Agreement between anatomical M-mode and tissue Doppler imaging in the assessment of fetal atrioventricular annular plane displacement in uncomplicated pregnancies: A prospective longitudinal study

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Running Title: TDI of fetal atrioventricular annular plane displacement

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Abstract

Aim: To evaluate the level of agreement between M-mode and pulsed wave-tissue Doppler imaging (PW-TDI) techniques in assessing fetal mitral (MAPSE), tricuspid (TAPSE) andseptal (SAPSE) annular plane systolic excursion in a low risk population.

Methods: This prospective longitudinal study included healthy fetuses assessed from 18 to 40 weeks of gestation. TAPSE, MAPSE and SAPSE were measured using anatomical M-mode and PW-TDI. The agreement between the two diagnostic tests was assessed using Bland-Altman analysis.

Results: Fifty fetuses were included in the final analysis. Mean values of TASPE were higher than that of MAPSE. There was a progressive increase of TAPSE, MAPSE and SAPSE values with advancing gestation. For each parameter assessed, there was an overall good agreement between the measurements obtained with M-mode and PW-TDI techniques. However, the measurements made with M-modewere slightly higher than those obtained with PW-TDI (mean differences: 0.03 cm, 0.05 cm and 0.03 for TAPSE, MAPSE and SAPSE, respectively). When stratifying the analyses by gestational age, the mean values of TAPSE, MAPSE and SAPSE measured with M-Mode were higher compared to those obtained with PW-TDI, although the mean differences between the two techniques tended to narrow with increasing gestation. TAPSE, MAPSE and SAPSE measurements were all significantly, positively associated with gestational age (all $p<0.001$).

Conclusions: Fetal atrioventricular annular plane displacement (AVPD) can be assessed with M-mode technique, or with PW-TDI as the velocity-time integral of the myocardial systolic waveform. AVPD values obtained with M-mode technique are slightly higher than those obtained with PW-TDI.

Keywords: Tissue Doppler Imaging, M-Mode, fetal echocardiography, atrioventricular plane systolic excursion.

Introduction

Fetal echocardiography is the primary tool for prenatal diagnosis of congenital heart disease. Although fetal echocardiography is mainly employed to detect structural anomalies, its use for the evaluation of fetal cardiac function has recently been proposed and is gradually being introduced in clinical practice. Functional assessment of fetal heart has been shown to have the potential to stratifyshort-term cardiovascular risk of several conditions occurring in fetal life, such as intrauterine growth restriction, twin-to-twin transfusion syndrome or fetal anemia.[1-7]

Traditionally, functional assessment of the heart relies on the quantification of ejection fraction as a proxy for systolic function. However, ejection fraction is not commonly used by perinatal cardiologists to assess fetal heart function. Due to its load-dependency, the need for assessing both ventricles separately because of the parallel arrangement of fetal circulation, and the lack of information on longitudinal and circumferential myocardial function, ejection fractionis not considered to represent an objective measure of fetal heart function.

Atrio-ventricular annular plane displacement (AVPD) is a reliable measure of longitudinal heart function, and it has been shown to correlate with myocardial performance better than ejection fraction alone in several pediatric and adult conditions such as valvular disease, heart failure and growth restriction. AVPDrefers to the distance covered by the atrio-ventricular plane between its positions farthest from the apex at the beginning of ventricular contraction and closest to the apex at the end of contraction. The relevance of AVPDrelies on the fact that it can provide information on the longitudinal function of the heart, which can be affected in early stages of cardiac dysfunction.[8-12]

Atrio-ventricular annular plane motion during a cardiac cycle can be evaluated using different ultrasound modalities, such as M-mode, color or pulsed-wave tissue Doppler imaging (PW-TDI) and two-dimensional speckle tracking.[12] However, it still has to be ascertained whether assessment of atrio-ventricular annular plane displacement is affected by the ultrasound technique adopted and whether gestational age at assessment may influence the level of agreement between different imaging modalities. This is fundamental, because the knowledge of the degree of correlation between different diagnostic tools is crucial for their interpretation in clinical practice.

