Journal of Cardiovascular Computed Tomography 13 (2019) 174–178

Contents lists available at ScienceDirect

Journal of Cardiovascular Computed Tomography

journal homepage: www.elsevier.com/locate/jcct

Research paper

Differences in left ventricular measurements: Attenuation versus contour based methods

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ARTICLE INFO

Keywords:
Attenuation
Computed tomography coronary angiography
Contour
Left ventricular volumes
Mid-diastolic volume

ABSTRACT

Background: Coronary computed tomography angiography (CCTA) left ventricle (LV) volumes have prognostic value. LV measurements however can differ depending on post-processing software. Two common methods are the contour (CON) or attenuation (ATT) based methods. This study aims to determine differences in LV volume measurements using the 2 methods.

Methods: LV mid-diastolic volumes (LVMDV) were measured using both ATT and CON from 2 vendors in 750 consecutive patients undergoing CCTA. 500 were measured in a derivation cohort to establish a linear regression equation that would correct for any detected differences between the two methods. The equation was then assessed in 250 cases in the validation cohort. Comparisons were made between intra-vendor $LVMDV_{CON}$ and $LVMDV_{ATT}$ as well as inter-vendor $LVMDV_{ATT}$.

Results: In the derivation cohort, the correlation between the two methods and vendors were very good (0.98 and 0.97 respectively). $LVMDV_{CON}$ was 20.4 ± 7.4% greater than $LVMDV_{ATT}$. $LVMDV_{ATT}$ was 9.2 ± 6.6% greater with one vendor compared to the other. Validation cohort corrected $LVMDV_{ATT}$ was not statistically different to measured $LVMDV_{ATT}$ ($p = 0.45$).

Conclusion: A systematic difference was found between ATT and CON measuring methods. Using a derived linear regression equation, we were able to correct for differences in measurement techniques. The method of LVMDV measurement requires careful consideration when establishing reference values and extrapolating published study results.

1. Introduction

CT measures of mid-diastole LV volumes (LVMDV) correlate with LVEDV,[2–5] and have prognostic value for major adverse cardiac events along with mid-diastole LV mass (LVMDM).[1–6] LV measurements however, can differ depending on post-processing method.[1–3]

LV measurements can be obtained using a contouring method that traces the LV endocardial border, or an attenuation based approach.[7–9] The contour (CON) 3-D model and edge-based method often includes papillary muscles in its volumetric measurements, and can yield larger volumes. The attenuation (ATT) 3-D model and thresholding method excludes papillary muscles, and can yield smaller volumes than CON.[10–14] The purpose of the study is to determine the differences and relationship between CON and ATT method based LVMDV measurements.

2. Method

2.1. Study population

756 consecutive patients who were referred for CCTA and were prospectively enrolled into a Cardiac CT Registry. Six patients with poor contrast opacification or significant artifacts were excluded. The remaining cohort was divided into a derivation cohort (500 consecutive patients) and a validation cohort (250 consecutive patients). The study was approved by the Institutional Research Ethics Board.

2.2. Coronary CTA image acquisition

Patients received beta-blockers targeting a heart rate of ≤65 beats/minute,[15] and sublingual nitroglycerin (0.8 mg). A triphasic (100% contrast, 40%/60% contrast/saline, 100% saline) intravenous contrast administration protocol (Omnipaque 350 or Visipaque 320, GE

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https://doi.org/10.1016/j.jcct.2019.08.003
Received 18 July 2018; Received in revised form 24 July 2019; Accepted 6 August 2019
Available online 07 August 2019

List of abbreviations

ATT	Attenuation based method
CON	Contour based method
CCTA	Coronary computed tomography angiography
LV	Left ventricle
LVEDV	Left ventricle end-diastolic volume
LVESV	Left ventricle end-systolic volume
LVMDV	Left ventricle mid-diastolic volume
LVMDM	Left ventricle mid-diastolic mass
MACE	Major adverse cardiac event

Healthcare, Princeton, NJ, USA) was used. Prospective ECG-triggered image acquisition (100msec acquisition window centered around the 70% phase, 80-120 kVp, using an automated tube current protocol (CARE dose 4D) was performed using a second-generation dual-source scanner (Somatom Definition Flash, Siemens, Forchheim, Germany; gantry rotation = 280 msec, 64 × 2 × 2 slices x 0.6 mm).

