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Tissue Doppler Is More Sensitive and Reproducible than Spectral Pulsed-Wave Doppler for Fetal Right Ventricle Myocardial Performance Index Determination in Normal and Diabetic Pregnancies

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Background: The aim of this study was to compare the reproducibility, agreement, and sensitivity of pulsed-wave Doppler tissue imaging (DTI) versus spectral Doppler assessment of right ventricular (RV) myocardial performance index (MPI) in midgestation fetuses in both a normal and a disease state.

Methods: RV MPI was calculated using pulsed-wave DTI and spectral Doppler in normal pregnancies (n = 69) and in women with pregestational diabetes (n = 51). Intraobserver and interobserver variability and agreement were evaluated using Bland-Altman analysis. Student's t tests were used for comparisons of differences.

Results: In normal fetuses, RV MPI derived by the two methods showed no statistical difference, were interchangeable (DTI, 0.51 ± 0.10; spectral Doppler, 0.50 ± 0.12; P = .686), and were in agreement by Bland-Altman analysis. However, in fetuses of mothers with diabetes, the two methods produced different RV MPI measurements (DTI, 0.56 ± 0.10; spectral Doppler, 0.51 ± 0.12; P < .001). Intraobserver and interobserver bias was lower for DTI.

Conclusions: The DTI method of measuring fetal RV MPI is more sensitive, has less variability and more precision, and is better able to demonstrate subtle abnormalities in cardiac function than the spectral Doppler method in diabetic versus normal pregnancies. (J Am Soc Echocardiogr 2013;26:507-14.)

Keywords: Cardiac function, Fetal echocardiography, Myocardial performance index, Pregestational diabetes, Doppler tissue imaging

The evaluation of fetal cardiac function is increasingly recognized as an important part of a complete fetal echocardiographic study.[1] Various methods have demonstrated evidence of both systolic and diastolic dysfunction in a variety of fetal and maternal disease states, including twin-twin transfusion syndrome, maternal pregestational diabetes mellitus (DM), and space-occupying chest lesions.[2-5] Early detection of myocardial dysfunction may help guide management and may improve outcomes. Noninvasive detection of subtle abnormalities of cardiac function during development may also have implications for our understanding of disease and management.[6] However, noninvasive evaluation of global cardiac function has been challenging in fetuses. Given the unique fetal physiology, functional assessments cannot be extrapolated directly from pediatric and adult studies. The fetal circulation is right ventricular (RV) dominant, whereas most validated measures used in adult and pediatric populations have examined the left ventricle rather than the right ventricle.[7-9]

A noninvasive measure of combined systolic and diastolic myocardial function, the myocardial performance index (MPI), first described by Tei *et al.*[10] in adults, is now being used in fetuses. MPI, traditionally derived from spectral Doppler (pulsed wave), is the ratio of ventricular isovolumic time to ejection time. Myocardial dysfunction results in prolongation of isovolumetric intervals and decreased ejection time, yielding an increased MPI. Typically obtained from a spectral Doppler trace simultaneously displaying mitral inflow and aortic outflow, spectral Doppler MPI measurements are reproducible and relatively easy to obtain. Spectral Doppler–derived MPI is widely accepted in the adult population as a quantitative measure of global cardiac function, and more recently it has been validated in children.[11-13] In mid and late trimester fetal studies, age-related changes in MPI appear for both the left and right ventricles.[14] Since then, other groups have examined the utility of assessing global MPI using spectral Doppler in fetal disease states such as twin-twin transfusion syndrome[15-17] and pregestational DM in later gestation.[18]

Spectral Doppler imaging in the right ventricle for the purpose of measuring MPI is more difficult than in the left ventricle, given the difficulty of simultaneously recording both inflow and outflow in a single Doppler sample. If the inflow and outflow Doppler signals are

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Abbreviations
DM = Diabetes mellitus
DTI = Doppler tissue imaging
MPI = Myocardial performance index
RV = Right ventricular

obtained separately, heart rate fluctuations may introduce errors and will increase variability in measurement. An easier alternative method for determining MPI for the right ventricle may be Doppler tissue imaging (DTI) of the lateral tricuspid annulus, which allows simultaneous recording of diastolic and systolic events in a single Doppler sample.[19] Although smaller studies have begun to apply the newer DTI MPI method to the assessment of fetal cardiac function in various fetal disease states, it is not known if the pulsed-wave DTI and spectral Doppler methods of determining MPI are interchangeable and produce similar values in a normal population. In addition, it is unclear if they are equally sensitive in demonstrating subtle abnormalities of global myocardial performance in at-risk midgestation fetuses without signs of overt dysfunction on standard imaging.