The primary aim of this study was to evaluate the level of agreement between anatomical M-mode and PW-TDI in assessing mitral (MAPSE), tricuspid (TAPSE) and septal annular plane systolic excursion (SAPSE) in a low risk population. The secondary aim was to ascertain the role of gestational age at ultrasound in affecting such agreement.

Methods

This was a prospective study of healthy fetuses assessed longitudinally from 18 to 40 weeks of gestation at an approximately 4-weekly interval at the University Hospital of North Norway, Tromsø, Norway during 2009-2012. Low risk pregnant women attending antenatal clinic for routine second trimester screening were invited to participate in the study. The study was approved by the Regional Committee for Medical Research Ethics (Ref. REK NORD 105/2008). Written informed consent was signed by each woman involved in the study.

Inclusion criteria were: women >18 years of age with uncomplicated singleton pregnancy and normal fetus on second trimester ultrasound, who were willing and able to attend for serial ultrasonographic examinations during the whole pregnancy. Women with a complicated obstetric history or with a medical condition that may have an adverse impact on the current pregnancy were not invited to participate. Exclusion criteria were: multiple pregnancy, fetus with structural or chromosomal anomaly and/or IUGR. Furthermore, fetuses presenting with signs of cardiomegaly or abnormal cardiothoracic ratio were not considered eligible for the inclusion as the assessment of atrio-ventricular annular plane displacement is known to be affected by heart size.[13,14]

Echocardiography was performed using Vivid 7 Dimension ultrasound system (GE Vingmed, Horten, Norway), equipped with a M4S transducer by a single operator. All PW-TDI and 2D recordings were performed from an apical four-chamber view and stored as cine loops of at least 5-10 consecutive cardiac cycles for offline analysis using a dedicated software (EchoPAC PC version112, GE Medical System). The angle of insonation to the long axis of the heart was kept as small as possible or adjusted manually. The TDIand 2D sector widths were minimized to obtain the highest possible frame rate (201-273 frames/s).[13,14]

Biventricular diameter was measured at the level of the annulus during the systole and at the level of the valves' tip during the diastole. Right and left ventricular length was measured in diastole from the corresponding lateral annulus to the apex. Septal length was measured in diastole from the offset to the apex.

TAPSE, MAPSE and SAPSE values were assessed offline using anatomical M-mode in an apical four-chamber view, placing the M-mode cursor on the lateral mitral annulus, lateral tricuspid annulus and the septum just below the offset, respectively. The excursion of mitral, tricuspid and septal annular planes was measured during the same cardiac cycle. Total displacement of the annular planes from the end of diastole until maximal expansion in systole was measured in cm (Figure 1a), avoiding oscillations due to fetal respiration or movements.[12]

Myocardial and septal wall motion was assessed with PW-TDI, with a sample size of 1-2 mm, aligned parallel (insonation angle <15 degree) to the myocardial wall at the level of the AV planes and to the interventricular septum at its basal part. The velocity waveforms were obtained during the whole cardiac cycle and three to six cardiac cycles were recorded for offline analysis at a sweep speed of 100 mm/s. The velocity-time integral of the systolic waveform (S`) that represents the AVPDwas measured in cm by tracing the maximum velocity waveform of the annular motion during the ejection phase of the cardiac cycle (Figure 1b)[12, 23]. All measurements were performed three times and an average value was used for analysis.

For each recorded variable, the agreement between the two diagnostic tests (M-mode and PW-TDI) was assessed using Bland-Altman analysis, which was performed in the overall sample, and in four subgroups stratified by gestational age (20^{+0}-23^{+6}, 24^{+0}-27^{+6}, 29^{+0}-33^{+6} and 34^{+0}-39^{+6} weeks).[15-17] In all analyses, the level of agreement was expressed as the mean difference between observations made using the two methods (M-mode minus PW-TDI), with 95$\%$ limits of agreement, which provide an interval within which 95$\%$ of differences are expected to lie. In the analysis of the overall sample, we used the Bland-Altman method for repeated observations, as more than one measurement was available for each fetus.[15-17] To further explore the relationship between gestational age and test agreement, we fitted a random-effect linear regression with individual test difference (i.e. value obtained by TDI minus value obtained by M-mode) as the dependent variable, and each fetus as the cluster variable.