2.3. Image analysis and volume measurement

CT images were reconstructed with a 0.6 mm slice thickness with an increment of 0.4 mm using both i26f and i36f kernels. Images were reconstructed in at least 3 phases (best diastolic phase and outer bounds of the acquisition window). CCTA images were post-processed using Syngo.via (Version 3.0, Siemens, Erlangen, Germany) (Vendor 1) and Aquarius iNtuition (TeraRecon, Inc., San Mateo, CA, USA) (Vendor 2) using both CON and ATT based methods (Fig. 1). The phase with the largest LVMDV was recorded. Cardiac structures and boundaries of the LV cavity were automatically detected by the software and were manually edited by trained users to ensure accuracy of the borders.

2.4. Statistical analysis

Statistical analyses were performed using SPSS Version 24 (IBM, Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation and categorical variables are presented as frequencies with percentages. Analysis was performed for the entire population, the derivation and validation cohorts. Comparisons between $LVMDV_{CON}$ and $LVMDV_{ATT}$, and inter-vendor $LVMDV_{ATT}$ were

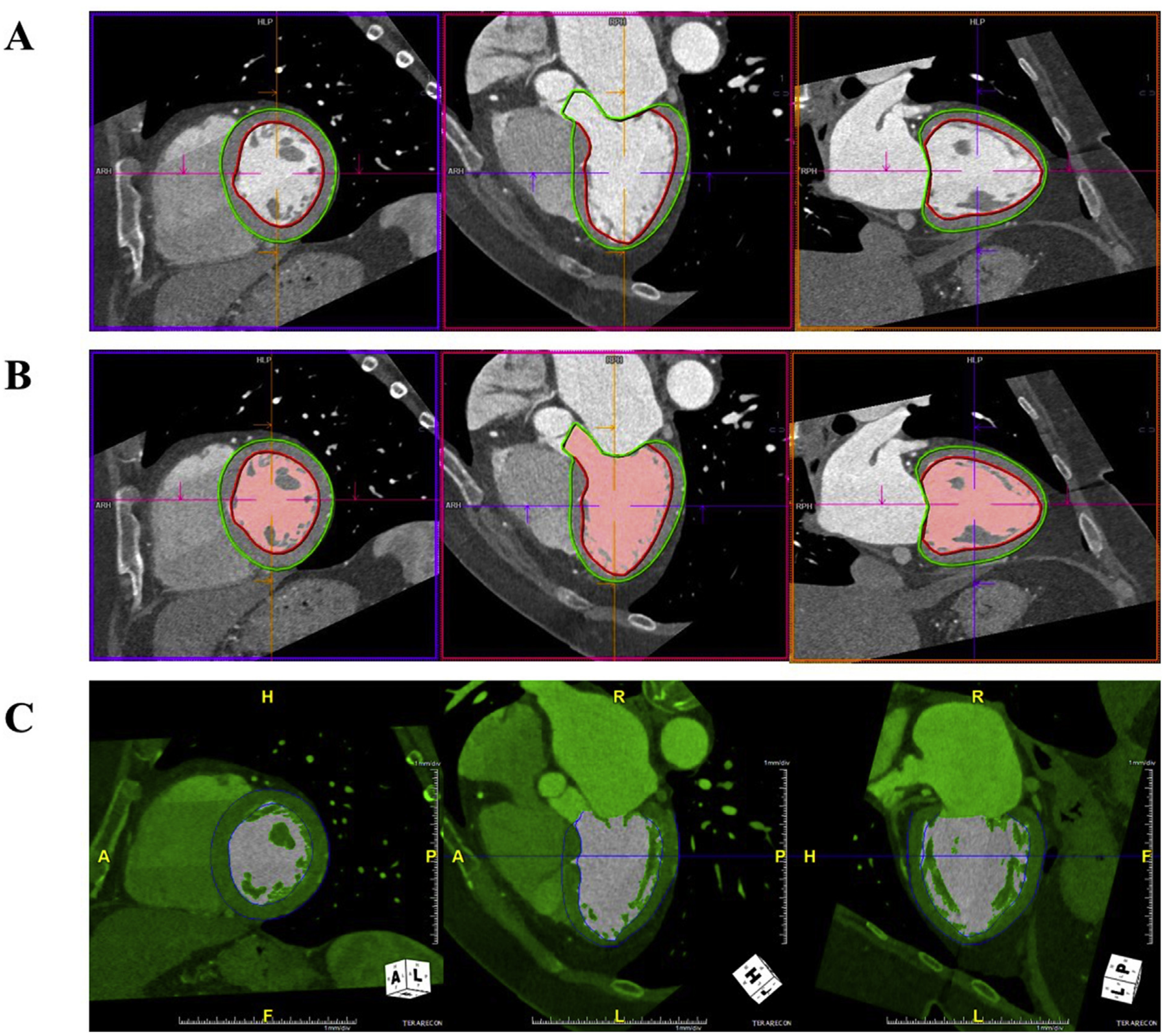

Fig. 1. Automated 3-D LV segmentations using mid-diastole contrast-enhanced fCCTA. A. Vendor 1 CON method represented by red and green contour lines. B. Vendor 1 ATT method represented by pink shading. Vendor 2 ATT method represented by grey shading. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

performed using paired *t*-tests, Pearson correlation and Bland-Altman plots. The derivation cohort's linear regression equation was applied to the validation cohort. The inter- and intra-observer variability for LV measurements were assessed using intra-class correlation coefficients (ICC) and correlation plots. Statistical significance was defined as $p < 0.05$.

