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A modified myocardial performance (Tei) index based on the use of valve clicks improves reproducibility of fetal left cardiac function assessment

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KEYWORDS: agreement; fetal cardiac valves; fetus; left ventricular function; myocardial performance index; reproducibility

ABSTRACT

Objective *To determine whether a modified myocardial performance index (Mod-MPI) involving assessment of the movements (clicks) of the mitral valve (MV) and aortic valve (AV), improves intra- and interobserver agreement as compared to the previously reported method for MPI estimation.*

Methods *The Mod-MPI was recorded by two experienced operators in the left cardiac chambers of 25 normally grown fetuses using pulsed Doppler ultrasonography. The isovolumetric contraction time (ICT) was measured from the closure of the MV to the opening of the AV, the ejection time (ET) from the opening to the closure of the AV, and the isovolumetric relaxation time (IRT) from the closure of the AV to the opening of the MV. The Mod-MPI was calculated as (ICT + IRT)/ET. In addition, the MPI was estimated without using the valve clicks (F-MPI) as previously described. Intra- and interobserver agreement were then analyzed for both modalities.*

Results *There was a significantly lower intra- and interobserver variability in the estimation of all time periods with the Mod-MPI than with the F-MPI (ICT: intraobserver, 9.9% vs. 13.9%; interobserver 9.9% vs. 15.6%; IRT: intraobserver, 9.9% vs. 14.8%; interobserver 10.4% vs. 18.3%; and ET: intraobserver, 4.5% vs. 6.1%; interobserver 2.8% vs. 5.2%, respectively). Intraclass correlation coefficient (IntraCC) for the Mod-MPI was 0.8 (95% confidence interval (95% CI), 0.56–0.9) and for the F-MPI, the IntraCC was 0.62 (95% CI, 0.26–0.84);* $P = 0.01$. *Agreement between observers using the Mod-MPI showed a mean difference of 0.0 with 95% limits of agreement (LA) −0.09 (95% CI, −0.1 to −0.075) to 0.09 (95% CI, 0.075–0.1) and for the F-MPI the mean difference was −0.01 with 95% LA −0.26 (95% CI, −0.3 to −0.22) to 0.25 (95% CI, 0.21–0.29).*

Conclusion *Calculation of the Mod-MPI based on Doppler echoes of the MV and AV clicks is associated with a lower variation and better inter- and intraobserver agreement than the previously used method for fetal cardiac evaluation. Copyright © 2005 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

The myocardial performance index (MPI) was originally proposed by Tei *et al.* for adult cardiac evaluation in cases of dilated cardiomyopathy[1]. The original approach included the measurements of the isovolumetric and ejection times in two steps; the first time period (isovolumetric (a)) was calculated between the end of the A-wave and the beginning of the next E-wave during the ventricular filling phase, and the second period (b), the ejection time, was recorded in the aortic or pulmonary outflow tracts; the final MPI was then calculated as (a – b)/b.

Different researchers then proposed the MPI as a potentially useful method of estimating fetal cardiac adaptive changes in complicated pregnancies[2–4]. However, their results showed a wide variation in the normal reference values, probably owing to the lack of clear landmarks in the Doppler waveforms to calculate the time-periods. In order to overcome this problem, Friedman *et al.* suggested that the MPI in the left ventricle could be evaluated from a single Doppler waveform, with the advantage of individually estimating the isovolumetric contraction time

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(ICT) and the isovolumetric relaxation time (IRT)[5]. Their results showed no changes in the MPI with advancing gestation.

Recently, Raboisson *et al.* proposed a further modification of the approach proposed by Friedman using the Doppler echo of the opening of the aortic valve (AV) as a landmark to better estimate the limits between the time periods of the MPI calculation[6]. Based on this approach, we considered that the additional evaluation of the mitral valve (MV) might substantially increase the accuracy of all the measurements of the MPI, thus improving the reproducibility of the method. Therefore, we propose a modified MPI (Mod-MPI) that includes the Doppler echoes from the MV and the AV movements (clicks) as reference points to measure the different time-periods for the MPI calculation. This modified MPI is obtained by placing the Doppler sample volume on the medial wall of the ascending aorta including the AV and MV, hence the movements of both valves are recorded simultaneously in the Doppler spectrum.

