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Chamber dimensions and functional assessment with coronary computed tomographic angiography as compared to echocardiography using American Society of Echocardiography guidelines

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Abstract

Background: The correlation between normal cardiac chamber linear dimensions measured during retrospective coronary computed tomographic angiography as compared to transthoracic echocardiography using the American Society of Echocardiography guidelines is not well established.

Methods: We performed a review from January 2005 to July 2011 to identify subjects with retrospective electrocardiogram-gated coronary computed tomographic angiography scans for chest pain and transthoracic echocardiography with normal cardiac structures performed within 90 days. Dimensions were manually calculated in both imaging modalities in accordance with the American Society of Echocardiography published guidelines. Left ventricular ejection fraction was calculated on echocardiography manually using the Simpson's formula and by coronary computed tomographic angiography using the end-systolic and end-diastolic volumes.

Results: We reviewed 532 studies, rejected 412 and had 120 cases for review with a median time between studies of 7 days (interquartile range ($IQR_{25,75}$) = 0–22 days) with no correlation between the measurements made by coronary computed tomographic angiography and transthoracic echocardiography using Bland–Altman analysis. We generated coronary computed tomographic angiography cardiac dimension reference ranges for both genders for our population.

Conclusion: Our findings represent a step towards generating cardiac chamber dimensions' reference ranges for coronary computed tomographic angiography as compared to transthoracic echocardiography in patients with normal cardiac morphology and function using the American Society of Echocardiography guideline measurements that are commonly used by cardiologists.

Keywords

Coronary computed tomographic angiography, computed tomography, chamber assessment

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Background

Coronary computed tomographic angiography (CCTA) is emerging as a promising tool with respect to quantifying chamber volumes and cardiac structure although standards for this are still evolving and under study. [1,2] The optimal performance of CCTA involves a number of factors designed to optimize image quality while minimizing radiation delivery to the patient, and accuracy improves with experience with the modality.[3,4]

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Motion artifact continues to be a limitation, and even the best temporal resolution achieved with dual-source scanners is inferior to echocardiography.[5,6] However, the single-source 64-slice computed tomography (CT) scanners can still provide quality images with acceptable spatial and temporal resolution when protocols to control for motion are utilized.[7] Nonetheless, there is more radiation, iodine contrast agent, and poorer resolution with CCTA as compared to echocardiography.[8]

In our analysis, we compared the chamber dimensions as well as cardiovascular function between CCTA and transthoracic echocardiography (TTE) to determine correlation, as well as obtain normal value ranges for CCTA as compared to the ranges measured on TTE following American Society of Echocardiography (ASE) guidelines. Standardized normal ranges for chamber size assessment and size, especially right-sided chamber assessment, remain unreported with CCTA within the small studies performed to date that focused only on cardiac volumetric measurements and ejection fraction (EF) assessment.

Methods

Study selection

We performed a chart review of symptomatic adults with chest pain syndrome at least 18 years of age who underwent retrospective 16- or 64-slice CCTA between January 2005 through July 2011 in our institution (Brooke Army Medical Center, Joint Base San Antonio-Fort Sam Houston, TX, USA). From January 2005 through December 2007, images were obtained using a 16-slice CT scanner (Brilliance-16®; Phillips, Amsterdam, the Netherlands). From January of 2008 to end of the review period, images were obtained using a retrospective helical protocol with a 64-slice CT scanner (Somatom Definition CT®; Siemens, Erlagen, Germany). Majority of the retrospective scans were done utilizing the 16-slice scanner, considering that most of the studies performed utilizing the 64-slice scanner were prospectively gated. Images were reconstructed with 20% increments from 0% to 80% of the R-R cycle. For the purpose of the study, end-diastole was determined to be 0% phase and end-systole was determined to be 40% phase to standardize approach and due to technical difficulties involving reconstructing different phases on studies performed with older technology. All subjects undergoing CCTA received nitroglycerin sublingual with a total dose of 800 µg, and contrast loading of 100–130 ml of Isovue® at a rate of 5 ml/s, followed by normal saline chase of 40 ml at a rate of 5 ml/s, presumed to alter right ventricular assessment. All echocardiographic images during the study period were obtained using ACUSON® (Sequoia C256; Siemens, Erlagen, Germany).