Finally, a random-effect linear regression (with each fetus as the cluster variable) was performed to explore the associations between AVPD parameters (TAPSE, MAPSE, and SAPSE) and cardiac dimensions (biventricular diameter, and the right ventricular, left ventricular and septal length, respectively). For each AVPD parameter, three separate models were fit considering as dependent variable: (1) the value obtained with M-mode technique (b) the value obtained by PW-TDI technique, and (c) the difference between the two techniques (PW-TDI minus M-mode).

Statistical significance was defined as a two-sided p-value <0.05 for all analyses. Bland-Altman plots were performed using MedCalc for Windows 15.2 (MedCalc Software, Ostend, Belgium, 2015); linear regression analysis was made using Stata 13.1 (Stata Corp., College Station, Texas, USA, 2013).

Results

Fifty uncomplicated singleton pregnancies studied longitudinally (a total of 174 examinations) were included in the final analysis. The baseline characteristics and outcome of these pregnancies are presented in Table 1. Median gestational age at scan was 26 weeks (interquartile range, IQR: 17.6-34.1). A total of 15.5% (95% CI 10.5-21.8; 27/174) of examinations were performed at 20^{+0}-23^{+6}, 35.6% (95% CI 28.5-43.2; 62/174) at 24^{+0}-27^{+6}, 29.3% (95% CI 22.7-36.8; 51/174) at 29^{+0}-$33^{+6}$and 19.5% (95% CI 13.9-26.2; 34/174) at 34^{+0}-39^{+6} weeks of gestation. Median number of examination per patient was 3 (IQR 3-5). Pregnancy outcome was uneventful for all the included cases.

Mean values of TAPSE were higher than that of MAPSE (Table 2). There was a progressive increase of TAPSE, MAPSE and SAPSE values with advancing gestation (Table 3). On random effect linear regression analysis, TAPSE (regression coefficient: 0.09, 95% CI 0.02; 0.16 for 1 cm increase; p= 0.02) and SAPSE (regression coefficient: 0.10, 95% CI 0.05-0.16 for 1 cm increase; p< 0.001), but not MAPSE (p= 0.6) were positively associated with bi-ventricular diameter (Table 4). Likewise, TAPSE (regression coefficient: 0.07, 95% CI 0.00-0.14; p= 0.045), but not MAPSE (p= 0.18) was positively associated with ventricular length, while the positive association was observed only between septal length and SAPSE measured with M-Mode (regression coefficient: 0.05, 95% CI 0.01; 0.09; p= 0.012) but not with TDI (p= 0.9).

For each excursion parameter, the overall agreement between the measurements obtained with M-mode and with TDI are shown in Figures 2-4. Each Figure reports the Bland-Altman plot performed separately for TAPSE, MASPE and SAPSE, respectively, and the results of each plot are summarized in Table 2. For all parameters, the measurements made with M-mode were slightly higher than those obtained with PW-TDI (mean differences between the two techniques: 0.03 cm, 0.05 cm and 0.03 for TAPSE, MAPSE and SAPSE, respectively). In all cases, however, the 95% limits of agreement were wide and not consistent, with the differences between the two techniques lying between -0.23 cm and

0.28 cm for tricuspid; -0.20 cm and 0.31 cm for mitral; -0.17 cm and 0.24 cm for septal annular plane systolic excursion.

When stratifying the analyses by gestational age, the mean values of TAPSE, MAPSE and SAPSE measured with M-mode were higher compared to those obtained with PW-TDI, although the mean differences between the two techniques tended to narrow with the increase of gestational age. In fetuses ≥34 weeks, the mean values obtained with PW-TDI were higher than those measured with M-mode. For all parameters, however, the limits of agreement remained wide in all age classes (Table 3). Random-effect linear regression showed a positive association between test differences and gestational age (regression coefficient: 0.008, 0.011, 0.008 for TAPSE; MAPSE and SAPSE, respectively, for each 1-week increase; all $p<0.001$) (Table 5).