The objective of this study was to estimate the intra- and interobserver agreement of this Mod-MPI in comparison with the approach suggested by Friedman *et al.* (F-MPI) for fetal cardiac evaluation[5].

METHODS

The left fetal cardiac function of 25 normal fetuses was prospectively evaluated by two experienced operators using the modified MPI (referred to as Mod-MPI) and the approach described by Friedman *et al.* (referred to as F-MPI)[5]. Median maternal age at enrolment was 26 (range, 18–32) years, and median gestational age 23 (range, 21–27) weeks.

Doppler recordings

For the gray-scale and Doppler studies, Siemens Sonoline Antares ultrasound equipment (Siemens Medical Systems, Malvern, PA, USA) with a 6–4-MHz curved array probe was used. All estimations were done in the absence of fetal corporal and respiratory movements and with the mother in voluntary suspended respiration. Special attention was given to the velocity of the Doppler sweep representation on the ultrasound screen using the highest

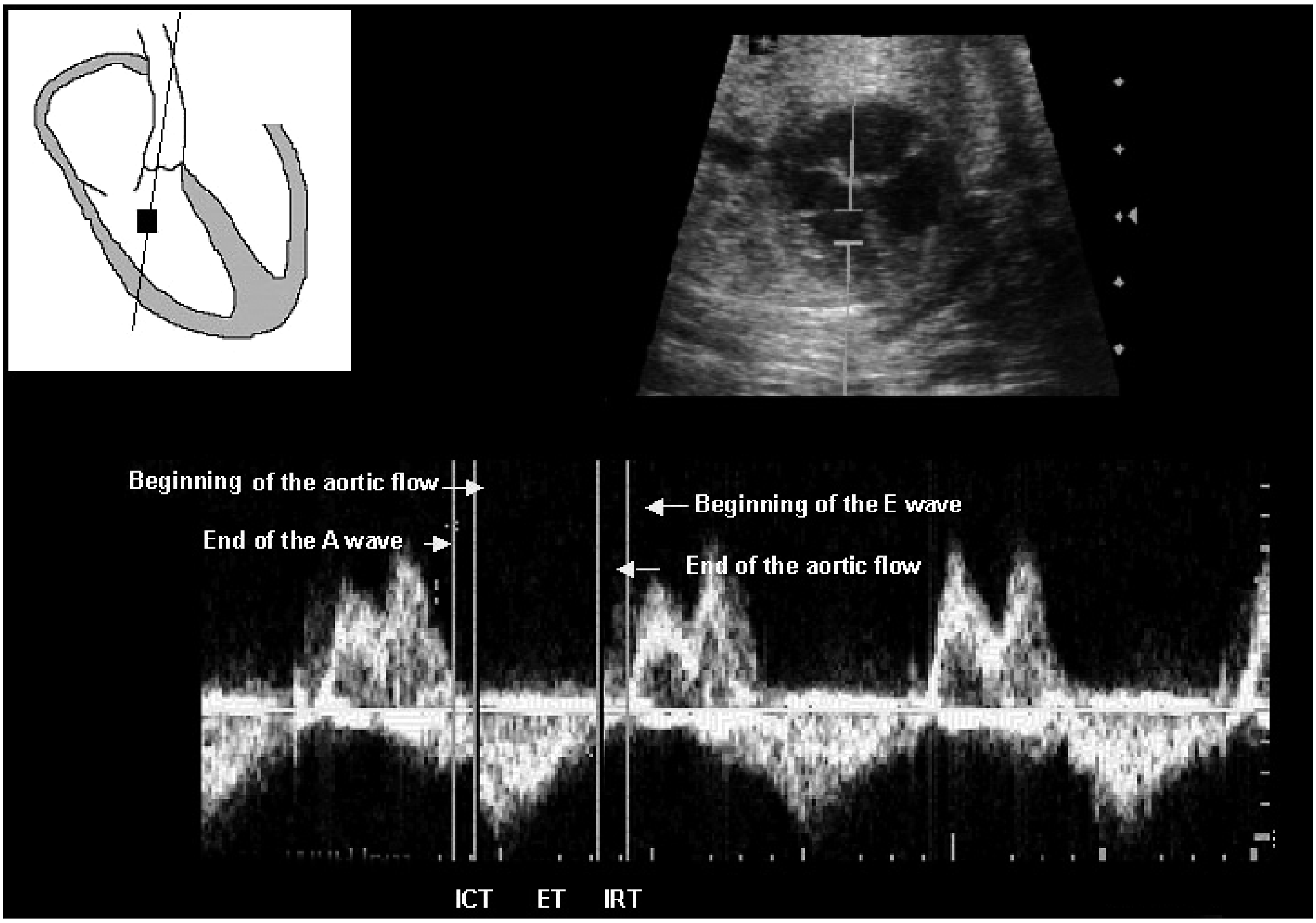


Figure 1 Doppler envelope of the myocardial performance index described by Friedman *et al.* (F-MPI)[5]. The sample volume is located in the left ventricle below the mitral valve. References for the time-period estimations were as follows: isovolumetric contraction time (ICT) from the end of the E/A waveform to the beginning of the aortic flow (AF), ejection time (ET) from the beginning to the end of the AF, and isovolumetric relaxation time (IRT), from the end of the AF to the beginning of the E/A waveform. The E/A waveform is always displayed as positive flow.

velocity available (15 cm/s) for clear identification of the components of the Doppler tracing. Additionally, the E/A waveform was always displayed as positive flow. The angle of insonation was always kept below 30° and the mechanical and thermal indices never exceeded 1. A cross-sectional image of the fetal thorax in the four-chamber view and an apical