

The Aortic, Mitral and Tricuspid Annuli and Their Velocities: A Comparative Echocardiographic Study

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Abstract

Objectives: The velocities at the mitral (MA) and tricuspid (TA) annuli have earlier been studied by using both colour coded tissue Doppler imaging (TVI) and pulsed wave tissue Doppler imaging (PW DTI) but the velocities at the aortic annulus (AA) and the both other annuli have only been examined using TVI and not PW DTI in one study before. Therefore the aim of the present study was to compare the systolic (s'), early (e')- and late (a') diastolic velocities at the three different annuli with both methods.

Design: 24 healthy subjects were examined by echocardiography and the velocities at the annuli were measured using PW DTI and TVI.

Results: For all the velocities there was a statistically significant difference ($p < 0.001$) between the two methods, the velocities obtained by PW DTI being higher. However some heterogeneity of the mean velocity differences between methods were noted by annuli and site, but PW DTI always showing highest mean levels. There were also statistically significant velocity differences between different sites and annuli. There was a good-very good intra- and inter observer reproducibility of measuring the velocities at the aortic annulus.

Conclusion: The velocities were significantly higher using PW DTI than using TVI at the different annuli, probably mainly due to the way the respective method is measuring the velocities. In addition there was shown some heterogeneity of the mean velocity differences and statistically significant velocity differences between different sites and annuli.

The both methods need different reference values and could not be used interchangeably.

The findings could be of importance in special cases where the interaction between the three different annuli and sites is of importance, but including the velocities at all the three different sites in a clinical routine echocardiographic examination will often not be necessary.

Keywords: Heart; Echocardiography; Tissue doppler imaging; Velocities

Introduction

The aortic (AA)-, mitral- (MA) and tricuspid (TA) annuli move in long-axis direction towards the apex of the heart during systole [1-6]. The velocities at the MA and TA could be used in the assessment of left and right ventricular function and there are guidelines how to use the velocities at the MA in the assessment of left ventricular (LV) diastolic function [7,8]. The interactions between the three different annuli could be of interest for instance in cardiac surgery and in transcatheter aortic valve displacement [9,10].

Comparisons between the three annuli and their amplitudes as well as their velocities obtained using colour-coded tissue velocity imaging (TVI) and the reproducibility of measuring the velocities at the AA have earlier been performed and reference values have been established by Dalen et al. at the MA and TA by TVI and pulsed-wave tissue Doppler imaging (PW-DTI), but in that study the AA was not investigated with any of the both methods [11-13]. In the former study investigating the relationship between the three different annuli (MA, TA and AA) and sites and their velocities only TVI was used, in the present study we wanted to study the relationship between the velocities at the three different annuli and sites using both TVI and PW DTI, which, to our knowledge, not has been done before [12].

Patients and Methods

Subjects

Twenty-four healthy subjects, eleven women and thirteen men aged

22 to 32 years, with mean age 24.5 years, were included and examined by echocardiography at the Department of Clinical Physiology, University Hospital Örebro. They had normal findings on physical examination, a normal electrocardiogram and no history of cardiac disease.

Informed consent was obtained from each subject and the examinations of the subjects were approved by the regional ethical committee. Some basic characteristics and measured and calculated variables are shown in Table 1.

Echocardiographic examination

A Vivid 7 echocardiograph (GE Vingmed Ultrasound A/S, Horten, Norway) equipped with a multi-frequency phased array transducer (M3S, 1.5-4.0 MHz) was used for the echocardiographic examinations and measurements were made during the examination except for the TVI measurements, which were measured after the examination using stored images in an EchoPac (GE Vingmed Ultrasound A/S, Horten,

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Characteristics	Mean(SD)
Age (years)	24.5(2.4)
Height (cm)	175.1(7.8)
Weight (kg)	69.8(9.7)
Left atrial size (cm ²)	17.1(2.0)
Right atrial size (cm ²)	15.1(1.4)
Left ventricular end-diastolic diameter (mm)	49.9(4.1)
Left ventricular end-systolic diameter (mm)	32.2(3.0)
Left ventricular septal thickness (mm)	9.0 (0.8)
Left ventricular posterior wall thickness (mm)	7.6(0.8)
Left ventricular ejection fraction obtained by biplane Simpson's methode (%)	62.3(3.9)
Left ventricular stroke volume obtained by biplane Simpson (ml)	68.0(15.6)

Table 1: Demographic and clinical characteristics (n = 24).

Norway) Compaq DeskPro Workstation 300 (Compaq Computer Corporation, Houston, Texas, USA).

The TVI mode shows a colour coded version of the mean velocity estimated from the received signal. The algorithm for estimating the mean velocity of the moving tissue utilizes the same type of processing as described in Kristoffersen, 1988 [14]. The height and width of the sample area was set to 6 mm and the tilt angle to 0 degrees. A frame rate of about 140 frames per second was used.

The subjects were studied in the left lateral recumbent position. Echocardiographic techniques and calculations of different cardiac

dimensions were performed in accordance with the recommendations of The American Society of Echocardiography Committee [15].

The systolic (s'), early (e') - and late (a') diastolic velocities at the AA were measured at a septal and at a lateral site using TVI from the apical five-chamber view and an anterior and posterior site in the apical three chamber view. Mean velocities were calculated as the average of the values at the four sites (Figure 1a). The same velocities at the MA were measured using TVI from four sites situated about 90° apart. Recordings from the septal and lateral part of MA were obtained from the apical four-chamber view and recordings from the inferior and anterior parts from the apical two-chamber view. Mean velocities were calculated as the average of the values at the four sites.

The velocities at the TA were measured from the right atrioventricular plane at the basal lateral site in the apical four-chamber view. The measurements from all the mentioned sites above using TVI were done from the peak point of the systolic curve and from the lowest point of the early diastolic and late diastolic curves respectively in accordance with Nikitin et al. [7]. When measuring the peak systolic velocities the initial peak that is observed during isometric ventricular contraction was ignored.