We hypothesized that the pulsed-wave DTI method is more reproducible and more precise and that it is more sensitive for distinguishing subtle differences in cardiac function in a diseased group.

Our aims were to measure RV MPI using both pulsed-wave DTI and spectral Doppler in midgestation fetuses (gestational age, 17–23 weeks) with and without subtle abnormalities of cardiac function and to compare the agreement, precision, and variability of the two methods. Prior studies have demonstrated subtle abnormalities in RV diastolic function in the fetuses of mothers with pregestational DM using spectral Doppler and DTI.[18,20] In these fetuses, diastolic myocardial velocities at the level of the mitral and tricuspid valve annuli were significantly higher, and E′/A′ ratios were higher than in normal fetuses, while the ratio of early diastolic peak inflow velocity to peak annular velocity (E′/E) was lower in the fetuses of mothers with DM. These changes in diastolic function are independent of the presence of myocardial hypertrophy. Using spectral Doppler, many of these patients did not show changes in transmitral or transtricuspid inflow, suggesting that DTI may be more sensitive than spectral Doppler for the diagnosis of fetal diastolic dysfunction.[21] Therefore, we chose this population, known to have subclinical, subtle diastolic abnormalities, as a "disease" population to evaluate sensitivity of the spectral Doppler or pulsed-wave DTI methods of determining MPI for the detection of subtle cardiac functional abnormalities in fetuses who were otherwise normal.

METHODS

DTI using spectral pulsed-wave sampling at the lateral tricuspid valve annulus has been part of the routine fetal echocardiographic protocol at our institution since 2008. We searched the database of the University of California, San Francisco, Fetal Cardiovascular Program for singleton-gestation fetuses with structurally normal hearts without evidence of ventricular hypertrophy in normal sinus rhythm and performed a retrospective cross-sectional study reviewing fetal echocardiograms from 2008 to 2010. All pregnant mothers underwent standard two-dimensional, spectral Doppler, pulsed-wave DTI, and color Doppler examinations using an Acuson Sequoia ultrasound system (Siemens Medical Solutions USA, Inc., Mountain View, CA) equipped with 8.0-MHz or 6.0-MHz curvilinear transducers. We used spectral pulsed-wave Doppler methods to record RV inflow and outflow blood velocities and also to measure annular tissue velocities. Doppler blood flow recordings are termed "spectral Doppler," while tissue Doppler recordings are termed "DTI." We then compared RV MPI using the two different "pulsed Doppler" methods.

Local institutional review board approval was obtained for this research. Criteria for inclusion in the study included a referral indication of family history of congenital heart disease (normal fetuses) or pregestational DM (DM fetuses). To eliminate issues related to gestational age–related changes in MPI previously reported by Tsutsumi *et al.*,[14] we included only studies of fetuses aged 17 to 23 weeks as determined by history of last menstrual period or documented first-trimester ultrasound dating, using measurements of biparietal diameter and femur length as secondary measures.

Previously stored digital images demonstrating good-quality spectral Doppler and DTI recordings of tricuspid inflow, pulmonary outflow, and longitudinal myocardial wall motion obtained at the level of the tricuspid valve annulus in an apical four-chamber view were chosen for measurement (Figure 1). For spectral pulsed-wave Doppler, tricuspid inflow and pulmonary outflow were obtained from tracings with similar heart rates. Significant heart rate differences (>5 beats/min) in the RV inflow and outflow tracing resulted in rejection of the patient for data collection. Peak tricuspid inflow velocities (peak E and peak A) and peak lateral tricuspid annular diastolic tissue velocities (E′ and A′) were measured on three consecutive beats and averaged, and the E/E′, E/A, and E′/A′ ratios were calculated for each fetus. MPI, defined as the sum of the isovolumetric contraction time and the isovolumetric relaxation time divided by the ejection time, was calculated. By convention, our measurements of ejection time were exclusive of valve clicks on the Doppler traces, as noted in the figure (which would shorten the measured ejection time and lengthen the measured isovolumetric time). Two independent investigators measured MPI using both DTI and spectral Doppler over three cardiac cycles and averaged them as previously described.[12] Specifically, for spectral Doppler, three measures of *a* were averaged and three measures of *b* (ejection time) were averaged, with MPI calculated as (average *a*−average *b*)/average *b*. For DTI, the MPI was calculated on each of three consecutive beats, and the results were averaged.

Study Sample Size

Using an expected mean difference of 8% in MPI and 80% power to detect this difference in fetuses of mothers with DM from previously published[22] MPI DTI data in normal fetuses, we determined that a study sample size of 51 DM fetuses would be necessary to detect this difference.