projection of the heart were obtained. For the F-MPI, the Doppler sample volume was placed below the MV towards the ventricular septum with the pulsed Doppler trace including the E/A waveform (positive) and the aortic (negative) blood flow waveforms. Three time-periods were then calculated: the isovolumetric contraction time (ICT) from the end of the E/A waveform to the beginning of the aortic flow (AF), the ejection time (ET) from the beginning to the end of the AF, and the isovolumetric relaxation time (IRT), from the end of the AF to the beginning of the E/A waveform (Figure 1).

For the Mod-MPI, using the above mentioned heart view, the Doppler sample volume was placed on the lateral wall of the ascending aorta, below the AV and just above the MV. The Doppler trace showed a clear echo corresponding to the opening and closure of the two valves at the beginning and at the end of the E/A (mitral valve) and AF (aortic valve) waveforms. The time-periods were then estimated as follows: the ICT was estimated from the closure of the MV, to the opening of the AV, the ET from the opening to the closure of the AV, and the IRT from the closure of the AV to the opening of the MV (Figure 2). The final value for the F-MPI and the Mod-MPI was calculated as: (ICT + IRT)/ET.

Reproducibility study

Each observer calculated the F-MPI and the Mod-MPI in the same fetus. For each variant of the MPI, two consecutive images were evaluated. For the first image, after the image had been frozen, the operator saved it without measurements (for agreement analysis), then made the measurements without seeing the results (a paper cover was placed in that part of the screen). For the second measurement, in order to estimate the elapsed time between calculations, the operator removed the probe from the maternal abdomen and started the process again. After finishing, the second operator followed the same sequence. Both operators were not present at the same time during the recordings.