3. Results

The final study cohort was comprised of 750 patients (mean age = 57.2 ± 11.04, 54.9% men, BMI = 29.37 ± 5.86 kg/m^2) (Table 1). Analysis of intra-vendor LVMDV demonstrated that $LVMDV_{CON}$ was larger than $LVMDV_{ATT}$ (124.21 ± 49.18 mL versus 102.06 ± 43.81 mL, respectively ($p < 0.0001$). Inter-vendor $LVMDV_{ATT}$ significantly differed (103.06 ± 41.03 mL versus 108.29 ± 44.14 mL, respectively for Vendor 1 versus Vendor 2 ($p < 0.0001$)) (Table 2).

3.1. Derivation cohort

The mean $LVMDV_{CON}$ (125.48 ± 46.75 mL) was 20.4 ± 7.4% larger than $LVMDV_{ATT}$ (103.06 ± 41.03 mL) (Table 2). The intra-vendor correlation of $LVMDV_{CON}$ and $LVMDV_{ATT}$ was excellent (0.984) (Fig. 2). The linear regression equation ($LVMDV_{ATT} = 0.86 LVMDV_{CON} - 5.29$) was applied to validation cohort. Bland-Altman plot confirmed that $LVMDV_{CON}$ was systematically greater than $LVMDV_{ATT}$ (Fig. 2). The inter-vendor measurements of $LVMDV_{ATT}$ were similar 103.06 ± 41.03 mL and 108.29 ± 44.14 mL ($p < 0.0001$). The inter-vendor correlation between $LVMDV_{ATT}$ was excellent (0.969) (Fig. 3). Bland-Altman plot showed that the mean inter-vendor difference was 9.2 ± 6.6% (Fig. 3).

3.2. Validation cohort

Similar to the derivation cohort, the mean $LVMDV_{CON}$ (121.68 ± 53.72 mL) was 20.6 ± 7.9% larger than the $LVMDV_{ATT}$ (100.06 ± 48.93 mL). The derivation cohort's linear regression equation was applied to the $LVMDV_{CON}$ to calculate the corrected $LVMDV_{ATT}$. The corrected $LVMDV_{ATT}$ was 99.80 ± 46.33 mL and was not statistically different from the measured $LVMDV_{ATT}$ ($p = 0.45$). The correlation between the measured and corrected $LVMDV_{ATT}$ was excellent (0.987).