Reproducibility

To assess intraobserver variability, measurements (with both methods) for 33 fetuses in each study group were repeated 1 week after the initial measurements were completed. Additionally, a subset in each group had all measurements independently performed by a second observer. Each observer was blinded to the original measurements.

Statistical Analysis

Data are expressed as mean values ± SD. Differences in peak diastolic tissue and blood pool velocities and E′/A′ and E/E′ ratios between groups were assessed using unpaired Student's *t* tests. To evaluate the agreement between the two methods for determining MPI within the same individual in a group, Student's sample paired *t* tests were performed, and Bland-Altman plots for assessment of bias (difference between measurements) were generated.[23] The precision was taken to be the standard deviation of these differences, indicating variability. Differences between the study groups using the

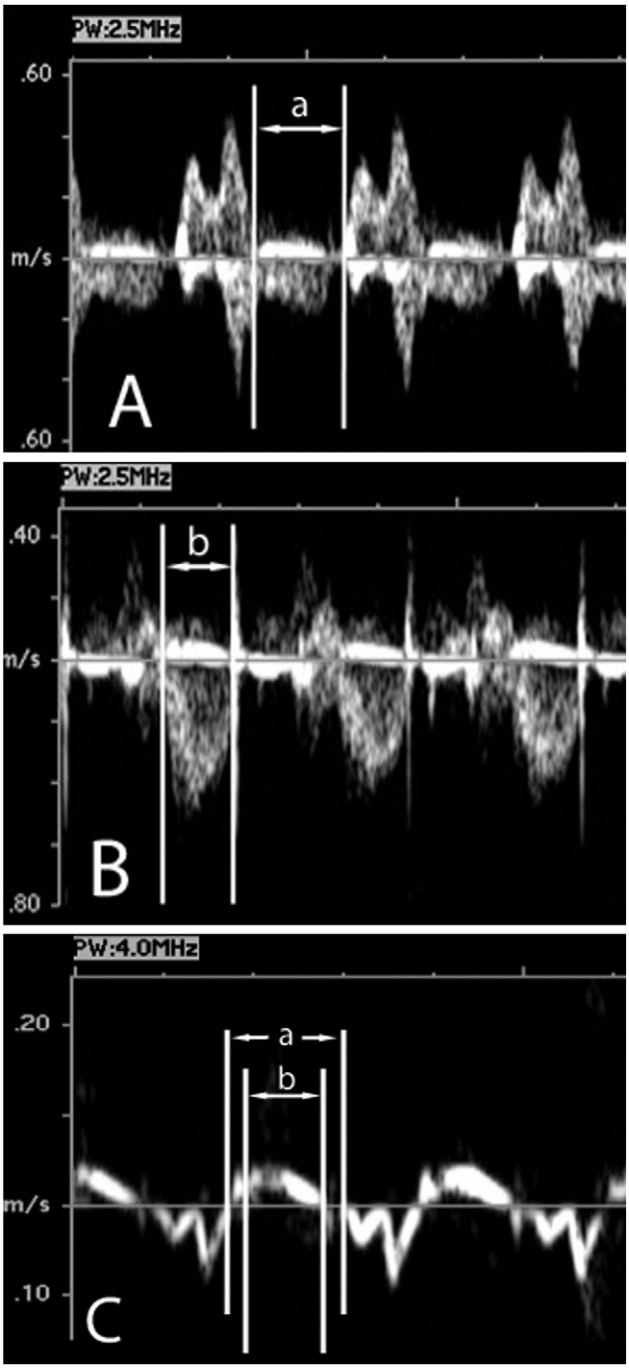

Figure 1 Doppler-derived measurements of MPI. **(A–C)** Measurement of MPI by pulsed-wave **(A,B)** or tissue Doppler method **(C)**. **(A)** Doppler trace of tricuspid inflow, with measurement of the time between inflows (*a*). **(B)** Spectral Doppler in the RV outflow tract at the level of the pulmonary valve, with measurement of the ejection time (*b*). Our measurement of ejection time was exclusive of valve clicks on the Doppler trace (which would shorten the measured ejection time and lengthen the measured isovolumetric time). **(C)** Tissue Doppler trace obtained at the lateral tricuspid annulus, allowing measurement of end-diastole to onset of diastole (*a*) and systolic ejection (*b*) (the initial positive deflection in the trace represents isovolumic tissue acceleration and is not included in the ejection time). For both methods, MPI is calculated as $(a-b)/b$.

same method of MPI were additionally assessed using unpaired *t* tests. A difference was considered significant at $P < .05$. For assessment of reproducibility, Bland-Altman plots of difference (bias) between the two repeated measurements for each method were generated. Interobserver and intraobserver variability was also expressed as mean percentage error, calculated as the absolute value of the difference between the two repeated measurements, divided by the average of the two observations and expressed as a percentage.