Intraobserver repeatability was evaluated with the intraclass correlation coefficient (IntraCC) and 95% confidence interval (95% CI). For interobserver variability

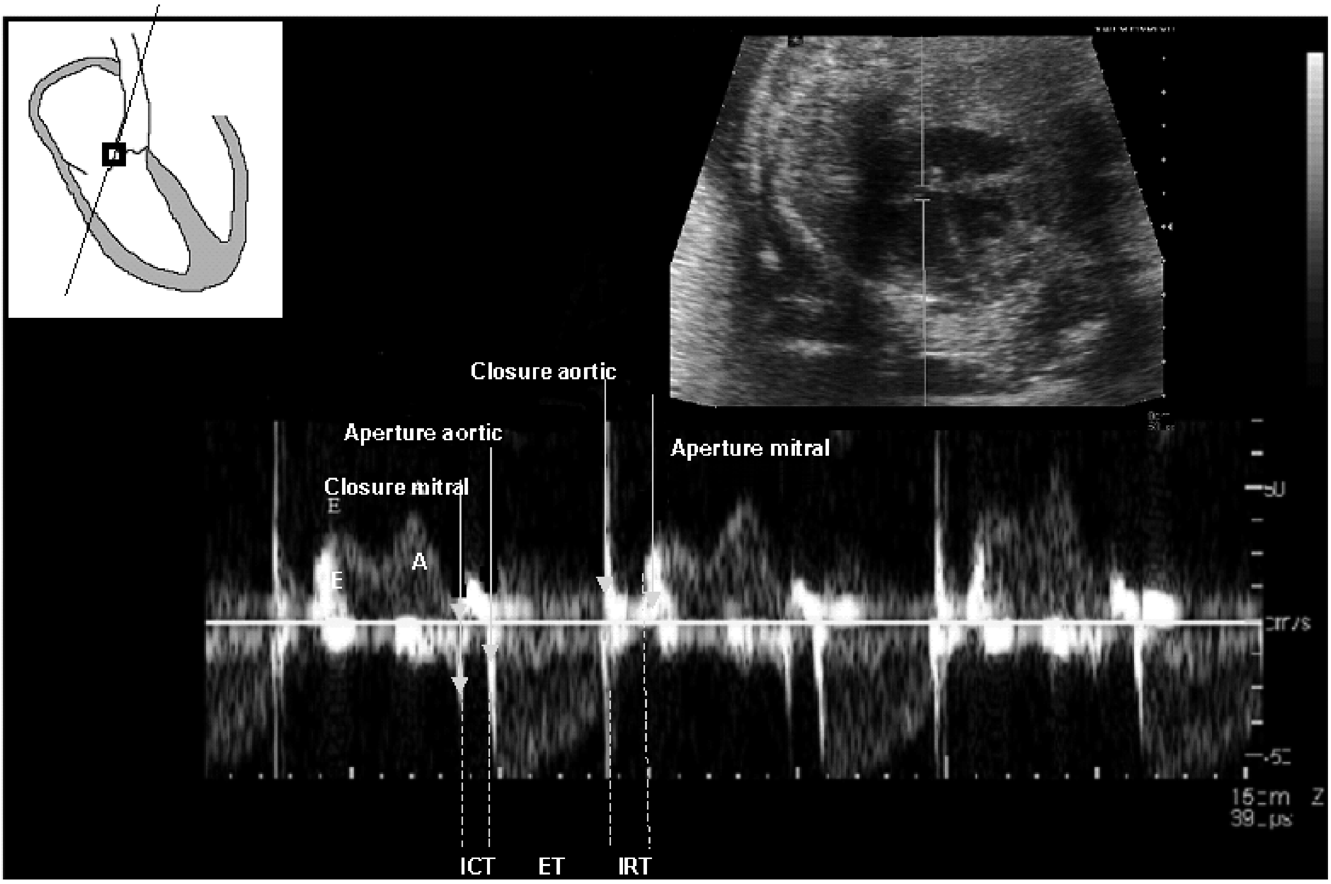
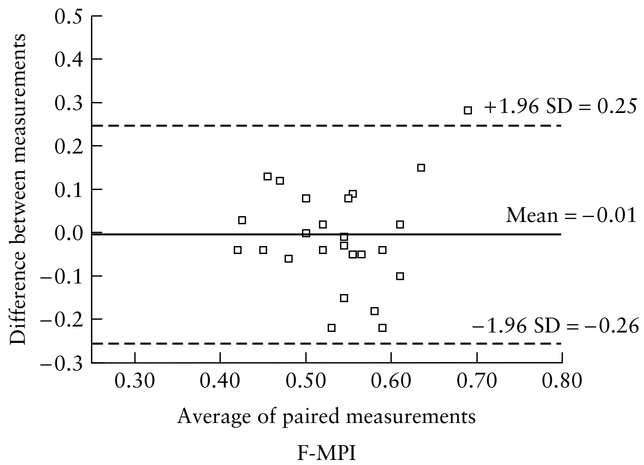