Discussion

Applicability PW-TDI to access AVPD as the velocity-time integral of myocardial systolic waveform has not been explored. In the absence of an electrocardiogram, compared to M-mode, PW-TDI has the advantage of more clearly identifying isovolumic events of the fetal cardiac cycle,[12]which should be excluded in the measurement of AVPD[25]. The findings from our study indicate that AVPD could be assessed by both techniques, but values obtained with M-mode were higher than those obtained with PW-TDI. However, when stratifying the analyses by gestational agethe mean differences between the two techniques tended to narrow with the increasing gestational age. It remains unclear whether this is a physiological phenomenon or related to the fact that recording M-mode and PW-TDI waveforms from the fetuses as well as defining the cardiac cycle events becomes easier with advancing gestation. Mean values of TAPSE were higher than that of MAPSE, and there was a progressive increase in AVPD values with advancing gestation which is in line with previous reports. Functional assessment of fetal heart may help to prenatally stratify the short-term cardiovascular risk of several fetal conditions.[1-7] Early detection of fetuses at high risk of post-natal cardiovascular compromise would allow early monitoring and intervention, thus potentially being able to change the natural history of the disease and improve children´s cardiovascular health.AVPD is a major contributor to ventricular pumping, accounting for 80% of right ventricular systolic performance and 60% of left ventricular one in adultsand has been recognized to differentiate myocardial disorders better than ejection fraction alone.[11,12,18-20]

Fetal AVPD may be affected in several relevant in utero conditions, but whether it can help in stratifying these fetuses to predict the short and long-term prognosis depends on how reliably it can be measured during pregnancy. Different ultrasound modalities such as M-mode, color-TDI, PW-TDI and speckle tracking echocardiography can be employed to measure AVPD in the fetus. It is therefore important that clinicians are provided with an up-to date estimation on the degree of concordance between different modalities in assessing this parameter.

M-mode is a relatively easy and accessible technique. Assessment of AVPD with M-mode is commonly performed by measuring the maximum systolic excursion as a distance between the nadir and the zenith of the annular motion profile. Measurement of AVPD using M-mode was introduced in 2001 and the gestational age-specific reference ranges have been recently provided.[21,22] One of the major advantages of using M-mode when assessing AVPD is its high sampling rate (>1000/s) and excellent interface definition. However, pre- and post-ejection phases of the cardiac cycle may be difficult to identify accurately in the absence of a fetal electrocardiogram[12].

Pulsed-wave TDI is a relatively recent ultrasound modality in fetal cardiovascular imaging and uses frequency shifts of ultrasound waves to calculate myocardial velocities that are displayed as the maximum velocity waveform envelope representing all phases of the cardiac cycle.[23] TDI requires operator expertise and a dedicated ultrasound equipment and it is not commonly performed in clinical practice. However, it allows better definition of the events of the cardiac cycle in the absence of an electrocardiogram and myocardial velocities can be simultaneously assessed.

AVPD can be assessed either by pulsed-wave or color TDI.[24] Assessment of AVPD by TDI is different from that performed on M-mode, where the measurements are expressed as the distance (cm) between the nadir and the zenith of the annular motion profile. Using TDI, AVPD measurements are derived by tracing the velocity-time integral (cm) of annular velocity waveform during the ejection phase of cardiac cycle, which essentially represents the systolic annular displacement. Both techniques are, however, angle dependent.

In adults, M-mode and TDI-derived AVPD have been demonstrated to have an overall good level of agreement.[25] However, there is still paucity of data in fetal period. Inour study, although the 95% limits of agreement were wide and not consistent between two techniques, mean excursion values measured by anatomical M-mode were slightly higher than those measured by PW-TDI. The difference between two techniques could be due to the fact that the M-mode assess the global motion along of the whole length of the ventricular wall/septum, whereas the PW-TDI derives the regional motion of the ventricular /septal basal areas. Difficulty associated with accurately identifying and excluding the components of excursion occurring during isovolumic phases of the cardiac cycle in the fetus when using the M-mode technique could be another explanation.