From all the above mentioned annuli, sites and projections the peak systolic and peak early- and late diastolic velocities in the myocardial walls were recorded also by using PW DTI in accordance with Alam et al. (Figures 1 b-c) [16]. Since the measured velocities of the tissues depend on the angel between the Doppler beam and the measured

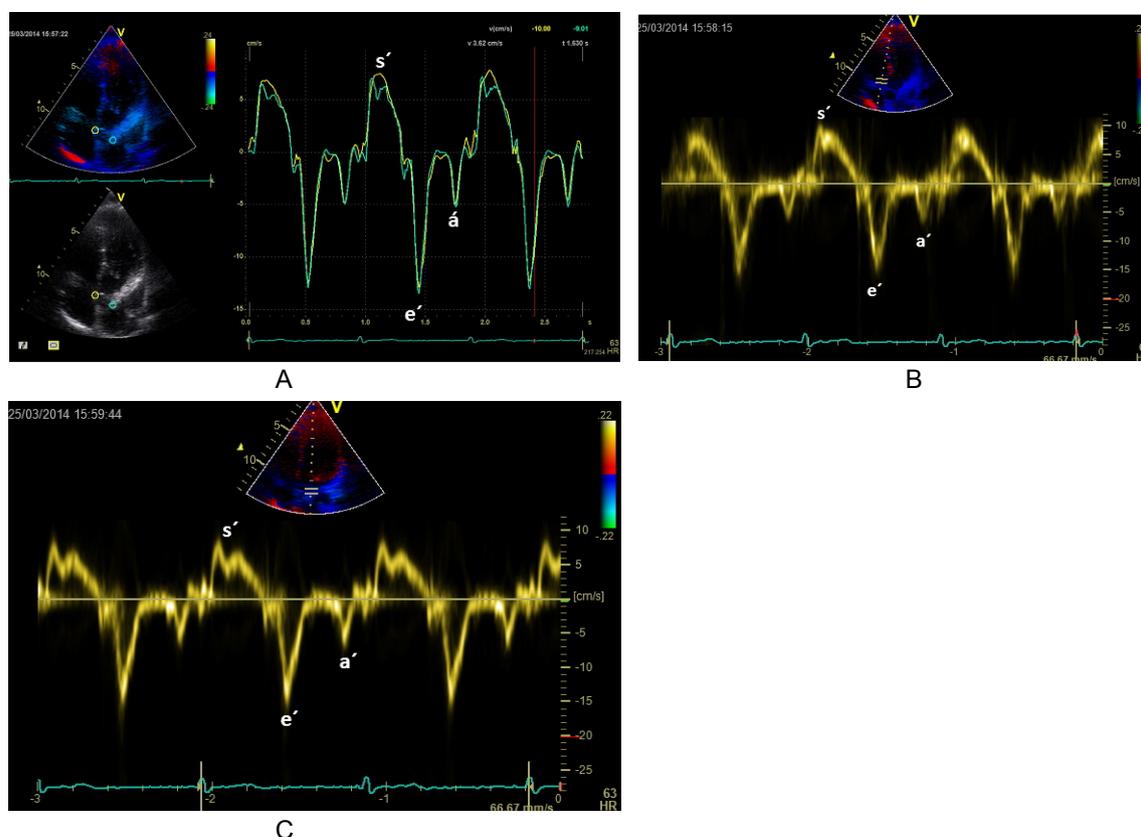


Figure 1 a - c: The systolic (s'), early diastolic (e') and late diastolic (a') velocities measured at a septal and at a lateral site of the aortic annulus (AA) by using quantitative two-dimensional color Doppler tissue Imaging (TVI) (a) and by using pulsed-wave Doppler tissue imaging at the septal site of AA (b) and from a lateral site of the AA (c) from the apical five-chamber view in a 28-year-old healthy woman.

tissue the angle to the beam was kept as small as possible with both methods.

All measurements were done at the end of expiration. The average of three beats was calculated for each cardiac measure.

Reproducibility

The intra- and interobserver reproducibility of measuring the velocities using TVI were performed at the septal and lateral sites of the AA. First one examiner (RE) measured the systolic and early- and late diastolic velocities off-line at the workstation and then the other examiner (BMN) did the same measurements and then the first examiner (RE) again.

Statistics

Shapiro Wilk's test was used to evaluate the normality assumption and no violation was found. Two-way repeated measurement ANOVA's was used to compare systolic velocities at MA between PW DTI and TVI methods at different sites (septal, lateral, posterior, anterior) and the statistical interaction methods x sites. The statistical interaction evaluates if the mean differences between methods were heterogeneous or not at different sites. The same statistical analyse strategy were also performed to compare systolic velocities between PW DTI and TVI methods at AA and early and late diastolic velocities at MA and AA. As the TA was measured at one site but MA and AA at four sites, mean level by site was calculated for MA and AA to be able to compare the three annuli. Two-way repeated measurement ANOVA's was performed to compare systolic velocities between PW DTI and TVI methods at different annuli (MA, AA and TA) and the statistical interaction methods x annuli. The same statistical analyse strategy were also performed to compare early and late diastolic velocities between PW DTI and TVI methods.

For 10 subjects test-retest intra as well as inter observer reliability were examined for the TVI method measured at the AA annuli. Reliability was quantified by ICC (Intra class correlation) and computed by means of one-way ANOVA and also visualized with Bland-Altman plots [17]. P<0.05 was regarded as statistical significant. Data are summarized with mean ± SD and mean differences with 95% confidence intervals (CI) are reported. SPSS statistical software version 22 (IBM SPSS, Armonk, NY, USA) were used.

Results

Systolic velocities

The systolic velocities were generally higher using PW DTI than using TVI at all annuli with a mean difference between the methods of 30.6 (95% CI 27.0 to 34.2) mm/s (Table 2) (Figure 2 a). As the interaction factors were statistical significant for the systolic velocities there were evidence of some heterogeneity of the mean differences between methods for different annuli, but PW DTI always showing higher mean levels compared to TVI at all annuli.

At the different sites of the MA and AA PW DTI also showed the highest systolic velocities with mean difference at the MA of 30.6 (95% CI 27.2 to 33.9) and at the AA 26.0 (95% CI 22.7 to 29.2) mm/s (Table 3) (Figure 2 b,c).