Institutional review board approval was obtained. We included patients with coronary artery disease on CCTA, but with structurally normal TTE within 90 days. Exclusion criteria included studies that were uninterpretable by CCTA due to motion artifact or significant arrhythmia, non-contrast gated calcium score studies, as well as studies with poor acoustic windows on TTE that precluded accurate measurement and systolic or diastolic dysfunction.

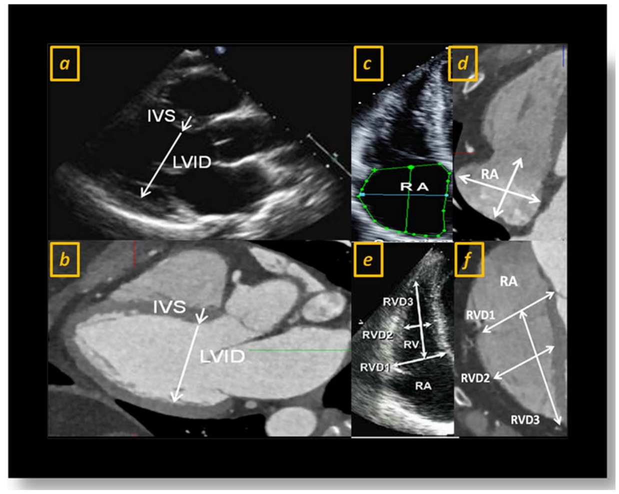

Figure 1. CCTA cardiac dimension reference ranges utilizing ASE recommended techniques in (a, b) parasternal long axis images for left ventricular dimensions, (c, d) apical 4-chamber view for atrial area measurement at end-systole, as well as (e, f) right ventricular dimensions at end-diastole as generated by Merge Cardio™ CVPACS (Merge Healthcare, Chicago, IL, USA) for TTE images and Vitrea® Workstation (Vital Images, Inc., Minnetonka, MN, USA) for CCTA images.
CCTA: coronary computed tomographic angiography; ASE: American Society of Echocardiography; CVPACS: CardioVascular Picture Archival System; TTE: transthoracic echocardiography.

Image analysis

TTE image analysis. The subject's TTE images were analyzed utilizing Merge Cardio™ (Merge Healthcare, Chicago, IL, USA). Measurements were manually calculated in accordance with the ASE published guidelines.[9,10] TTE images were obtained initially to determine whether the study met the inclusion and exclusion criteria. Images were evaluated in the apical 4-chamber view at end-diastole based on chamber size for right ventricular dimensions (RVD). Basal right ventricular dimension was obtained at the level of the valve insertion (RVD1), while the mid right ventricular dimension was at the level of the left ventricular papillary muscle (RVD2), and finally the base-to-apex length (RVD3) extending from the visible apex to the level of RVD1. Apical 4-chamber view at end-systole was utilized for atrial area measurements to assess left atrial area (LA) as well as right atrial area (RA) as illustrated in Figure 1. Parasternal long axis view was used to determine left ventricular dimensions at end-diastole and end-systole based on chamber size as illustrated in Figure 1. Left ventricular ejection fraction

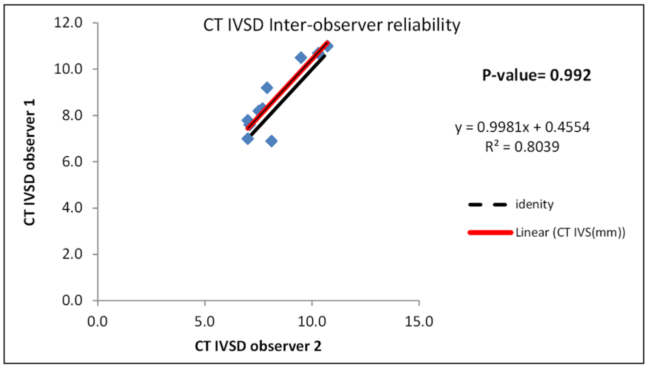

Figure 2. Bland–Altman and regression plot comparing regression lines between two observers on measurement of interventricular septum at end-diastole (n = 10) utilizing CCTA to assess for inter-observer reliability.
CCTA: coronary computed tomographic angiography; CT IVSD: computed tomography interventricular septal defect.