Only few studies have assessed the degree of correlation between different prenatal ultrasound modalities in evaluating AVPD. In the study by Cruz-Lemini et al., 69 fetuses affected by intra-uterine growth restriction requiring delivery before 34 weeks of gestation were compared with 46 normal pregnancies.[3] The authors reported that MAPSE and TAPSE were significantly lower in fetuses affected by intra-uterine growth restriction compared to controls; furthermore, M-mode measurements showed a similar performance to TDI in assessing AVPD. However, the authors did not explore the level of agreement between these two different techniques according to the gestational age at scan and the included fetuses were delivered at a relatively large gestational age window, i.e. between 26 and 34 weeks of gestation.Furthermore, the authors compared M-mode with TDI velocities rather than TDI-derived AVPD. Messing et al. explored the correlation between MAPSE, gestational age and fetal weight.[24]They compared values obtained by M-mode withspatiotemporal image correlation between 20 and 38 weeks of gestation and provided gestational age specific reference ranges.[24] These investigators reported that MAPSE had a linear correlation with gestational age and fetal weight, and that the two different ultrasound modalities were comparable.[24] Our study shows similar results although different techniques (M-mode and pulsed-wave TDI) were compared. Mean values of TAPSE, MAPSE and SAPSE increased through pregnancy as previously reported; this finding might be related to the increase in heart size and body surface area rather than to an actual improvement of fetal systolic function which has been reported to be relatively constant throughout pregnancy.[26-28]

The major strength of our study is its prospective longitudinal design, which allowed us to assess the effect of gestational age on the agreement between two techniques of AVPD measurement. Its limitationsare a relatively small sample size and lack of a concurrent electrocardiographic evaluation. Furthermore, AVPD was assessed using anatomical rather than real time M-mode. Although the two techniques have been shown to have an overall good agreement between, mean excursion values were higher when anatomical M-mode was used, and this should be consideredwhen comparing with TDI.[29]

Mean AVPDvalues are slightly higher when measured by anatomical M-mode compared to PW-TDI. These differences should be considered when evaluating longitudinal fetal heart function. TAPSE, MAPSE and SAPSE showed a linear correlation with gestational age. Further large studies aimed at assessing the degree of correlation between M-mode and PW-TDI in different pathological conditions and at different gestational age windows are needed to ascertain whether routine assessment of AVPD may help in identifying fetuses at risk of cardiovascular dysfunction during pregnancy.

Disclosure

No conflict of interest to declare from any of the authors

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Table 1. General characteristics of the study population ~~analyzed~~.

Variables	Overall sample (n=50)
Maternal age (year)*	30.4±3.9
Maternal height (m) *	1.7±0.04
Body mass index (Kg/m^2)*	23.2±3.1
Gestational age at birth (weeks)§	40 (39-40)
Caesarean section	10% (5/50)
Birthweight (g)*	3378±0.5
Livebirth	100% (50/50)
Apgar score <7 at 5 min	4% (2/50)
pH*	7.25±0.1
Base excess (mmol/L)	-4.29±3.7

*: Values expressed as mean (±standard deviation).
§: Values expressed as median (interquartile range).

Table 2. Overall agreement between ~~the tests~~ (M-mode vs pulsed wave tissue Doppler imaging (PW-TDI) techniques in assessing systolic atrioventricular annular plane displacement (AVPD) in fetus.

Variables AVPD	M-mode Mean (SD)	PW-TDI Mean (SD)	Mean difference* (95% LoA)
TAPSE (cm)	0.58 (0.12)	0.56 (0.16)	0.03 (-0.23; 0.28)
MAPSE (cm)	0.47 (0.10)	0.42 (0.14)	0.05 (-0.20; 0.31)
SAPSE (cm)	0.36 (0.06)	0.33 (0.10)	0.03 (-0.17; 0.24)

TAPSE = Tricuspid anular plane systolic excursion; MAPSE = Mitral anular plane systolic excursion; SAPSE = Septal annular plane systolic excursion. SD = Standard deviation. LoA = Limits of agreement. M-mode vs TDI.