Concerning the MA the systolic velocity was statistically significant different at different sites (p<0.001). The statistical interaction was significant showing some heterogeneity but for each site PW DTI showing higher levels than the TVI method. Regarding the

systolic velocities at the different sites at the AA there was no statistically significant difference between the sites.

Diastolic velocities

Both the early and late diastolic velocities were generally higher using PW DTI than using TVI at all annuli with a mean difference of 27.5 (95% CI 24.5 to 30.4) and 25.4 (95% CI 20.1 to 30.6) mm/s respectively (Table 2) (Figures 3 a-b). As the interaction factors were statistical significant for the early diastolic velocities there were evidence of some heterogeneity of mean differences between methods for the different annuli, but PW DTI always showing higher levels compared to TVI at all annuli.

At the different sites of the MA and AA PW DTI also showed the highest diastolic velocities with mean difference of the early diastolic velocity at the MA of 35.7 (95% CI 32.7 to 38.6) and at the AA 20.2 (95% CI 16.5 to 23.9) mm/s and with mean difference of the late diastolic velocity of 27.0 (95% CI 23.2 to 30.7) at the MA and 21.1 (95% CI 17.0 to 25.1) mm/s at the AA (Table 3) (Figure 3c-f). Both the early and

	Method (PW-DTI vs TVI)		Annuli (MA vs TA vs AA)	Interaction (Method x Annuli)
	Method mean difference (95 % CI)	p	p	p
Systolic	30.6 (27.0 to 34.2)	<0.001	<0.001	0.001
Early diastolic	27.5 (24.5 to 30.4)	<0.001	<0.001	0.003
Late diastolic	25.4 (20.1 to 30.6)	<0.001	<0.001	0.063

Table 2: Comparison between PW DTI and TVI methods for systolic, early and late diastolic velocities measured at MA, TA and AA annuli assigned by two-way within factor ANOVA's. (Velocities in mm/s). MA: Mitral Annulus; TA:Tricuspid Annulus; AA:Aortic Annulus; PW DTI: Pulsed Wave Tissue Doppler Imaging; TVI:Colour Coded Tissue Doppler Imaging; CI: Confidence Interval (n=24).

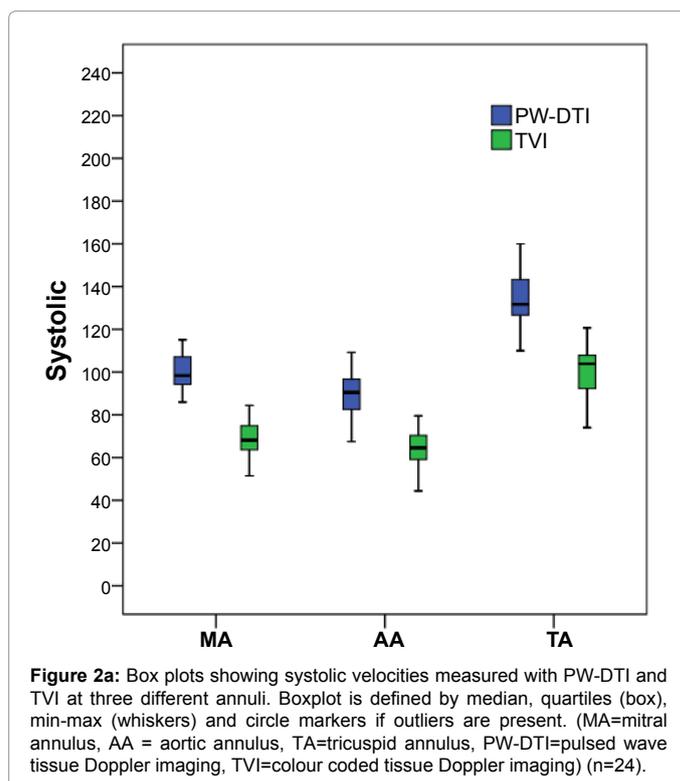


Figure 2a: Box plots showing systolic velocities measured with PW-DTI and TVI at three different annuli. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (MA=mitral annulus, AA = aortic annulus, TA=tricuspid annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).

	Method (PW DTI vs TVI)		Sites (Septal vs. lateral vs. posterior vs. anterior)	Interaction (Method x Site)
	Method mean difference (95 % CI)	p	p	p
Systolic				
MA	30.6 (27.2 to 33.9)	<0.001	<0.001	<0.001
AA	26.0 (22.7 to 29.2)	<0.001	0.83	0.14
Early diastolic				
MA	35.7 (32.7 to 38.6)	<0.001	<0.001	<0.001
AA	20.2 (16.5 to 23.9)	<0.001	<0.001	0.36
Late diastolic				
MA	27.0 (23.2 to 30.7)	<0.001	<0.001	0.022
AA	21.1 (17.0 to 25.1)	<0.001	<0.001	0.81

Table 3: Comparison between PW DTI and TVI methods at MA and AA annuli for systolic, early and late diastolic velocities measured at different sites and assigned by two-way within factor ANOVA's.

MA: Mitral Annulus; AA: Aortic Annulus; PW DTI: Pulsed Wave Tissue Doppler Imaging; TVI: Colour Coded Tissue Doppler Imaging, CI: Confidence Interval (n=24) (Velocities in mm/s).