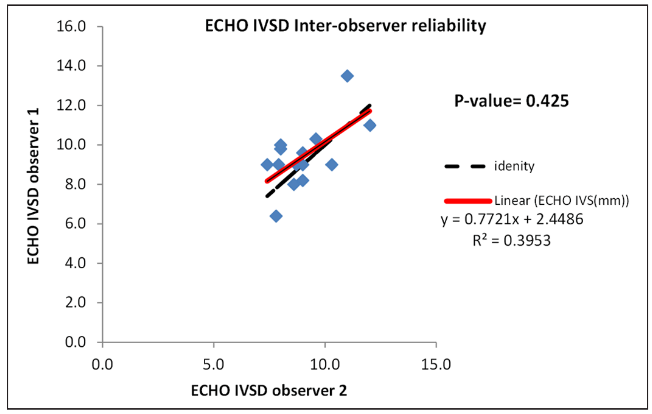

Figure 3. Bland–Altman and regression plot comparing regression lines between two observers on measurement of interventricular septum at end-diastole (n = 10) utilizing TTE to assess for inter-observer reliability.
TTE: transthoracic echocardiography; IVSD: interventricular septal defect.

(LVEF) was calculated on echocardiography manually using Simpson's formula in the apical 4- as well as the apical 2-chamber views and averaged.

CCTA image analysis. The subject's CCTA images were evaluated using Vitrea® software (Vital Images, Inc., Minnetonka, MN, USA) which allowed replication of the CCTA cardiac dimension reference ranges utilizing ASE recommended techniques. Images were evaluated in the apical 4-chamber view at end-diastole (0% phase of the R-R cycle) for RVD. Basal RVD was obtained at the level of the valve insertion (RVD1), while the mid-RVD was at the level of the left ventricular papillary muscle (RVD2), and finally the base-to-apex length (RVD3) extending from the visible apex to the level of RVD1. Apical 4-chamber view at end-systole (40% phase of the R-R cycle) was utilized for atrial area measurements to assess LA as well as RA as illustrated in Figure 1. Parasternal long axis view was used to determine left ventricular dimensions at end-diastole and end-systole based on chamber size as illustrated in Figure 1. LVEF was calculated on CCTA using the end-systolic and end-diastolic volumes.

All measurements were performed by the same cardiologist experienced in both imaging modalities. The first 10 consecutive CCTA and TTE studies were evaluated by a Society of Cardiovascular Computed Tomography (SCCT) level III imaging cardiologist to assess for inter-observer variation with no statistically significant differences between the lines of identity on measurements as represented by Figures 2 and 3 using interventricular septal defect (IVSD) measurements as an example in both imaging modalities.

Statistical analysis

We used SPSS Sample Power 2.0 (IBM, Arnock, NY, USA) to estimate a sample size of 108 subjects needed for a power of 80% with a level of confidence of 95%. Continuous variables are reported as mean ± standard deviation and compared by paired t-test (IBM SPSS version 19.0). Medians are provided with interquartile ranges (IQRs). Proportions are reported as counts (percentage) and compared by Fisher's exact test. Agreement between echocardiography and CCTA was assessed using a Bland–Altman analysis.[11] Agreement between methods was also assessed by comparing the slope of regression lines to the line of identity (p values < 0.05 were considered significant).[12]

Results

We reviewed 532 studies and excluded 412 studies where the CCTA images were uninterpretable due to motion artifact or significant arrhythmia, non-contrast gated calcium score studies, as well as studies with poor acoustic windows on TTE that precluded accurate measurement and systolic or diastolic dysfunction. Thus, 120 cases were included with a median time between studies of 7 days ($IQR_{25,75}$ = 0–22 days). The study population was predominantly male (56%) with an average age of 46 ± 14 years and an average female age of 55 ± 13 years. The incidence of coronary artery disease (discovered on CCTA evaluation), diabetes mellitus, hypertension, and dyslipidemia in the population was 34%, 11%, 46%, and 43%, respectively.