Table 3. Overall agreement between M-mode vs pulsed wave tissue Doppler imaging (PW-TDI) techniques in assessing systolic atrioventricular annular plane displacement (AVPD) in fetus for each selected variable, stratified by gestational age.

Variables	**M-mode Technique**	**Tissue Doppler**	**Mean difference***
AVPD	**Mean (SD)**	**Mean (SD)**	**(95% LoA)**
TAPSE (cm)			
20^{+0}-23^{+6} weeks	0.42 (0.08)	0.48 (0.09)	-0.06 (-0.14; 0.26)
24^{+0}-27^{+6} weeks	0.55 (0.10)	0.49 (0.09)	0.06 (-0.10; 0.22)
29^{+0}-33^{+6} weeks	0.63 (0.10)	0.61 (0.12)	0.02 (-0.22; 0.27)
34^{+0}-39^{+6} weeks	0.65 (0.10)	0.73 (0.14)	-0.08 (-0.41; 0.26)
MAPSE (cm)			
20^{+0}-23^{+6} weeks	0.40 (0.07)	0.28 (0.07)	0.11 (-0.06; 0.29)
24^{+0}-27^{+6} weeks	0.46 (0.09)	0.36 (0.07)	0.10 (-0.12; 0.32)
29^{+0}-33^{+6} weeks	0.50 (0.10)	0.45 (0.11)	0.05 (-0.21; 0.30)
34^{+0}-39^{+6} weeks	0.51 (0.08)	0.57 (0.12)	-0.06 (-0.29; 0.18)
SAPSE (cm)			
20^{+0}-23^{+6} weeks	0.33 (0.06)	0.23 (0.05)	0.10 (-0.05; 0.24)
24^{+0}-27^{+6} weeks	0.35 (0.04)	0.29 (0.06)	0.06 (-0.07; 0.19)
29^{+0}-33^{+6} weeks	0.37 (0.06)	0.36 (0.08)	0.01 (-0.18; 0.20)
34^{+0}-39^{+6} weeks	0.39 (0.06)	0.42 (0.10)	-0.03 (-0.26; 0.20)

TAPSE = Tricuspid annular plane systolic excursion; MAPSE = Mitral annular plane systolic excursion; SAPSE = Septal annular plane systolic excursion. SD = Standard deviation. LoA = Limits of agreement. * M-mode vs PW-TDI.

Table 4. Associations of the atrio-ventricular annular plane displacement (AVPD) parameters (TAPSE, MAPSE, and SAPSE) with cardiac dimensions (biventricular diameter, and the right ventricular, left ventricular and septal length, respectively). For each excursion parameter, the analyses were repeated three times, considering: (a) the result of the M-mode assessment (b) the results of the Pulsed-wave Tissue doppler imaging (PW-TDI) assessment, and (c) the difference between the two techniques (PW-TDI minus M-mode).

	M-mode			**PW-TDI**			**Difference ᵠ**	
	Reg. coefficient (95% CI)*	**p**		**Reg. coefficient (95% CI)***	**p**		**Reg. coefficient (95% CI)***	**p**
	Bi-ventricular diameter, 1-cm increase							
TAPSE (cm)	0.1 (0.11; 0.23)	<0.001		0.09 (0.03; 0.15)	0.004		0.09 (0.02; 0.16)	0.02
MAPSE (cm)	0.04 (-0.02; 0.10)	0.17		0.03 (-0.03; 0.00)	0.3		0.02 (-0.05; 0.09)	0.6
SAPSE (cm)	0.07 (0.03; 0.12)	0.001		-0.03 (-0.06; 0.00)	0.09		0.10 (0.05; 0.16)	<0.001
	Right ventricular length, 1-cm increase							
TAPSE (cm)	0.14 (0.08; 0.20)	<0.001		0.08 (0.03; 0.14)	0.004		0.07 (0.00; 0.14)	0.045
	Left ventricular length, 1-cm increase							
MAPSE (cm)	0.04 (-0.01; 0.10)	0.11		0.00 (-0.05; 0.05)	0.9		0.04 (-0.02; 0.11)	0.18
	Septal length, 1-cm increase							
SAPSE (cm)	0.05 (0.01; 0.09)	0.012		0.00 (-0.03; 0.03)	0.9		0.05 (-0.00; 0.10)	0.06

* All models were adjusted for gestational age (1-week increase). ᵠ PW-TDI minus M-mode.