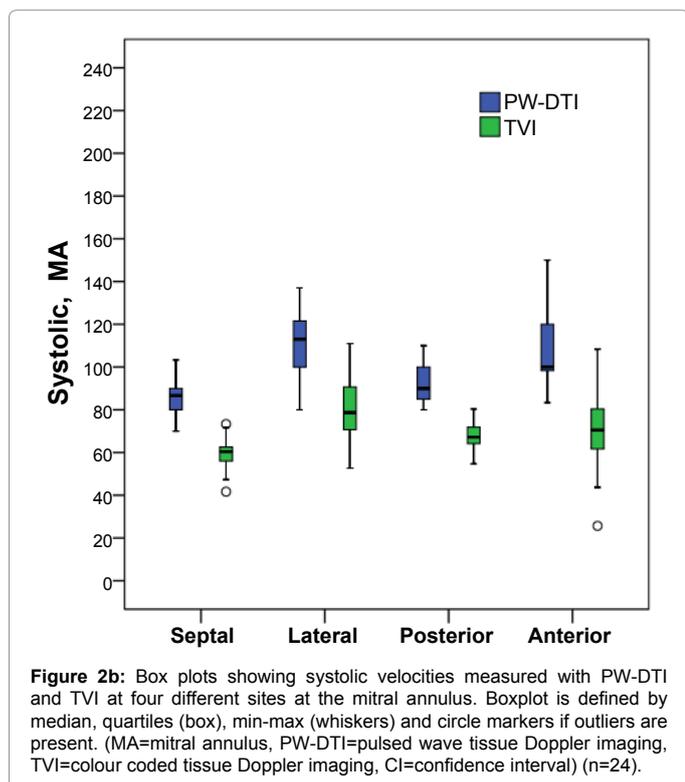


Figure 2b: Box plots showing systolic velocities measured with PW-DTI and TVI at four different sites at the mitral annulus. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (MA=mitral annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging, CI=confidence interval) (n=24).

late diastolic velocities at the MA and AA were statistically significant different between sites ($p < 0.001$).

Reproducibility

The intra- and interobserver reproducibility of measuring the systolic, early- and late diastolic velocities at the AA in ten subjects using TVI is shown in Table 4. The ICC of intra observer reliability varied from 0.88 to 0.98 and ICC of inter observer reliability varied from 0.72 to 0.98. The intra- and interobserver absolute agreement are also presented in Bland-Altman plots (Figures 4 a-f and 5 a-f).

Discussion

Theoretical implications

In the present study it has been shown that the systolic, early- and late diastolic velocities respectively at the three different annuli

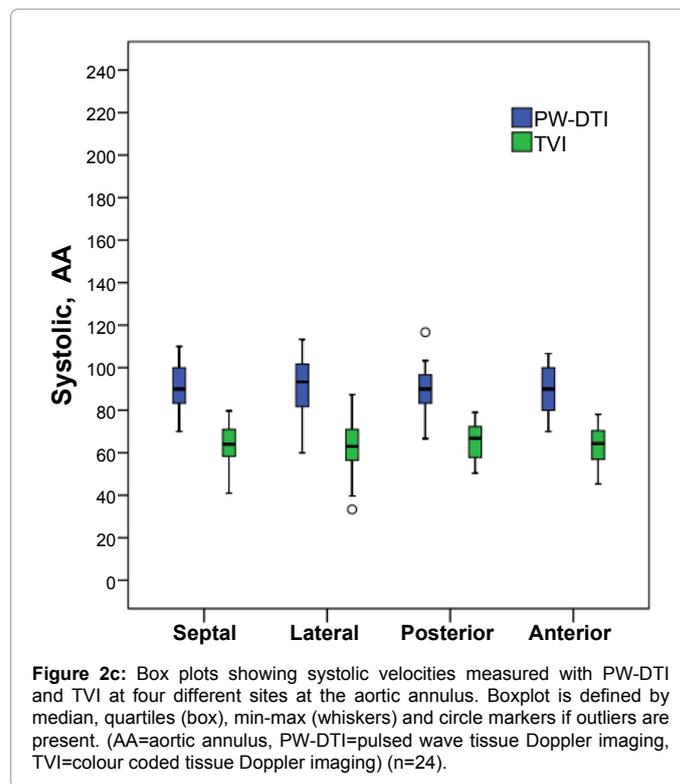


Figure 2c: Box plots showing systolic velocities measured with PW-DTI and TVI at four different sites at the aortic annulus. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (AA=aortic annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).

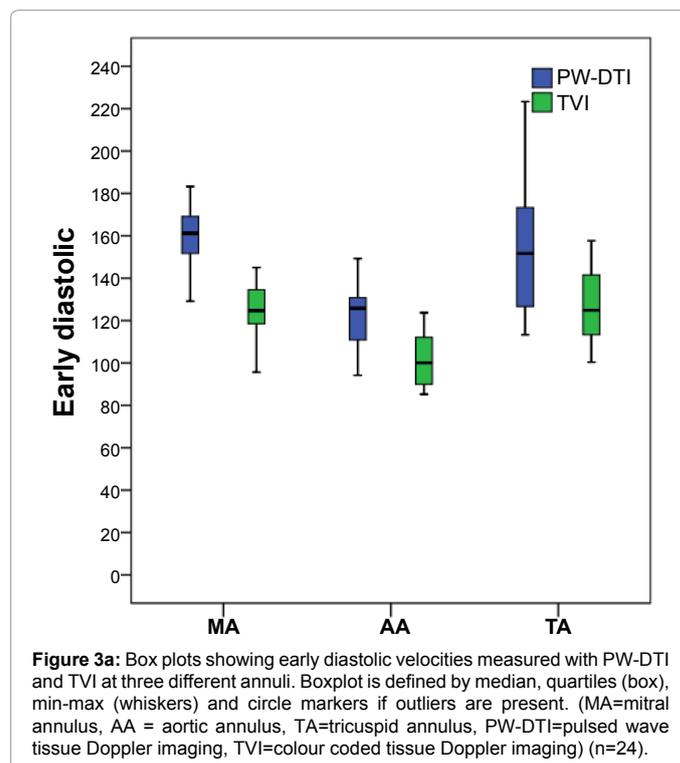


Figure 3a: Box plots showing early diastolic velocities measured with PW-DTI and TVI at three different annuli. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (MA=mitral annulus, AA = aortic annulus, TA=tricuspid annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).