As noted in Table 1, the mean left ventricular end-diastolic dimension was 48.9 ± 6.0 mm by TTE as compared to 44.7 ± 4.7 mm by CCTA (bias = −4.10, limits of agreement = −15.13 to 6.92). The mean left ventricular end-systolic dimension was 30.9 ± 6.7 mm by TTE versus 29.2 ± 4.8 mm by CCTA (bias = −1.716, limits of agreement = −12.53 to 9.10). The mean diastolic interventricular septal thickness was 9.3 ± 1.5 mm by TTE as compared to 8.9 ± 1.4 mm by CCTA (bias = −0.37, limits of agreement = −3.04 to 2.30). The mean LA

Table 1. Summary of dimensions and measurements as performed by computed tomography and echocardiography.

	LVEDD (mm)	LVESD (mm)	IVSED (mm)	LA (cm^2)	RA (cm^2)	RV base (cm)	RV mid (cm)	RV base–apex (cm)	LVEF by Simpson's (%)
Mean ± SD by TTE	48.9 ± 6.0	30.9 ± 6.7	9.3 ± 1.5	15.4 ± 4.7	13.9 ± 4.5	2.6 ± 0.6	2.7 ± 0.5	6.8 ± 1.1	61 ± 11%
Mean ± SD by CCTA	44.7 ± 4.7	29.2 ± 4.8	8.9 ± 1.4	20.5 ± 5.1	18.1 ± 4.5	4.1 ± 0.5	3.2 ± 0.5	7.3 ± 0.9	58 ± 12%
Bias	−4.10	−1.72	−0.37	5.41	3.44	1.50	0.41	0.54	−0.04
Agreement ± 95% CI	−15.13 to 6.92	−12.53 to 9.10	−3.04 to 2.30	−5.19 to 16.01	−5.95 to 12.84	0.16 to 2.83	−0.52 to 1.34	−1.61 to 2.70	−0.32 to 0.23
p value	0.017	0.051	0.0001	0.0001	0.020	0.031	0.125	0.044	0.001

LVEDD: left ventricular end-diastolic dimension; LVESD: left ventricular end-systolic dimension; IVSED: interventricular septal thickness in end-diastole; LA: left atrial area; RA: right atrial area; RV: right ventricular; LVEF: left ventricular ejection fraction; ASE: American Society of Echocardiography; TTE: transthoracic echocardiography; CCTA: coronary computed tomographic angiography; SD: standard deviation; CI: confidence interval.

was 15.4 ± 4.7 cm^2 by TTE as compared to 20.5 ± 5.1 cm^2 by CCTA (bias = 5.41, limits of agreement = −5.19 to 16.01). The mean RA was 13.9 ± 4.5 cm^2 by TTE as compared to 18.1 ± 4.5 cm^2 by CCTA (bias = 3.44, limits of agreement = −5.95 to 12.84). The mean RVD when measured at the base was 2.6 ± 0.6 cm, at the mid-ventricle was 2.7 ± 0.5 cm, and from base to apex was 6.8 ± 1.1 cm by TTE as compared to 4.1 ± 0.5, 3.2 ± 0.5, 7.3 ± 0.9 cm by CCTA (bias = 1.50, limits of agreement = 0.16 to 2.83; bias = 0.41, limits of agreement = −0.52 to 1.34; and bias = 0.54, limits of agreement = −1.61 to 2.70, respectively). The EF (Simpson's method) was 61 ± 11% by TTE as compared to 58 ± 12% by CCTA (bias = −0.04, limits of agreement = −0.32 to 0.23). Summary of the mean values for men and women as measured by CCTA and TTE is shown (Tables 2 and 3).

