements [6].

While clinically the most important data that could be obtained by CTA lie in the coronaries, no normative values for cardiac chambers and structures have been identified. Technical guidelines for proper imaging, as well as incidental findings on CTA have been well described in the review literature [7]-[9]. Standardizations regarding how to image heart valves by CTA, and accurate measurements of LV and LA dimensions and volumes when compared to echocardiogram have been published, but not in a normal population [10] [11]. There are even normative values for the superior vena cava and reviews of atrial septal defect evaluations by CTA, but once again the populations were not screened for CAD [12] [13]. Values of RV and LV volumes by MRI have been published for years [14]. However, a recent European retrospective study looked at 120 patients who underwent CTA and recorded values of septal wall thickness, posterior wall thickness, LV inner diameter, LA anterior posterior diameter, end-systolic volume, and end diastolic volume [15]. Although their patient population was selected to be free of cardiac disease, their images were obtained on two different CT scanners and no evaluation of right heart structures was done.

Until now there has been limited normative data published for cardiac structures, especially right heart structures. Our study's retrospective design, size and stringent exclusion criteria make it the most extensive publication of normative four chamber CTA data to date. Prospectively selecting a healthy population without cardiac disease to undergo testing is not feasible given the cost of the test and the risk of kidney damage and radiation exposure.

Limitations of the this study include a non-traditional measurement axis in the axial plane, but as mentioned above, values obtained are consistent with standard echocardiogram values (Women: LA diameter 27.0 - 38.0 mm, RA diameter 29.0 - 45.0 mm, LV diameter 39.0 - 53.0 mm, Aortic Annulus 23.0 - 29.0 mm. Men: LA diameter 30.0 - 40.0 mm, RA diameter 29.0 - 45.0 mm, LV diameter 42.0 - 59.0 mm, Aortic Annulus 23.0 - 29.0 mm) [4]. Measuring in the axial plane also allowed for easy reproducibility of measured cardiac structures. Since every study was measured in this standard plane it was susceptible to variation in cardiac positioning from patient to patient, which could affect the measurements.

Another consideration is the normality of the population of our study. All patients were referred to a private cardiology practice either by physician referral or hospital follow-up. All patients evaluated had some form of health care insurance coverage and it is unclear if or how this factor affected ethnic variation in the study population.

Given the relative differences in body size between genders, it is expected that there would be some differences between sexes. Unexpected was that all but five measurements showed significant differences between the sexes. It is unclear why there were no significant differences in five of the measurements, but the very angular nature of the coronary sinus and left atrial appendage makes two-dimensional measurements difficult and may account for higher variation in measurements.

Most of our data showed significant size differences between cardiac structures between the sexes as well as values that fell within the already accepted sex specific norms as measured by echocardiogram [4]. However, it raises the question: do these measurements remain consistent between other variables such as age and BMI? This, in turn, leads inevitably to the larger, and more philosophical question of what exactly is a normative value and how we define this standard. For instance, should a patient's BMI be the main consideration when evaluating ventricular hypertrophy to account for normal variations in size difference or do age and sex end up being better predictors?

6. Conclusion

To the best of our knowledge, this is the most complete set of cardiac structure normative data published to date. It further confirms the accuracy of CTA measurements in respect to the already accepted echocardiographic values, but it goes further by presenting standard axial images as a new, but consistent means of measuring cardiac structures. We hope this study will serve as a basis for further investigation and confirmation of normative cardiac CTA values. We are also excited about further analysis of our data, specifically investigating the correlations between cardiac structures and other variables such as age, BMI and investigating what normative data truly means.

References

[1] Lloyd-Jones, D., *et al*. (2009) Heart Disease and Stroke Statistics—2009 Update: Report from the American Heart Association Statistics Committee and Stroke Subcommittee. *Circulation*, **119**, e21-e161.

[2] Henneman, M., *et al*. (2006) Global and Regional Left Ventricular Function: A Comparison Between Gated SPECT, 2D Echocardiography and Multi-Slice Computed Tomography, *European Journal of Nuclear Medicine and Molecular Imaging*, **33**, 1452-1460.

[3] Prat-Gonzalez, S., Sanz, J., Garcia, M. and Cardiac, C.T. (2008) Indications and Limitations. *Journal of Nuclear Medicine Technology*, **36**, 18-24. http://dx.doi.org/10.2967/jnmt.107.042424

[4] Ryding, A. (2008) Essential Echocardiograpy. Elsevier Limited, Amsterdam.

[5] Erbel, R., Schweizer, P., Krebs, W., Meyer, J. and Effert, S. (1984) Sensitivity and Specificity of Two Dimensional Echocardiography in Detection of Impaired Left Ventricular Function. *European Heart Journal*, **5**, 477-489.

[6] Sibley, C. and Lima, J. (2008) Assessment of Ventricular Structure and Function with Multidetector CT and MRI. *Current Cardiology Reports*, **10**, 67-71. http://dx.doi.org/10.1007/s11886-008-0013-5

[7] Flohr, T.G., *et al*. (2008) Image Reconstruction and Image Quality Evaluation for a Dual Source CT Scanner. *Medical Physics*, **35**, 5882-5897. http://dx.doi.org/10.1118/1.3020756

[8] Lee, S.H., *et al*. (2008) Incidental Cardiac and Pericardial Abnormalities on Chest CT. *Journal of Thoracic Imaging*, **23**, 216-226. http://dx.doi.org/10.1097/RTI.0b013e318166a485

[9] Burt, J.R., *et al*. (2008) Incidental Findings on Cardiac Multidetector Row Computed Tomography among Healthy Older Adults. *Archives of Internal Medicine*, **168**, 756-761. http://dx.doi.org/10.1001/archinte.168.7.756

[10] Manghat, N., *et al*. (2008) Imaging the Heart Valves Using ECG-Gated 64-Detector Row Cardiac CT. *The British Journal of Radiology*, **81**, 275-290. http://dx.doi.org/10.1259/bjr/16301537

[11] Stolzman, P., *et al*. (2008) Left Ventricular and Left Atrial Dimensions and Volumes, Comparison Between Dual-Source CT and Echocardiography. *Investigative Radiology*, **43**, 284-289. http://dx.doi.org/10.1097/RLI.0b013e3181626853

[12] Mahlon, M. and Yoon, H.C. (2007) CT Angiography of the Superior Vena Cava: Normative Values and Implications for Central Venous Catheter Position. *Journal of Vascular and Interventional Radiology*, **18**, 1106-1110. http://dx.doi.org/10.1016/j.jvir.2007.06.002

[13] Gade, C., *et al*. (2007) Comprehensive Evaluation of Atrial Septal Defects in Individuals Undergoing Percutaneous Repair by 64-Detector Row Computed Tomography. *The International Journal of Cardiovascular Imaging*, **23**, 397-404. http://dx.doi.org/10.1007/s10554-006-9149-9

[14] O'Brien, J., *et al*. (2007) Anatomy of the Heart at Multidetector CT: What the Radiologist Needs to Know. *Radio-*

Graphics, **27**, 1569-1582. http://dx.doi.org/10.1148/rg.276065747

[15] Stolzmann, P., *et al*. (2008) Reference Values for Quantitative Left Ventricular and Left Atrial Measurements in Cardiac Computed Tomography. *European Radiology*, **18**, 1625-1634. http://dx.doi.org/10.1007/s00330-008-0939-4