RESULTS

Sixty-nine normal fetuses and 51 DM fetuses with both DTI and spectral Doppler obtained and interpretable were included in the study. Mean gestational age did not differ between the two groups (19 weeks in normal fetuses vs 19.6 weeks in DM fetuses). Spectral Doppler and DTI velocities and ratios are presented in Table 1. MPI results for both groups are presented in Table 2.

Differences in Peak Diastolic Spectral Doppler Velocities and Ratios (E′/A′ and E/E′) between the Normal and DM Groups

As shown in Table 1, there was a significant difference in E/E′ ratios between the DM and normal groups, with E/E′ ratios lower in the DM group, as expected.[20] DTI annular velocities and E′/A′ ratios trended toward higher values in the DM group, though this difference did not reach statistical significance. Also as expected, there was no difference in peak inflow (E and A) velocities in DM versus normal fetuses.[20]

MPI by Pulsed-Wave DTI versus Spectral Doppler in Normal and DM Fetuses

Paired analysis within normal fetuses indicated that the two methods produced equivalent MPI values (DTI, 0.51 ± 0.10; spectral Doppler, 0.50 ± 0.12; $P = .69$) and were in agreement by Bland-Altman analysis (bias, -0.0006 ± 0.1541). In the DM fetuses, however, the two methods produced significantly different values and were not in agreement. DTI MPI values were consistently higher than spectral Doppler MPI values in the DM fetuses, resulting in a larger bias (-0.06) and a larger standard deviation of the bias, indicating more variability in DM fetuses (Table 2, Figures 2 and 3).

MPI by Pulsed-Wave DTI versus Spectral Doppler for Distinguishing Normal versus Disease State: Unpaired Analysis

As shown in Table 2, DM fetuses had higher measured DTI MPI values than normal fetuses, but there was no difference between groups when using spectral Doppler for the measurement of MPI.

Reproducibility

Intraobserver and interobserver variability was assessed by Bland-Altman bias (Figures 4 and 5) and mean percentage error. The intraobserver bias (difference between the means of repeated MPI measurements) for RV MPI was greater in the DM group than the normal group. Of note, in the DM group, the bias was less with the DTI method than with the spectral Doppler method. Additionally, the standard deviation of the bias was smaller, indicating better

Table 1 Peak tricuspid velocities and E′/A′ and E/E′ ratios in normal fetuses and fetuses of mothers with DM*

Doppler parameter	Normal fetuses (n = 69)	Fetuses of mothers with DM (n = 51)	P (unpaired t test)
E′ (cm/sec)	3.9 ± 2.8	4.0 ± 0.9	.18
A′ (cm/sec)	6.9 ± 2.0	7.3 ± 1.4	NS
E′/A′ ratio	0.52 ± 0.13	0.55 ± 0.12	.16
Peak E (cm/sec)	27 ± 7.2	28.2 ± 6.6	NS
Peak A (cm/sec)	43.8 ± 9.7	43.6 ± 9.4	NS
E/E′ ratio	8.2 ± 2.7	7.3 ± 2.1	<.05

Data are expressed as mean ± SD.
*As determined by tricuspid valve inflow pulsed-wave Doppler (E, A) or pulsed-wave DTI (E′, A′).

Table 2 Fetal RV MPI values*

Study group	RV MPI DTI	RV MPI pulsed-wave Doppler	P (paired t test)
Normal fetuses (n = 69)	0.512 ± 0.098	0.503 ± 0.118	.69
Fetuses of mothers with DM (n = 51)	0.563 ± 0.104	0.509 ± 0.120	<.001†
P (unpaired t test)	<.01‡	.83	

Data are expressed as mean ± SD.
*As determined by conventional pulsed-wave Doppler or DTI.
†Paired analysis refers to comparison of the two different methods within the same individuals.
‡Unpaired analysis compares normal fetuses as a group versus fetuses of mothers with DM.

precision when MPI was determined by the DTI method in the both the diseased and normal fetuses. The interobserver bias was considerably less for the DTI method for both disease and normal groups.