Figure 4 shows the Bland–Altman and regression analysis comparing the agreement between CCTA and TTE measurements as it pertains to left ventricular end-systolic dimension (LVESD), left ventricular end-diastolic dimension (LVEDD), interventricular septal thickness in end-diastole (IVSED), and LA in all 120 subjects. Figure 5 shows the Bland–Altman and Regression analysis comparing the agreement between echocardiography and CCTA measurements as it pertains to right ventricular measurements at the base, mid-segment, and base to apex as well as the right atrium (RA). Figure 6 shows the Bland–Altman and regression analysis comparing the agreement between echocardiography and CCTA measurements as it pertains to the EF as determined by Simpson's method.

The first 10 consecutive CCTA and TTE studies were evaluated by an SCCT level III imaging cardiologist to assess for inter-observer variation with no statistically significant differences between the lines of identity on measurements as represented by Figures 2 and 3 using IVSD measurements as an example in both imaging modalities ($p = 0.992$ and $p = 0.425$, respectively).

Discussion

Although our findings indicate that there was no correlation between the measurements made by CCTA and the ones made by TTE using a Bland–Altman analysis in our retrospective study of 120 patients, we were able to generate, within the limitations of our study, CCTA cardiac dimension reference ranges utilizing ASE recommended techniques on apical 4-chamber, as well as parasternal long axis, images.

Our study has several limitations, including the fact that this is a retrospective image review of studies performed in symptomatic patients with chest pain complaints and variable coronary artery disease burden. In addition, the sample size was small due to the fact that technically limited studies were excluded to allow for accurate measurements as well as the fact that only retrospectively gated studies were evaluated to obtain the set definition of end-diastole for our study. The study was limited by the fact that end-systole and

Table 2. Reference ranges for cardiac CT dimensions versus ASE reference ranges with echocardiography in men.

	LVEDD (mm)	LVESD (mm)	IVSED (mm)	LA (cm^2)	RA (cm^2)	RV base (cm)	RV mid (cm)	RV Base–Apex (cm)	LVEF by Simpson's (%)
ECHO	42.0–59.0	n/a	6.0–10.0	<20	10–18	2.4–4.2	2.0–3.5	5.6–8.6	>55
CCTA	34.5–55.1	19.4–39.2	6.8–11.8	12.1–29.5	9.3–27.5	3.2–5.4	2.4–4.4	6.0–9.4	40–80

LVEDD: left ventricular end-diastolic dimension; LVESD: left ventricular end-systolic dimension; IVSED: interventricular septal thickness in end-diastole; LA: left atrial area; RA: right atrial area; RV: right ventricular; LVEF: left ventricular ejection fraction; CT: computed tomography; ASE: American Society of Echocardiography; ECHO: echocardiography; CCTA: coronary computed tomographic angiography.

Table 3. Reference ranges for cardiac CT dimensions versus ASE reference ranges with echocardiography in women.

	LVEDD (mm)	LVESD (mm)	IVSED (mm)	LA (cm^2)	RA (cm^2)	RV base (cm)	RV mid (cm)	RV base–apex (cm)	LVEF by Simpson's (%)
ECHO	39.0–53.0	n/a	6.0–9.0	<20	10–18	2.4–4.2	2.0–3.5	5.6–8.6	>55
CCTA	36.8–52.2	19.5–36.9	5.4–10.8	8.4–31.6	11.6–23.8	3.0–4.8	2.1–3.7	5.5–7.9	40–80

LVEDD: left ventricular end-diastolic dimension; LVESD: left ventricular end-systolic dimension; IVSED: interventricular septal thickness in end-diastole; LA: left atrial area; RA: right atrial area; RV: right ventricular; LVEF: left ventricular ejection fraction; CT: computed tomography; ASE: American Society of Echocardiography; ECHO: echocardiography; CCTA: coronary computed tomographic angiography.