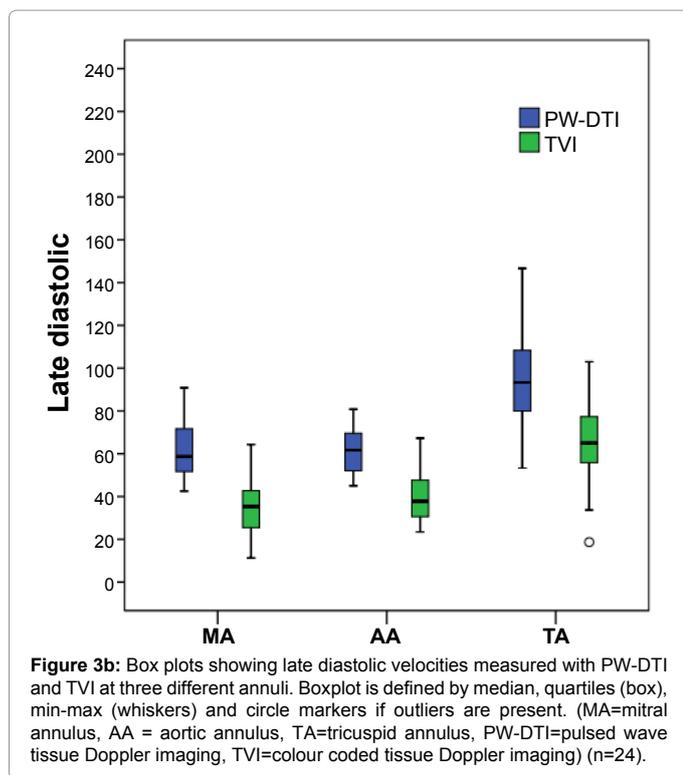


Figure 3b: Box plots showing late diastolic velocities measured with PW-DTI and TVI at three different annuli. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (MA=mitral annulus, AA = aortic annulus, TA=tricuspid annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).

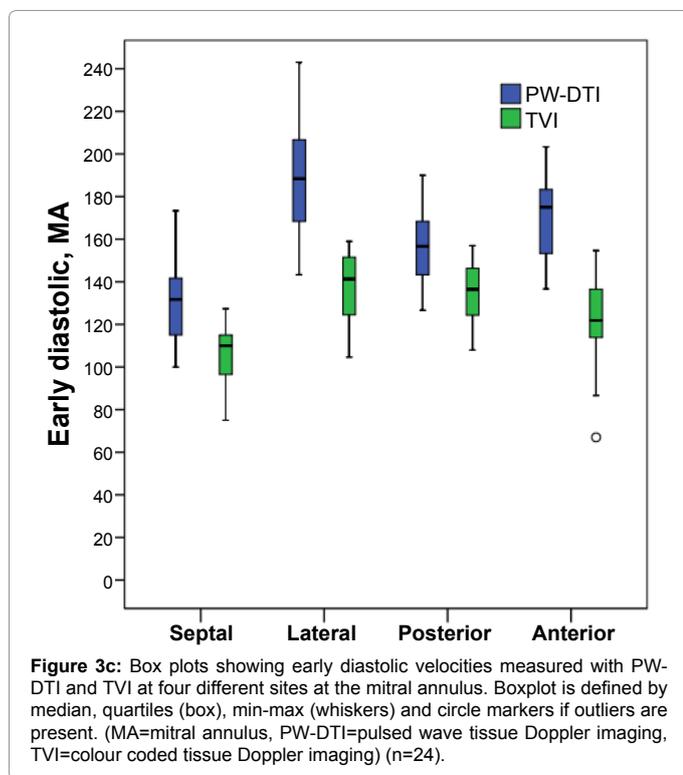


Figure 3c: Box plots showing early diastolic velocities measured with PW-DTI and TVI at four different sites at the mitral annulus. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (MA=mitral annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).

measured with PW DTI and TVI are statistically significantly higher when using PW DTI. This is a novel finding concerning the three different annuli since the velocities at all the three different annuli and sites earlier only have been measured using TVI [12]. In the present study also PW DTI was used. In an earlier study it has been measured

with the both methods at the MA and TA but not also at AA and the different sites as in the present study [13]. However, the difference between the methods is in accordance with the findings by Hummel et al. and Kukulski et al. and is due to that the both methods are not, as some echocardiographers may still think, measuring the same

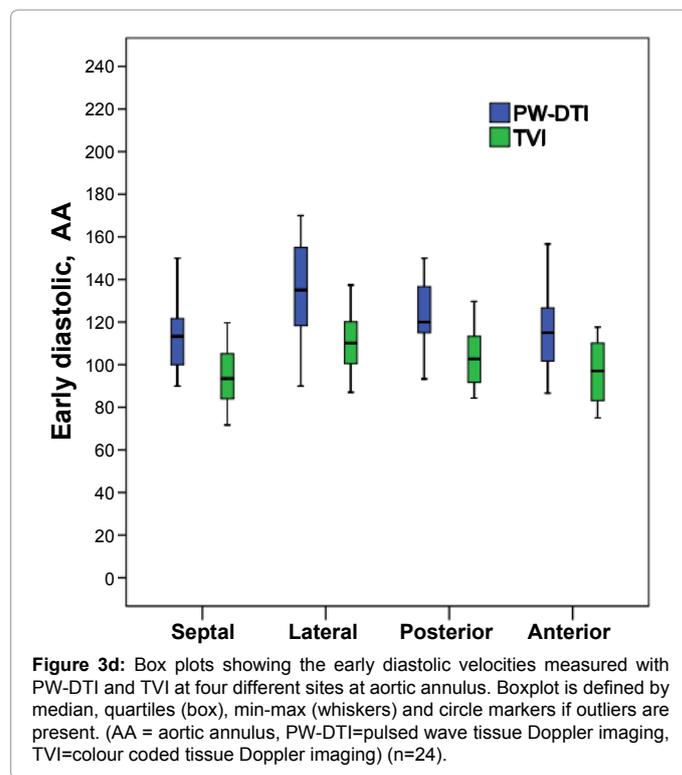


Figure 3d: Box plots showing the early diastolic velocities measured with PW-DTI and TVI at four different sites at aortic annulus. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (AA = aortic annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).