The intraobserver variability mean percentage error for the DTI method in normal fetuses was 11% and in DM fetuses was 11%, while that for the spectral Doppler method in normal fetuses was 10% and in DM fetuses was 15%. The interobserver variability mean percentage errors for the DTI method were 21% (normal fetuses) and 19% (DM fetuses), while those for the spectral Doppler method were 19% (normal fetuses) and 25% (DM fetuses). Intraobserver and interobserver variability was greater in the DM group compared with normal fetuses, but overall, there was less variability for the DTI method.

DISCUSSION

This is the first study to evaluate the sensitivity of spectral pulsed-wave Doppler versus pulsed-wave DTI determination of MPI in the right ventricle for distinguishing midgestation fetuses at risk for subtle cardiac function differences versus normal fetuses. In this study, we measured MPI by both spectral Doppler and DTI for two defined mid-gestation fetal populations with structurally normal hearts: those with no risk factors other than family history of structural disease and those with maternal pregestational DM. We demonstrated that RV MPI derived by pulsed-wave DTI and spectral Doppler was easily measurable and reproducible in midgestation fetuses (17–23 weeks). After establishing that RV MPI derived by DTI or spectral Doppler is easily measurable and reproducible, we found that both measures

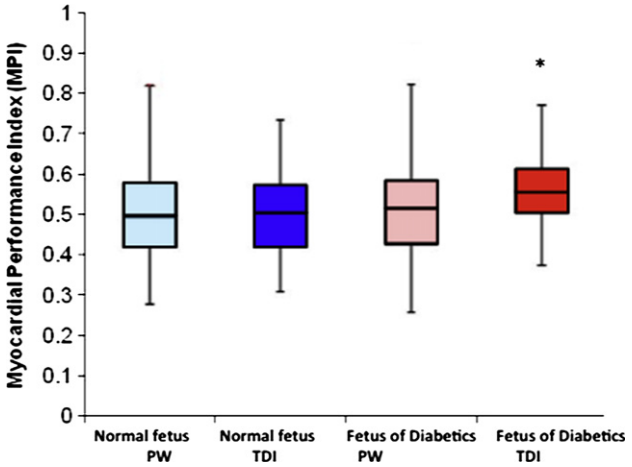

Figure 2 TDI versus spectral Doppler method for MPI assessment. Comparison of DTI method to spectral Doppler (PW) for determining MPI in normal fetuses and fetuses of mothers with DM. *Horizontal bars* represent medians, *boxes* show upper and lower quartiles, and whiskers show 1.5 × interquartile range. *P < .001 for comparison of the two different methods within the same DM fetuses.

were the same in normal fetuses (i.e., resulted in the same absolute number for the index) but not in fetuses with subtle disease (diastolic dysfunction previously shown to be prevalent in fetuses of mothers with DM even in the absence of hypertrophy[20] and as demonstrated by abnormalities in tissue Doppler indices (E/E′) in the present study group.) In the disease state, the DTI MPI was significantly higher than spectral Doppler MPI within the same fetus. Furthermore, DTI MPI is more sensitive than spectral Doppler MPI for distinguishing subtle differences in myocardial performance in midgestation fetuses of mothers with pregestational DM.

Although the mean values and distributions of MPI results for normal and DM fetuses were not identical, considerable overlap was apparent, and the ranges were wide, suggesting the possibility of limited application of the technique to fetuses with milder forms of disease. However, our Bland-Altman plots showed good intraobserver and interobserver agreement in the study. Therefore, use in assessing for abnormality or longitudinal assessment may be possible, and our results suggest that DTI may be a better technique for subtle abnormality detection. Of note, there was more variability in the disease group and when using spectral Doppler. We speculate that this may be reflective of both the inherent nature of the disease group and variability in the measurements themselves, and we thus suggest that further validation be done before application in routine clinical practice. The different values for MPI that we obtained by two methods in the diabetic population may reflect inherent differences in the Doppler sampling sites used to measure MPI. Pulsed-wave DTI relies on myocardial velocities, whereas spectral Doppler relies on blood flow velocity; thus, time-interval measurements using these different modalities may yield slightly different MPI values and may vary with afterload conditions. These different MPI values may be exaggerated in a disease state such as fetal exposure to maternal DM. Although individual components of isovolumetric time (isovolumetric relaxation and contraction) were not analyzed in the present study, given that MPI is derived from the ratio of ventricular isovolumetric time to ejection time, increased MPI may be reflective of increased isovolumetric relaxation time. This parameter could have different behaviors in both the right and left ventricles and in different phases of gestation in fetuses of