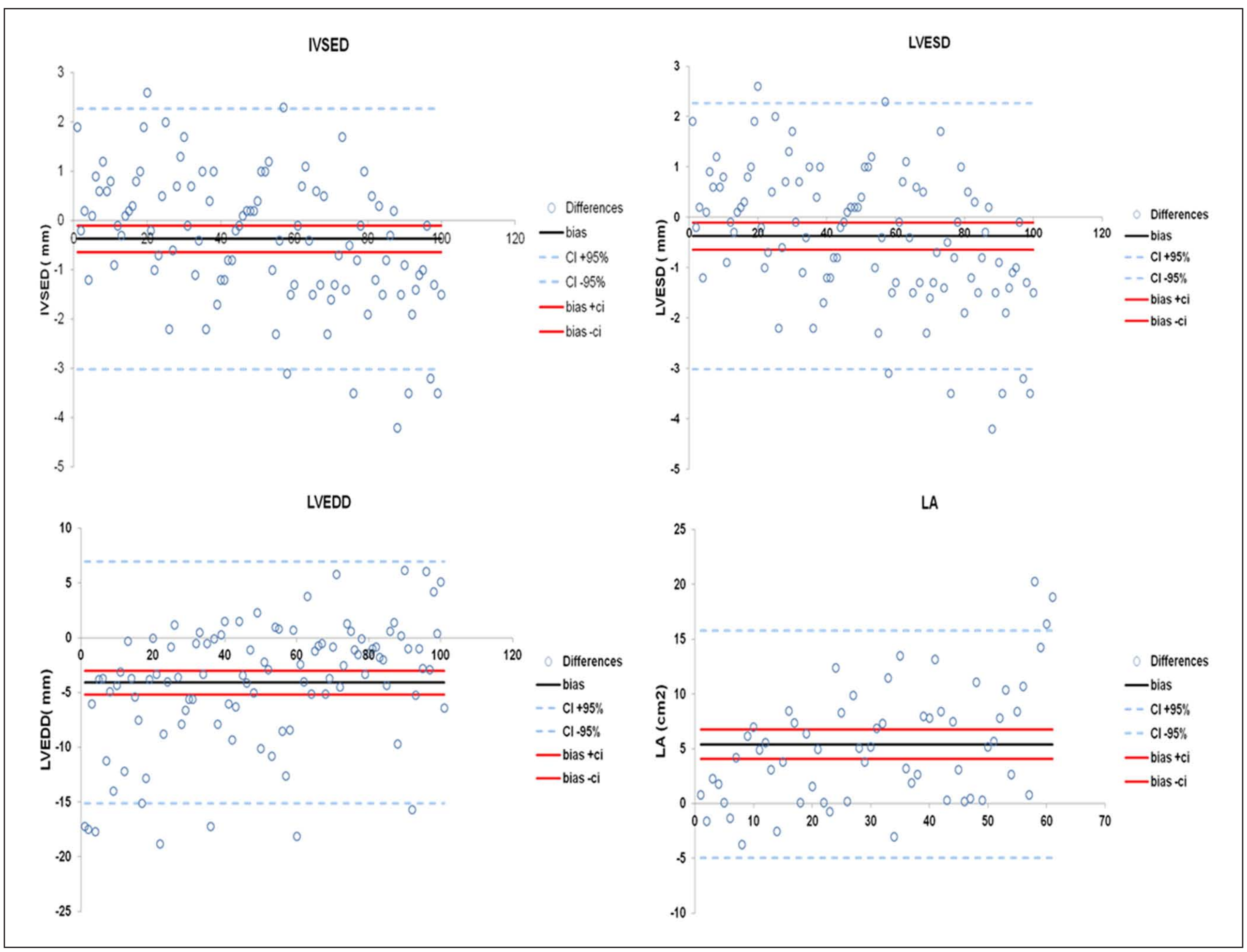

Figure 4. Bland–Altman and regression plot comparing left ventricular end-systolic dimension (LVESD), left ventricular end-diastolic dimension (LVEDD), interventricular septum at end-diastole (IVSED), and left atrial area (LA) as measured by CCTA (n = 120) versus TTE.

CCTA: coronary computed tomographic angiography; TTE: transthoracic echocardiography.