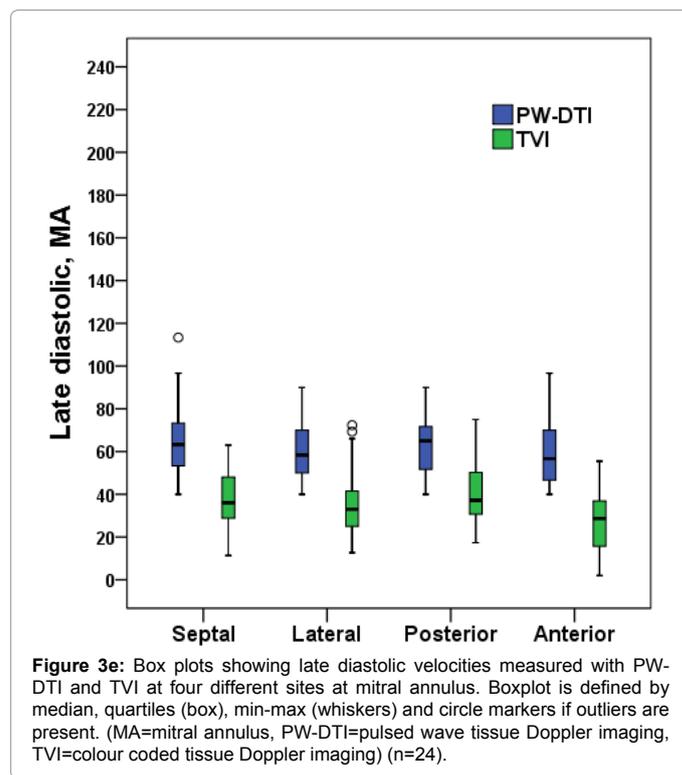
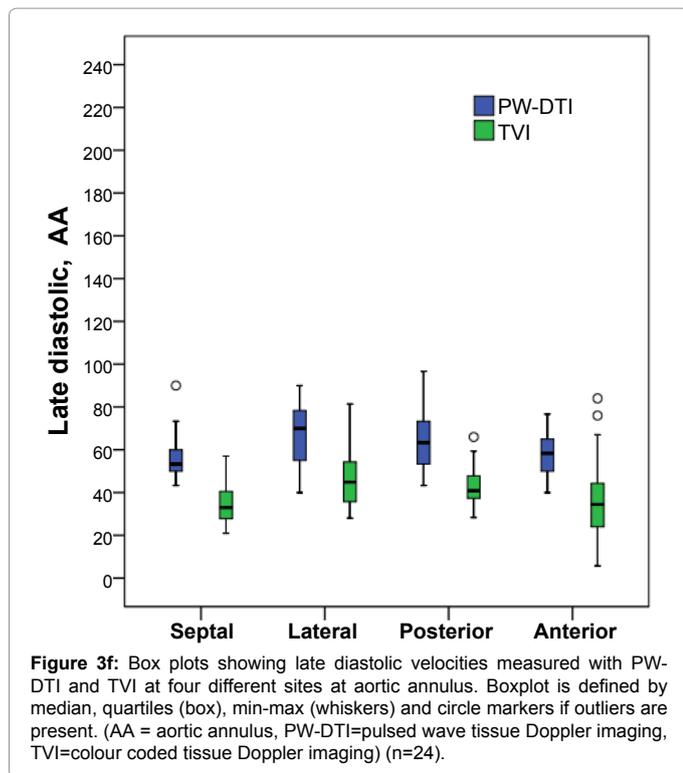


Figure 3e: Box plots showing late diastolic velocities measured with PW-DTI and TVI at four different sites at mitral annulus. Boxplot is defined by median, quartiles (box), min-max (whiskers) and circle markers if outliers are present. (MA=mitral annulus, PW-DTI=pulsed wave tissue Doppler imaging, TVI=colour coded tissue Doppler imaging) (n=24).



thing [18,19]. The lower velocities using TVI might be explained by autocorrelation methodology resulting in peak mean velocity, while PW DTI is computed with a fast Fourier transformation technique resulting in measured peak velocities [7,18,20].

Other reasons to the differences between the two methods could be where the sample volume is placed in the myocardium at the basal part of the ventricles and at the AA. Another cause to the differences could be the transducer angulation, which however was kept as small and similar as possible between the methods in the present study. From this it is obvious that the reference values could not be used interchangeably between the two methods and different reference values have to be used for each method. To our knowledge the present study is the first study to compare the velocities at the AA, MA and TA with the both methods.

The relationship between different velocities and methods was not always the same at the different annuli. Why?

The frame rate is of importance, especially when measuring using TVI. A low frame rate may do that you miss the peak velocities and you

get a lower velocity than it actually is. Another reason could, as already has been mentioned, be where the gate/sample volume have been settled, even a few millimeters difference between where it is settled with the both methods could cause significant differences between the velocities. Also gain settings may have played a role.

The results in the present study obtained using TVI are not fully comparable with the findings in the study by Emilsson et al. since in that study also the septal site of the TA was examined, which not was the case in the present study [12]. The septal site of the TA is anatomically in close connection to the septal site of the MA and it is difficult to separate those sites using tissue Doppler, which was the reason to omit it in this study.

The intra- and interobserver reproducibility for all the velocities was measured at the AA using TVI and there was very good intraobserver reproducibility and a good-very good interobserver reproducibility as shown in Table 4.

Clinical implications

The difference between the obtained values at the different annuli with the both methods is of clinical importance since the both methods thus needs different reference values.

The velocities at the MA and TA could, as has earlier been shown, be used in the assessment of LV and RV (right ventricular) function [7].

The assessment of LV diastolic function should, according to the guidelines, be an integral part of a routine examination, especially in patients with dyspnea or heart failure, and is of importance in the assessment of prognosis and to identify the underlying cardiac disease [8]. In those guidelines concerning assessment of the LV diastolic function, PW Doppler to acquire MA velocities is recommended and especially the ratio E/e' to estimate LV filling pressures. TVI is not recommended since the validation studies were performed using PW Doppler. However, an advantage of TVI compared to PW Doppler is that you can do your measurements off-line on a workstation after the examination, something that is very useful in the echolab nowadays when many patients have to be examined quickly. Perhaps will this recommendation be changed in the future since newer echocardiographs are more often equipped with TVI and the possibilities to use this method will increase.

Increased longitudinal displacement of the aortic root as in patients with aortic insufficiency is associated with increased longitudinal stress and puts the patients at risk of dissection [6]. Measuring the velocities at the AA could in such cases be of interest.