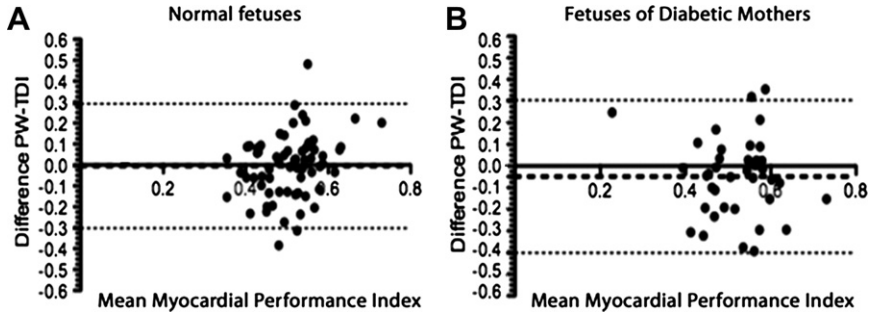

Figure 3 Bland-Altman analysis comparing methods. Comparison of differences in RV MPI measured by spectral Doppler (PW) and DTI methods in **(A)** normal fetuses and **(B)** fetuses of mothers with DM. The *heavy dashed line* represents the bias (difference between measurements.) The *small dashed lines* represent the 95% limits of agreement of the difference between repeated measurements (by spectral PW or DTI), indicated along the y axis. In normal fetuses, bias was −0.01 ± 0.15, and in DM fetuses, bias was −0.06 ± 0.18.

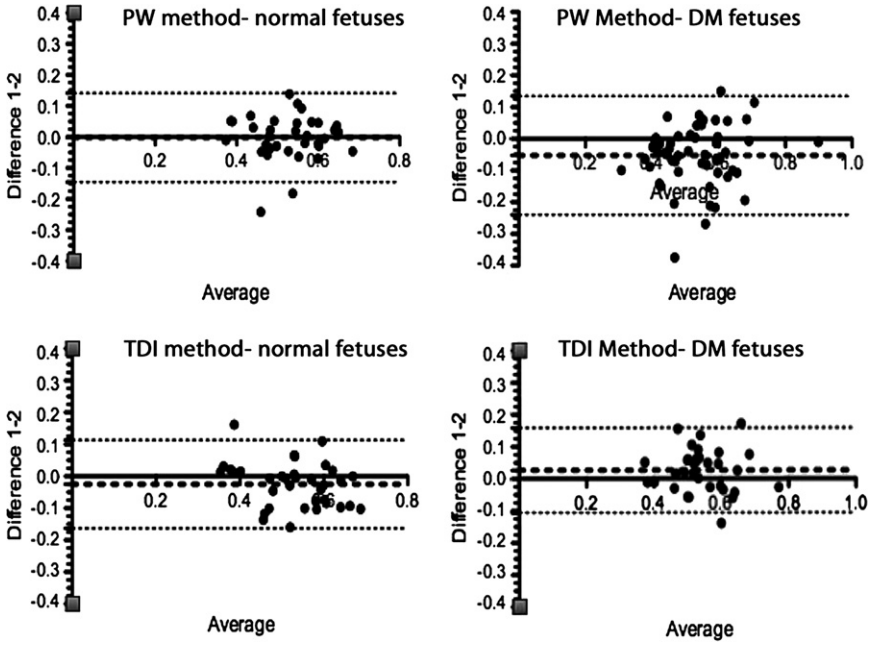

Figure 4 Bland-Altman analysis of intraobserver reproducibility. The y axis represents the difference between two observations by the same observer. The x axis represents the mean MPI of two repeated observations. The *heavy dashed line* represents the bias, and the *thin dashed lines* represent the 95% limits of agreement of the difference between repeated measurements 1 and 2, indicated along the y axis. On spectral Doppler (PW), in normal fetuses, bias was 0.00 ± 0.07, and in the DM group, bias was +0.05 ± 0.10. On DTI, in normal fetuses, bias was +0.01 ± 0.06, and in the DM group, bias was +0.03 ± 0.07. In the disease state, bias and limits of agreement were better when using the DTI method.

mothers with DM compared with control fetuses and deserves further study. Additionally, the dependence of the spectral Doppler method on heart rate and preload may also contribute to different measured MPI values when determined by DTI, which is less dependent on heart rate and preload. Altered ventricular compliance and proposed higher preload related to increased myocardial mass in fetuses of mothers with DM[24] may also contribute to these differences. Fetuses of mothers with DM have been shown to have diastolic tissue velocity augmentation by DTI, with increased systolic and diastolic myocardial velocities and decreased longitudinal cardiac function compared with normal fetuses.[25] Therefore, it is not surprising that the DTI method of deriving MPI, a measure of global (systolic and diastolic) function, would be able to demonstrate a difference between DM fetuses and normal controls that is not seen when using the spectral Doppler method.