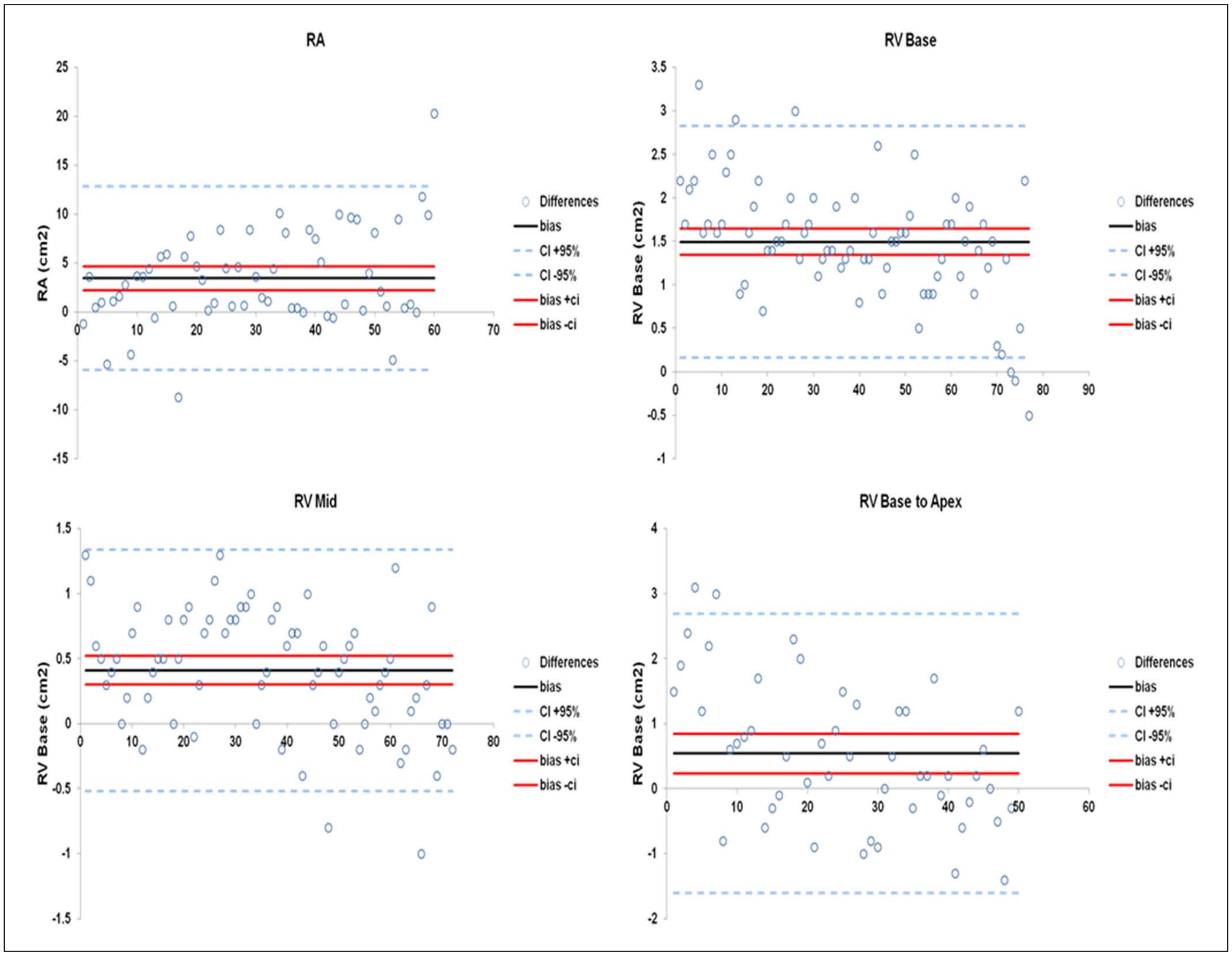

Figure 5. Bland–Altman and regression plot comparing right ventricular measurements at the base, mid-segment, and base to apex as well as right atrial area (RA) as measured by CCTA (n = 120) versus TTE.
CCTA: coronary computed tomographic angiography; TTE: transthoracic echocardiography.