	Intra observer reliability				Inter observer reliability			
	Mean	SD _{between}	SD _{within}	ICC (95% CI)	Mean	SD _{between}	SD _{within}	ICC (95% CI)
Systolic								
Septal site	6.8	0.84	0.31	0.88 (0.61 – 0.97)	6.9	0.79	0.49	0.72 (0.25 – 0.92)
Lateral site	6.3	1.18	0.25	0.96 (0.84 – 0.99)	6.4	1.08	0.38	0.89 (0.65 – 0.97)
Early diastolic								
Septal site	9.1	1.45	0.34	0.95 (0.82 – 0.99)	9.1	1.19	0.43	0.88 (0.62 – 0.97)
Lateral site	9.7	1.60	0.33	0.96 (0.85 – 0.99)	9.8	1.55	0.38	0.94 (0.80 – 0.98)
Late diastolic								
Septal site	5.3	1.43	0.29	0.96 (0.86 – 0.99)	5.5	1.59	0.48	0.91 (0.71 – 0.98)
Lateral site	4.6	1.31	0.17	0.98 (0.94 – 1.00)	4.6	1.33	0.16	0.98 (0.95 – 1.00)

Table 4: Test-retest of intra- and interobserver reliability for TVI method measured on 10 subjects at the aortic annulus. TVI: Colour Coded Tissue Doppler Imaging; SD_{between}: Standard Deviation Between Subjects; SD_{within}: Standard Deviation Within Subjects; ICC: Intra Class Correlation; CI: Confidence Interval.

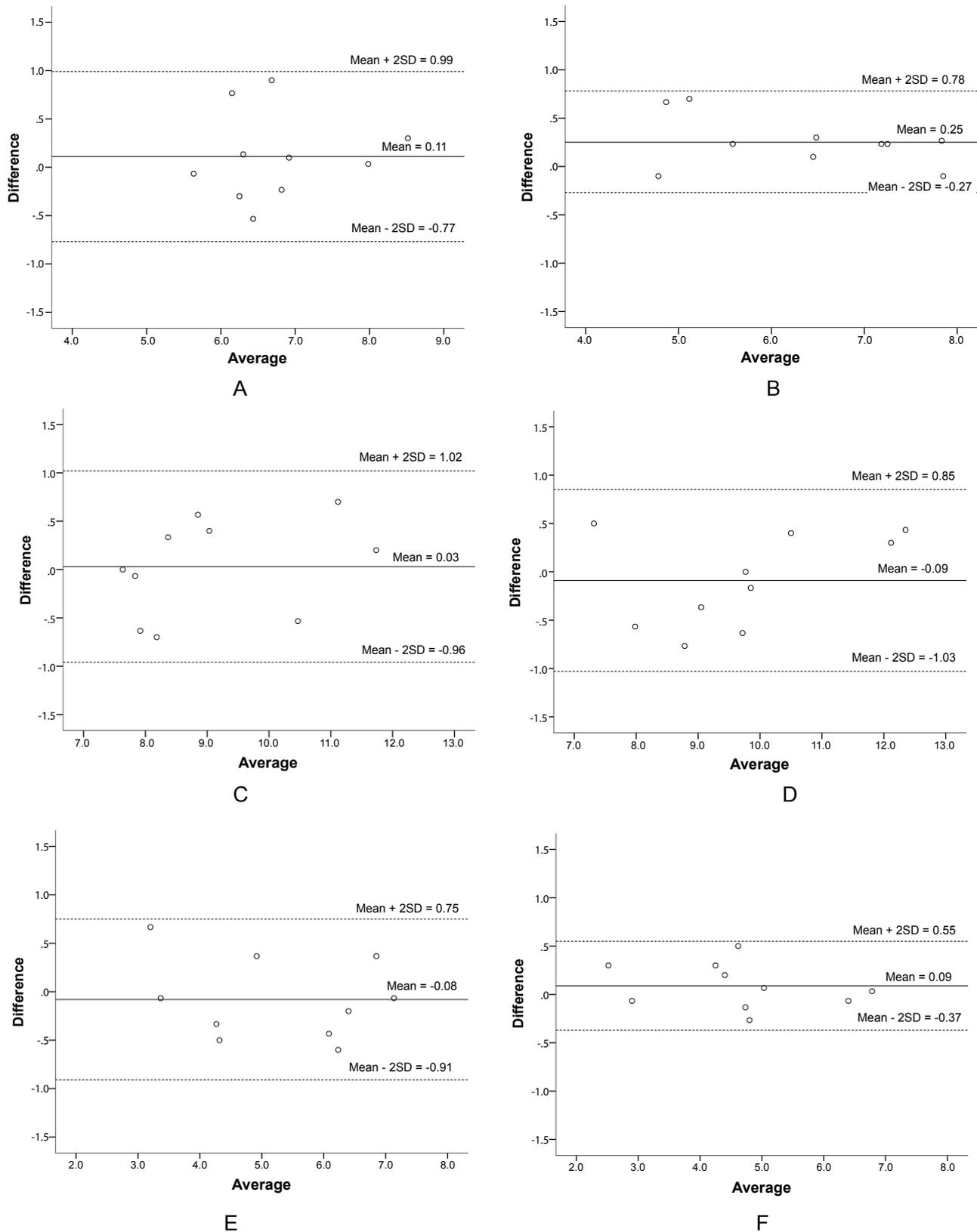


Figure 4a-f: Bland-Altman plots showing the intraobserver agreement of measuring the systolic velocities using TVI (colour coded tissue Doppler imaging) at the septal (a) and lateral sites (b), the early diastolic velocities at the septal (c) and lateral (d) sites and the late diastolic velocities at the septal (e) and lateral (f) sites at the aortic annuli. (n=10).