Figure 2 Doppler envelope of the modified myocardial performance index (Mod-MPI). The sample volume is located over the lateral wall of the aorta, close to the mitral valve. References for the time-period estimations are based on the echoes from the mitral and aortic valve movements. The E/A waveform is always displayed as positive flow. ET, ejection time; ICT, isovolumetric contraction time; IRT, isovolumetric relaxation time.

(agreement) 25 means from each observer were plotted and 95% limits of agreement (LA) with 95% CI were then calculated according to the method proposed by Bland and Altman[7]. For interobserver variability evaluating the same frozen image, 100 pairs were analyzed (50 images from Operator 1 later measured by Operator 2, and vice versa). The data were recorded in a purpose-designed database and analyzed with a Statview 5.0.1 (SAS Institute Inc, 1998 USA) statistical package.

RESULTS

The IntraCC for the Mod-MPI was 0.8 (95% CI, 0.56–0.9) and for the F-MPI the IntraCC was 0.62 (95% CI, 0.26–0.84), $P = 0.01$. Agreement between observers evaluating the same patient at different times showed normally distributed differences with a mean difference for the F-MPI of −0.01 (95% LA, −0.26 (95% CI, −0.3 to −0.22) to 0.25 (95% CI, 0.21–0.29)), and for the Mod-MPI: mean difference of: 0.0 (95% LA, −0.09 (95% CI, −0.1 to −0.075) to 0.09 (95% CI, 0.075–0.1)) (Figure 3). The interobserver variability measuring the same image



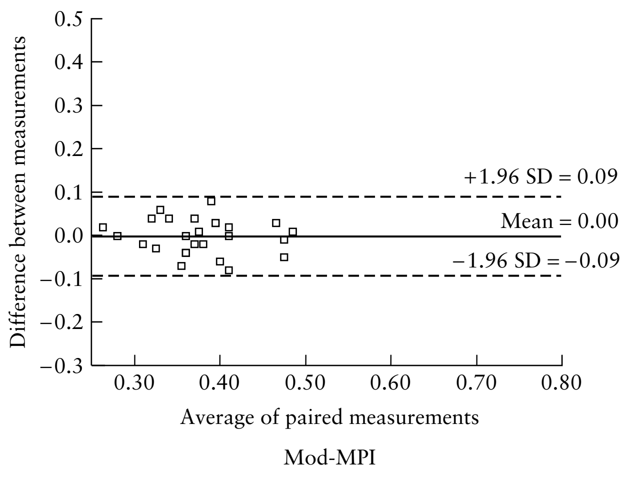


Figure 3 Plot of the differences between observers calculating the myocardial performance index as described by Friedman *et al.*[5] (F-MPI), and the modified myocardial performance indices (Mod-MPI) in the same subject. The mean of the differences and 95% limits of agreement are quoted.