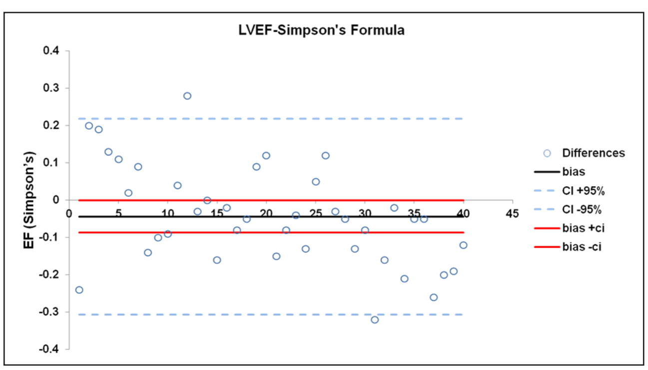

Figure 6. Bland–Altman and regression plot comparing left ventricular ejection fraction (LVEF) using Simpson's formula as measured by CCTA (n = 120) versus TTE.
CCTA: coronary computed tomographic angiography; TTE: transthoracic echocardiography.

end-diastole were assumed to be 40% and 0%, respectively, and shorter increments of R-R cycle were not obtained to allow for true chamber size evaluation to assess for true end-systole and end-diastole. In addition, the measurements that were made of the atrial areas in both modalities were technically difficult, despite of excellent images, since using the length–width method was operator dependent. This further supports the ASE recommendation to use volumetric measurement of both atria on TTE for accurate reflection of size.

In a small study of 50 patients evaluating automatic analysis of ventricular and atrial volumes with qualitative and quantitative evaluation of segmentation quality, there was mild overestimation of the left atrium due to inclusion of pulmonary veins as well as left ventricular volume with automatic analysis as compared to manual qualitative assessment.[13] In a 52-patient small study, contrast-enhanced, retrospectively gated, 16-slice CCTA was used without dose modulation to compare volumetric assessment of the left ventricle between CCTA and two-dimensional (2D) echocardiography with both studies performed on the same day. Left ventricular systolic and diastolic volumes and EF were compared in 4-chamber, 2-chamber, and biplane views between the two modalities and showed that biplane measurement by these two techniques correlated well for left ventricular volumes in both diastole (r = 0.69 and $p < 0.01$) and systole (r = 0.73 and $p < 0.01$).[14] Although the temporal resolution of CCTA surpasses 2D echocardiography, the data correlating volumetric measurements, chamber dimensions, as well as EF are still lacking.[15] Our data complement the current published work by Lin et al.,[16] where they focused their efforts on establishing norms for 105 healthy non-obese patients undergoing 64-slice multidetector computed tomography (MDCT) with obvious variation among EF measured with three-dimensional (3D) technique as compared to 2D technique as well as LA end-systolic volume (LAESV). We focused our efforts on utilizing Simpson's method for EF calculation to allow reproducibility among the two modality's users utilizing 20% increment phase that showed similar disagreement as shown previously by Lin et al. with <5% difference in mean EF though statistically significant. This disagreement will likely be due to the utility of the 20% phase increment versus the 10% phase increment as noted by Lin et al.[16]

This is the first analysis to generate right atrial and ventricular dimensions reference ranges in the setting of vasodilator use, nitroglycerin 800 µg sublingual, and contrast loading, 100–130 ml of Isovue® at a rate of 3–5 ml/s, presumed to alter right ventricular assessment.

Conclusion

Our findings are the first step towards generating chamber dimension reference ranges for CCTA of left ventricular end-diastolic dimension, left ventricular end-systolic dimension, interventricular septal thickness, LA, RA, and RVD using the ASE guideline measurements that are commonly used by cardiologists while utilizing echocardiography in patients with normal cardiac morphology and function. We demonstrated that cardiac dimensions measured by CCTA and TTE on the same patients did not correlate. The data are further divided into CCTA reference for both genders considering the morphologic differences acknowledged in ASE guidelines.

Declaration of conflicting interests

The opinions in this manuscript do not constitute endorsement by San Antonio Army Medical Center, the US Army Medical Department, the US Army Office of the Surgeon General, the Department of the Army, Department of Defense, or the US Government of the information contained therein. The authors declare no conflict of interest in preparing this article.

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