Finding similar spectral Doppler MPI values in normal and DM fetuses in midgestation is consistent with the results reported by Russell *et al.*,[26] who demonstrated a similar lack of difference using the spectral Doppler method between DM fetuses and normal fetuses in the first and second trimesters. Because DTI RV MPI measurements were not included in their study, it is unknown whether they would have also documented a difference in MPI using the DTI method. Our study is the first to directly compare the sensitivity of two methods via paired analysis within the same fetus and demonstrates that DTI may be more sensitive than spectral Doppler in distinguishing fetuses with early subtle functional abnormalities. Identification of fetuses early in gestation with subtle alterations in myocardial performance may be helpful in assessing fetal health.

Previous smaller studies of more heterogenous populations have demonstrated variable success in using spectral Doppler and DTI

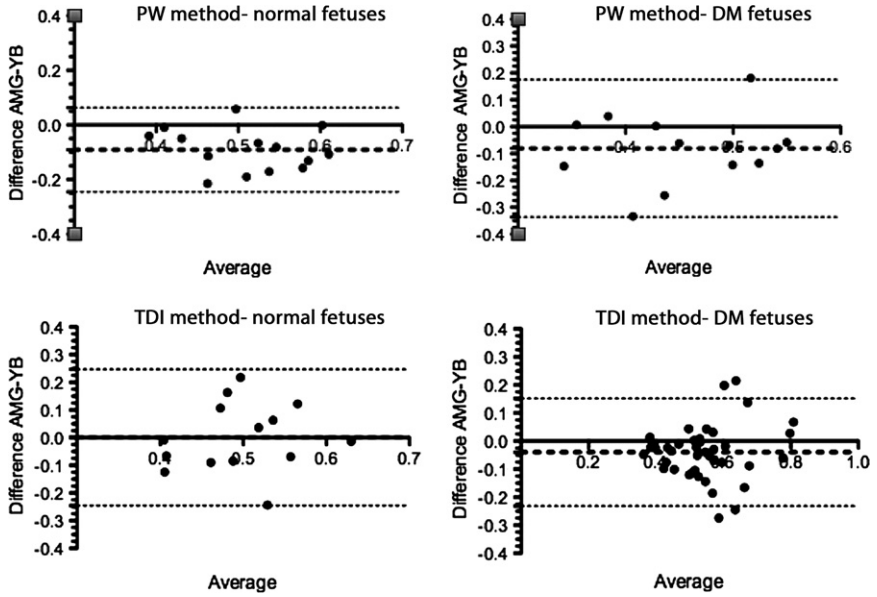

Figure 5 Bland-Altman analysis of interobserver reproducibility. The y axis represents the difference between observations made by two different observers. The x axis represents the mean MPI of two repeated observations. The *heavy dashed line* represents the bias, and the *thin dashed lines* represent the 95% limits of agreement of the difference between repeated measurements (by two observers, Y.B. and A.M.G.) indicated along the y axis. On spectral Doppler (PW), in normal fetuses, bias was −0.09 ± 0.08, and in the DM group, bias was −0.08 ± 0.13. On DTI, in normal fetuses, bias was +0.00 ± 0.13, and in the DM group, bias was −0.04 ± 0.10. In the disease state, bias and limits of agreement were better when using the DTI method.

RV MPI for evaluating fetal cardiac function. Acharya *et al.*[27] retrospectively evaluated a diverse fetal population ranging from 18 to 41 weeks, included both normal fetuses and those with structural heart disease, and found poor agreement and precision between the two methods. This may have been due in part to the inclusion of both normal and disease fetuses in the same analysis, given that our results show that the tests behave differently in the two groups. Conversely, Duan *et al.*[19] reported agreement between both methods for RV MPI, but in later gestation fetuses (aged 24–39 weeks; average, 29 ± 4 weeks). Their mean value for MPI was estimated from a heterogeneous group of fetuses with multiple gestation, maternal hypertension, or DM compiled together with normal fetuses.