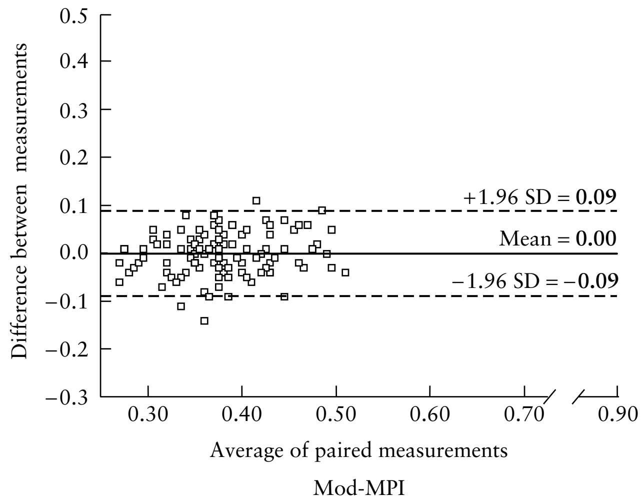


Figure 4 Plot of the differences between observers calculating the modified myocardial performance index (Mod-MPI) in the same image. The mean of the differences and 95% limits of agreement are quoted.

with the Mod-MPI was: mean difference of 0.00 (95% LA, −0.09 (95% CI, −0.098 to −0.082) to 0.09 (95% CI, 0.082–0.092)) (Figure 4).

Similar differences in agreement were observed in the estimation of the three time periods involved in the calculation of the Mod-MPI and F-MPI. There was a significantly lower intraobserver and interobserver variation with the Mod-MPI than with the F-MPI (Table 1). The mean time spent in obtaining and calculating the Mod-MPI was 110 (range, 35–235) seconds.

DISCUSSION

This study evaluated a modification of the fetal myocardial performance index that allows a more precise estimation of the periods measured for the calculation of the index. The results showed that calculation of the Mod-MPI periods delimitated by the Doppler echoes of the MV and AV had a lower variation, better reproducibility and improved interobserver agreement than the F-MPI.

The currently available literature contains a wide variation in reported reference MPI values for left fetal cardiac assessment. Falkensammer *et al.* reported a mean left fetal cardiac MPI of 0.41 that remained constant throughout pregnancy[3]. Conversely, Tsutsumi *et al.* described a gradual reduction in the left MPI with advancing gestation with normal values above 0.6, and Eidem *et al.* reported a normal left MPI value of 0.35 with no changes during gestation[2,4]. In addition, Huggon *et al.* reported a normal value of the left MPI of 0.38 in normal fetuses at 11–14 weeks of gestation[8]. A common factor for these studies is that they were all performed as originally described by Tei *et al.* using two recordings at different locations, one for the ventricular filling time, and one for the aortic ejection time[1]. The differences in the results may be related to various factors, including the

Table 1 Comparison of the intra- and interobserver variation in the measurement of each of the time-periods for the modified myocardial performance index (Mod-MPI) and the myocardial performance index estimated as described by Friedman *et al.*[5] (F-MPI)

	Isovolumetric contraction time		*Isovolumetric relaxation time*		*Ejection time*	
	F-MPI, mean (range) (%)	*Mod-MPI, mean (range) (%)*	*F-MPI, mean (range) (%)*	*Mod-MPI, mean (range) (%)*	*F-MPI, mean (range) (%)*	*Mod-MPI, mean (range) (%)*
Intraobserver variation	13.9 (0–40.8)	9.9 (0–35.4)*	14.8 (0–36.6)	9.9 (0–43)*	6.1 (0–22.3)	4.5 (0–17.1)*
Interobserver variation	15.6 (0–58.5)	9.9 (0–44.1)*	18.3 (0–52.8)	10.4 (0–40)*	5.2 (0–23.1)	2.8 (0–16.1)*

$^*P < 0.05$.

elapsed time between the two recordings, small variations in the fetal heart rate, displacements of the time-lines and the off-line analysis of taped images.