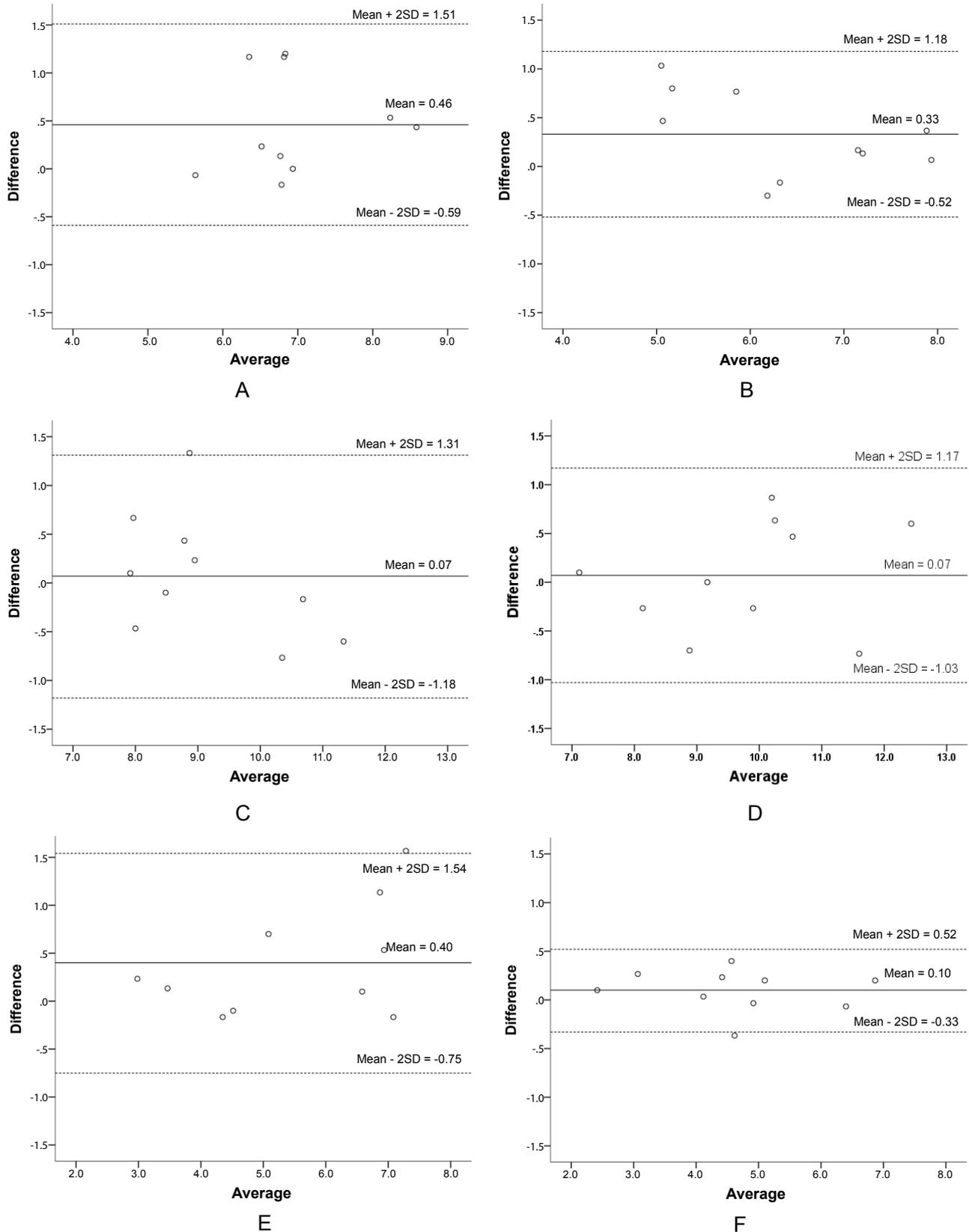


Figure 5a-f: Bland-Altman plots showing the interobserver agreement of measuring the systolic velocities using TVI (colour coded tissue Doppler imaging) at the septal (a) and lateral sites (b), the early diastolic velocities at the septal (c) and lateral (d) sites and the late diastolic velocities at the septal (e) and lateral (f) sites at the aortic annuli. (n=10).

Not much is written about the interaction between AA, MA and TA but knowledge about this interaction and the velocities at the three different annuli may be of importance for instance in thoracic surgery and in the choice of prosthetic valve or annuloplasty ring and how the valves are implanted within the ostium of the diseased valve.

The motion of the AA “up-and down” during the cardiac cycle, as has been shown by measuring the velocities in the present study, contributes to the stroke volume and flow pattern in the ascending aorta [21]. If an aortic prosthesis is implanted by the surgeon in the aortic ostium in such way that the aortic root does not move as in a healthy subject this may have effects on the stroke volume and flow pattern in the ascending aorta causing decreased performance compared to if the surgeon had taken notice of the movement of the AA. However, to examine this was not the aim of the present study but could be the aim in future studies.

There are other examples of where it can be of interest to study the interaction between the different annuli and sites: The natural shape of the mitral annulus changes dynamically during the cardiac cycle, obtaining a saddle shape in systole and having a flatter configuration in diastole, which probably minimize stress in the leaflets and the surrounding tissue. These findings have prompted a re-evaluation of mitral valve annuloplasty ring designs [7,22]. Recently it has been found that aortic stenosis can affect the mitral valve due to the calcification in the aortic-mitral fibrous continuity [10]. Contrary could patients having mitral valve repair and an annuloplasty ring implantation get a less pulsatile and less mobile aortic annulus due to alterations in the mitral-aortic coupling [23].

Sughimoto et al. showed recently by measuring the angle variation between the mitral and aortic valve the effects of the annulus excursion on the cardiac function and its cardiac output [3].

However, most of the mentioned usability of the interaction between the different annuli and sites are of most interest during special conditions. During a clinical routine echocardiographic examination it is in most cases of minor importance to establish this interaction between the annuli and sites, since it also is time consuming, but it is of importance to have those interactions in mind.

Conclusions

In this study, in which both TVI and PW DTI were used and not only TVI, it was found that the velocities were significantly higher using PW DTI than using TVI at the different annuli and sites, probably mainly due to the way the respective method is measuring the velocities. In addition there was shown some heterogeneity of the mean velocity differences and statistically significant velocity differences between different sites and annuli.

The both methods need different reference values and could not be used interchangeably.

The findings could be of importance in special cases where the interaction between the three different annuli and sites is of importance, but including the velocities at all the three different sites in a clinical routine echocardiographic examination will often not be necessary.

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