3.3. Inter & intra-observer variability

50 patients were randomly selected to determine inter-observer and intra-observer variability. Both inter and intra-observer correlations were excellent. Inter-observer correlation for $LVMDV_{ATT}$ was 0.998 (0.992–0.999) and for $LVMDV_{CON}$ was 0.992 (0.973–0.997). Intra-observer correlation for $LVMDV_{ATT}$ was 0.981 (0.958–0.991) and for $LVMDV_{CON}$ was 0.992 (0.984–0.996).

4. Discussion

Our study results demonstrate that the CON method yields higher volumes than the ATT method, but are highly correlated.

LV volumes are essential in the assessment of ventricular function and are important for clinical diagnosis, risk assessment, therapeutic decision making, and determining prognosis in patients with cardiac conditions.[10]

The adoption of prospective-ECG triggered and narrow acquisition window CCTA which minimizes patient radiation exposure has eliminated the ability to directly measure LVEF, LV end-diastolic and systolic volumes. However, LVEDV can be estimated on prospective-ECG gated CCTA using LVMDV, and the estimated LVEDV is an independent predictor of major adverse cardiac events (MACE).[3,5] LVMDV is demonstrated to be strongly correlated with LVEDV, and is able to reliably identify patients with LV enlargement and at risk for MACE, demonstrating its prognostic value.[3,4] Recently, normal reference values for LVMDV, and the mean LVMDVs were determined to be 57.5 ± 15.3 mL/m^2 for women and 64.5 ± 20.2 mL/m^2 for men.[2] However, the LV volumes may not be transferred to other centers using different post-processing methods and software.

Our study demonstrates that different automatic or semi-automatic post-processing methods can generate significant differences in volume measurements (20.4 ± 7.4%). Variations also exist between vendors (4.5 ± 10.4%). These results remind physicians that measurements may differ depending on algorithm and vendor software. Since there appears to be differences between vendors and processing techniques, vendors should consider publishing their results against current gold standard techniques such as manual contouring short axis slices.

4.1. Limitations

The effect of beta blockers on both heart rate and ejection fraction likely leads to higher mid diastolic LV volumes. The use of beta blockers is an uncontrolled variable thus our values may not be directly applicable in patients who have not received beta-blockers.

CT post-processing software from 2 vendors were assessed, so results cannot be used to extrapolate measurements for other software. The spatial and temporal resolution of the dual-source scanner could impact edge detection and affect segmentation. CT imaging hardware, software and imaging properties may vary between vendors, therefore validation needs to be optimized for each of these variables.

LVMDV measurements were obtained from prospectively ECG-triggered CCTA, so measurements are derived from slightly different phases ranging from 65 to 80% of R-R interval which can introduce measurement variability. The inclusion of patients with cardiovascular conditions can also contribute to variability in differences seen between ATT and CON, as patients with conditions that involve trabeculations and papillary muscles could cause additional differences between the methods. Thus, future studies comparing the impact of cardiac conditions affecting LV muscular structures, LV trabeculae and papillary muscles in different post-processing methods may be useful.

LVMDV, like EDV, can only identify incremental risk related to conditions that cause remodeling with LV dilatation (such as coronary artery disease, cardiomyopathy, and valvular heart disease). However

Table 1
Patient demographics.

	All Patients N = 750	Derivation N = 500	Validation N = 250
Age (years)	57.2 ± 1.0	57.3 ± 1.1	57.1 ± 11.0
Male Gender	412 (54.9%)	273 (54.6%)	139 (55.6%)
Body Mass Index (kg/m^2)	29.4 ± 5.9	29.3 ± 5.6	29.5 ± 6.4
Cardiac Risk Factors			
Smoker/Ex-smoker	240 (32.0%)	163 (32.6%)	77 (30.8%)
Hypertension	356 (47.5%)	240 (48.0%)	116 (46.4%)
Dyslipidemia	403 (53.7%)	267 (53.4%)	136 (54.4%)
Diabetes	115 (15.3%)	73 (14.6%)	42 (16.8%)
Family History of CAD	260 (34.7%)	167 (33.4%)	93 (37.2%)
Symptoms			
Chest pain	448 (59.7%)	278 (55.6%)	170 (68.0%)
Dyspnea	410 (54.7%)	274 (54.8%)	136 (54.4%)
Palpitations	283 (37.7%)	192 (38.4%)	91 (36.4%)
Past History			
Myocardial Infarction	38 (5.1%)	27 (5.4%)	11 (4.4%)
PCI	22 (2.9%)	15 (3.0%)	7 (2.8%)
CABG	29 (3.9%)	23 (4.6%)	6 (2.4%)
Heart Failure/ Cardiomyopathy	29 (3.9%)	19 (3.8%)	10 (4.0%)
Artificial Pacemaker	6 (0.8%)	4 (0.8%)	2 (0.8%)