This study had several limitations to consider. Whereas both spectral Doppler and DTI left ventricular MPI have been shown to correlate with invasive measurements of left ventricular function in adults,[28] correlative studies have not been demonstrated for RV function in adults and children. Furthermore, there is a lack of a gold standard to compare the noninvasive measurements of the right ventricle in assessing fetal cardiac function. Our study began with an a priori assumption that our study population of fetuses of mothers with DM would show subtle differences, as previously suggested, and was powered to detect the expected difference in MPI.[18,25,26,29] We further provide additional characterization of our study groups by demonstrating the expected differences in peak velocities and ratios of E/E′ between groups that have been previously shown by others and that suggest that diastolic function abnormalities can exist in this population even in the absence of myocardial hypertorphy.[20] Of note, our study also confirmed a trend toward increases in E′ and A′, though it was not adequately powered to detect statistically significant difference in these values for peak myocardial velocities (which have been shown in prior studies to be increased in fetuses of mothers with DM). The differences in MPI RV DTI between normal and diabetic mothers was small but statistically significant; whether the difference is clinically significant is unclear. Follow-up data on this cohort of otherwise normal fetuses in our retrospective review were not available. However, our aim was not to determine whether fetuses of mothers with DM have abnormal function. Rather, we sought to evaluate which method of MPI is more sensitive and thus better able to identify a population with very subtle measurement differences. Our study was powered to detect an 8% difference in MPI (by either method) between the normal and DM fetuses and thus may not have had adequate power to detect a very small difference in MPI assessment methods themselves in the normal population. This seems unlikely, however, given the degree of agreement between the two methods in our normal fetuses and the good intraobserver and interobserver agreement in the study. The control group was obtained from an initially increased-risk population with family history of congenital heart disease in first-degree, second-degree, or third-degree relatives of the fetus. Although a familial predisposition to structural heart disease could have biased our results, all the included fetuses had no known extracardiac abnormalities and had no structural cardiac abnormalities detected at the time of our examinations. We therefore chose to include this population as our normal population rather than other groups of patients typically referred to our program, such as those with increased nuchal translucency, abnormal serum screen results, use of assisted reproductive technology, or histories of teratogen exposure (all of whom were excluded). Finally, somewhat higher values of MPI were observed in our study than have been previously published, likely because of the method used and our measurement of ejection time exclusive of valve clicks on the Doppler trace (which would shorten the measured ejection time and lengthen the measured isovolumic time). Our reported higher MPI values are similar to those reported for fetuses of gestational age 24 to 41 weeks reported by Comas *et al.*,[30] using the same valve-click method. Although some have reported differing values throughout gestation, others have not.[30] The observation that systematic technical variations in measurements among institutions may complicate interpretation of results highlights the

previously proposed need to establish laboratory-specific measures when determining MPI in fetuses.[31]

MPI derived by pulsed-wave DTI may be a promising tool for detecting early subtle differences in myocardial performance. Previous studies have reported significant changes in spectral Doppler MPI with increasing gestational age, highlighting the importance of developing normal ranges throughout gestation. Similar data for various age groups are not yet available for DTI RV MPI. Others have begun to evaluate fetal RV function in other structural congenital heart disease using echocardiographic measures and have shown increased spectral Doppler RV MPI in hypoplastic left heart syndrome.[32] Our study demonstrates that RV MPI assessment by DTI can detect differences in a diabetic population; we hope to apply this new approach for the evaluation of RV function to other disease populations in which there might subtle abnormalities. Future studies assessing DTI MPI in a larger longitudinal series of other pathologic conditions with risk of cardiac failure (including fetuses with growth restriction, twin-twin transfusion syndrome, hydrops, and congenital heart disease) may identify altered myocardial performance earlier, which may further guide perinatal management.

CONCLUSIONS

We demonstrated that the measurement of RV MPI by pulsed-wave DTI is reproducible, and we report values for MPI by both DTI and spectral Doppler in normal fetuses and DM fetuses, showing that the measurement techniques are interchangeable in normal fetuses in midgestation. However, we demonstrated that in a disease state (fetuses of mothers with pregestational DM with diastolic functional abnormalities demonstrated by pulsed Doppler inflow and tissue velocity abnormalities), RV MPI measured by DTI is different from that measured by spectral Doppler. DTI MPI is a more sensitive test, able to differentiate a population with subtle myocardial changes, whereas spectral Doppler MPI does not show a difference between diabetic and normal groups. In addition, because Bland-Altman analysis of intraobserver and interobserver variability indicates that the DTI method has a smaller bias and standard deviation compared with spectral Doppler, MPI measurement of RV MPI by DTI is more sensitive and precise. DTI allows one to measure isovolumic intervals and the duration of ejection in a single beat, while spectral Doppler blood flow recordings of tricuspid and pulmonic flow cannot be made (using most instruments) in a simultaneous manner. It is likely that eliminating the possibility of heart rate–induced variability when making nonsimultaneous measurements results in less variability in MPI measurements. Furthermore, the pulsed-wave RV DTI method may provide better discrimination between normal and subtle disease states with abnormal cardiac performance, suggesting that it is an excellent alternative or may even be superior to the spectral Doppler MPI determination method.

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