AVPD = Atrio-ventricular annular plane displacement; TAPSE = Tricuspid annular plane systolic excursion; MAPSE = Mitral annular plane systolic excursion; SAPSE = Septal annular plane systolic excursion; Reg. = regression.

Table 5. Random-effect linear regression exploring the relationship between test difference (PW-TDI minus M-mode) and gestational age.

Test differences	Regression coefficient for 1 week increase (95% CI)	p
TAPSE (cm)	0.008 (0.005; 0.012)	<0.001
MAPSE (cm)	0.011 (0.008; 0.014)	<0.001
SAPSE (cm)	0.008 (0.006; 0.010)	<0.001

PW-TDI = Pulsed-wave tissue Doppler imaging; TAPSE = Tricuspid annular plane systolic excursion; MAPSE = Mitral annular plane systolic excursion; SAPSE = Septal annular plane systolic excursion.

Figure 1 (a-,b). Measurement of atrioventricular annular plane displacement (AVPD) in a fetus at 36 weeks of gestation: Figure 1a. Tricuspid annular plane systolic excursion (TAPSE) measured as the distance between nadir and zenith (between the calipers) of its motion recorded at a horizontal sweep speed of 100 mm/s with M-mode technique. Figure1b. Tricuspid annular plane systolic excursion (TAPSE) measured as the velocity time integral (VTI) of the myocardial systolic waveform (S´) recorded at a horizontal sweep speed of 100 mm/s with pulsed wave tissue Doppler imaging (PW-TDI) technique using a 1 mm Doppler gate. Note that the isovolumic contraction velocity (IVCV) component is not included in the measurement. E´ represents the myocardial velocity during early filling and A´ represents the myocardial velocity during the atrial contraction phase of the cardiac cycle.

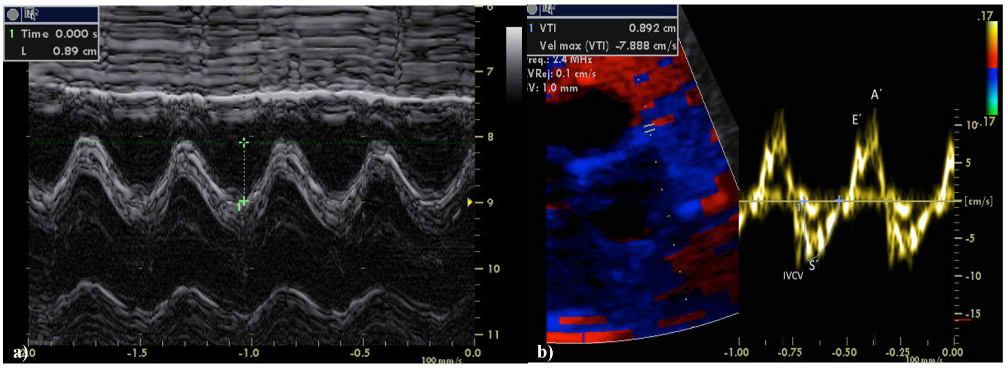

Figure 2 (a-c). Bland-Altman plot of the difference in TAPSE, MAPSE and SAPSE measurement between M-mode and tissue Doppler. The central red line represents the mean difference between the two measurements; the two blue lines represent the upper and the lower Limits of Agreement (LoA). (TAPSE = Tricuspid annular plane systolic excursion; MAPSE = Mitral annular plane systolic excursion; SAPSE = Septal annular plane systolic excursion; SD = Standard Deviation).