Abbreviations: CABG, coronary artery bypass grafting; CAD, coronary artery disease; PCI, percutaneous coronary intervention.

Table 2
LV volume (mL) and mass (g) using different post-processing methods.

	Vendor 1				Vendor 2	
	CON		ATT		ATT	
	LVMDV	LVMDM	LVMDV	LVMDM	LVMDV	LVMDM
All patients (N = 750)	124.2 ± 49.2	n/a	102.1 ± 43.8	n/a	n/a	n/a
Derivation cohort (N = 500)	125.5 ± 46.8	116.27 ± 32.9	103.1 ± 41.0	147.6 ± 42.1	108.3 ± 44.1	151.3 ± 47.1
Validation cohort (N = 250)	121.7 ± 53.7	n/a	100.1 ± 48.93	n/a	n/a	n/a

Abbreviations: ATT, attenuation-based; CON, contour-based; LVMDM, left ventricle mid-diastolic mass; LVMDV, left ventricle mid-diastolic volume.
Values are mean ± SD. Statistically significant differences are present between CON and ATT measurements within same vendor, and ATT measurements of different vendors ($p < 0.0001$).

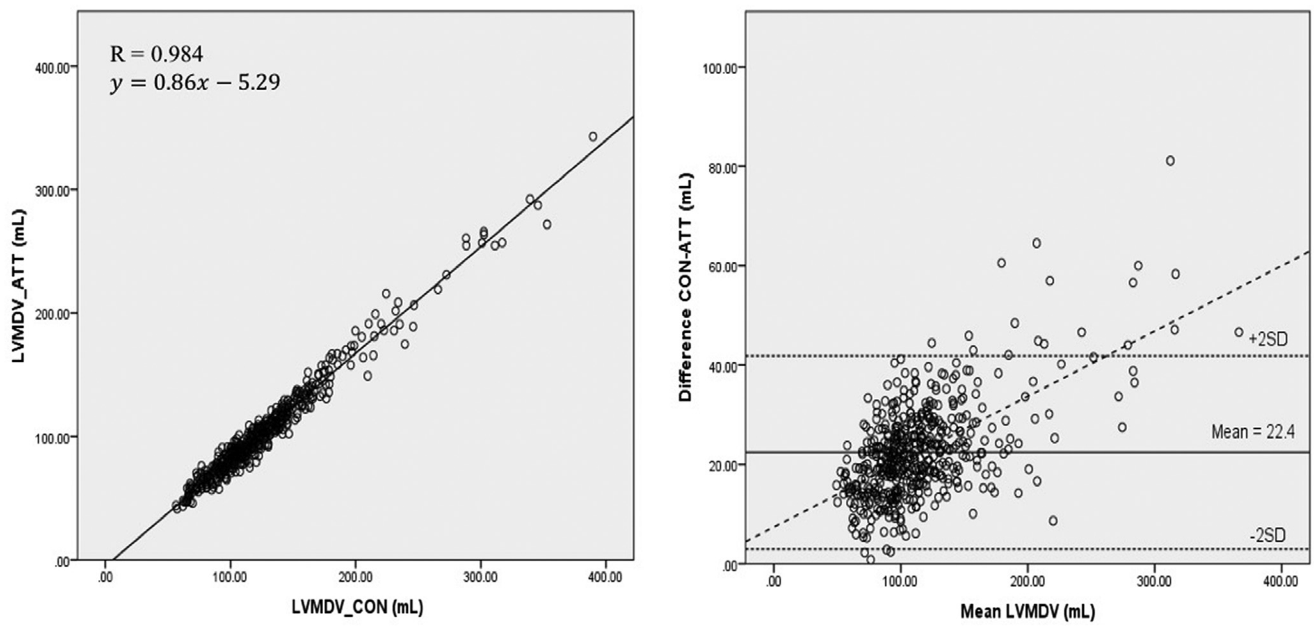

Fig. 2. Correlation and Bland-Altman plots between $LVMDV_{ATT}$ and $LVMDV_{CON}$ of the same vendor (n = 500).

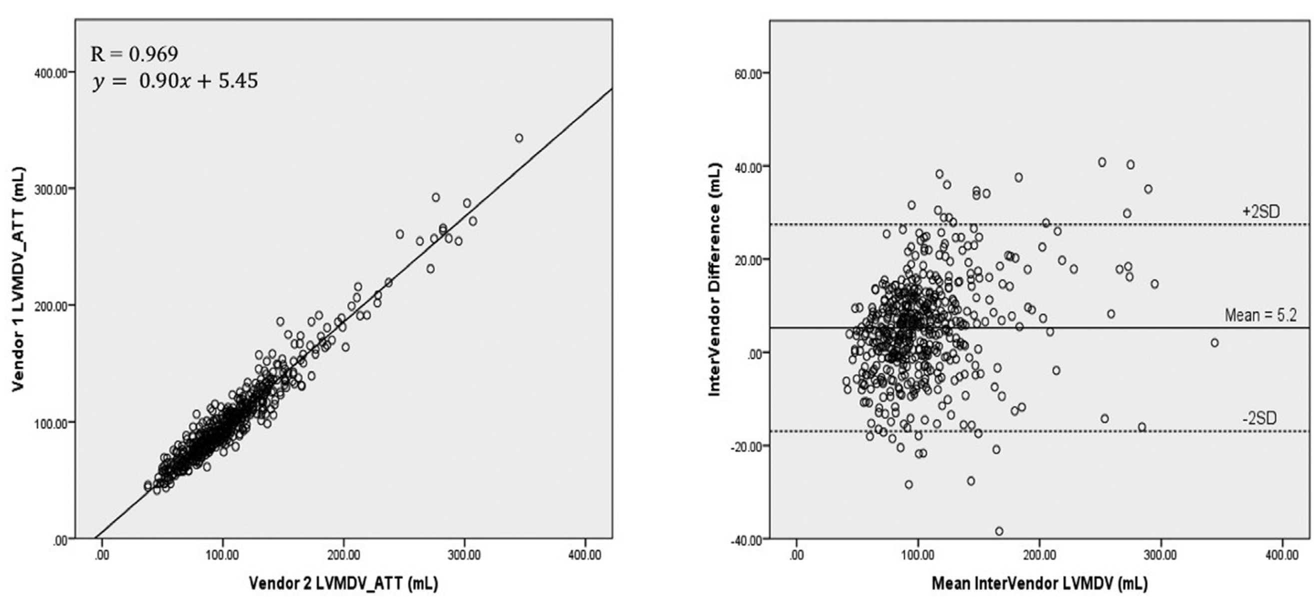

Fig. 3. Correlation and Bland-Altman plots between $LVMDV_{ATT}$ of two different vendors (n = 500).

this may not apply to conditions causing LV hypertrophy (such as hypertension, hypertrophic or infiltrative cardiomyopathies). Since we studied few such patients, the results could well differ in dilated and/or misshapen ventricles.

5. Conclusion

The study shows that post-processing methods can affect LVMDV measurements. Therefore, LVMDV measures using different post-processing software should not be used interchangeably.

Disclosures

BJC holds the Saul and Edna Goldfarb Chair in Cardiac Imaging Research, receives research support from CV Diagnostix and AusculSciences, Siemens Healthineers, and educational support from TeraRecon Inc. He has equity interest in General Electric. All other authors have no conflict of interest or disclosure.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcct.2019.08.003.

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