In the approach later suggested by Friedman *et al.* the main advantage was to measure the different MPI time-periods in the same Doppler trace, reducing the influence of the elapsed time between two separate recordings and the differences related to variations in the fetal heart rate[5]. However, despite the authors providing clear indications about measurements (from the beginning to the end of each waveform), in practice it is difficult to define the exact location of these points. Slow blood movements are recorded at the end and at the beginning of each waveform, rendering identification of the limits of the waveform difficult. In addition, if the Doppler wall-filter is raised to avoid these slow blood velocity movements, the end of the waveform is then missed.

According to our results, the recognition of the valve clicks in the Doppler envelope offered clear landmarks for more reproducible measurements. By definition, the isovolumetric period occurs when the semilunar and sigmoid valves are both closed, either at the end of diastole (ICT) or at the end of systole (IRT)[9]. At the end of the A-wave the movement of the MV gives a strong 'needle-shaped' echo easily recognizable in opposite direction to the A-waveform. As the aortic flow is a high-velocity flow, there is no elapsed time between the aperture of the AV and the blood flow envelope, nevertheless, the valve opening click is identified as a strong linear echo at the beginning of the aortic waveform. The opposite pattern is observed at the end of systole when the closure of the AV is easily identified as a 'needle-shaped' echo, and the aperture of the MV is registered together with the beginning of the E-wave. Using this approach the blood flow envelope is not crucial in estimating the time-periods. Hence, by lowering the Doppler gain, the echoes from the MV and AV can be more easily identified.

The inter- and intraobserver agreement was greatly improved using the Mod-MPI. Our results and mean MPI values are in accordance with those reported by Raboisson *et al.*, who also used the AV as the reference point for the time period measurements[6].

We explored different components of the Mod-MPI reproducibility. For the intraobserver analysis, the operator was blinded to his measurements, and to control selection bias, the operator could not exclude any measured image once it had been stored. The operator's technical ability and the time effect were assessed by repeating the complete process for the acquisition of the second image. In this study we used the fastest Doppler sweep in the ultrasound screen for the precise recognition of the boundaries of the valve clicks for calculation of the different time periods. With a slow sweep speed, the space between the echoes is reduced and the risk of measurement error increases. In our ultrasound equipment, the ICT, IRT and ET were estimated in milliseconds (ms). Using the fastest Doppler sweep (15 cm/s) the minimal displacement of the time-line corresponded to 2 ms. Thus, if the ICT was 28 ms, the minimal time-line movement can account for almost a 10% variation. Conversely, with a slow sweep speed (7.5 cm/s), the minimal displacement of the time-lines accounted for almost 4 ms. As an example, with an ICT of 35 ms, an IRT of 35 ms, and an ET of 150 ms, using the fastest Doppler sweep, the ICT and IRT measurements might vary from 33 to 37 ms, and the final MPI from 0.44 to 0.49. With a slow Doppler sweep the ICT and the IRT might vary from 31 to 39 ms and the final MPI from 0.41 to 0.52. This is of clinical relevance when the MPI is used to consider normal or abnormal fetal cardiac function.

The assessment of the right ventricular MPI needs two different anatomical planes to estimate the isovolumetric (tricuspid) and ejection (pulmonary) times with a time-period in between. Small differences in the fetal heart rate at the time of the recordings can alter the final MPI calculation, thus increasing the variability. Another drawback is that the individual ICT and IRT cannot be calculated. According to the information available in the literature, the IRT is the first to be affected when the heart function is impaired[10]. Tissue Doppler modalities can be applied to improve the estimation of the time-periods for the MPI calculation. Harada *et al.* applied pulsed tissue Doppler in the tricuspid valve ring, and were able to estimate both time-periods in the same Doppler waveform[11].

It cannot be assumed that the Mod-MPI can be an isolated parameter to estimate the fetal cardiac performance. It has several advantages as the individual calculation of the isovolumetric times. However, as an indirect marker of the diastolic and systolic function the Mod-MPI should be correlated with the established parameters of fetal heart function and with the newly emerging techniques such as tissue Doppler modalities[12,13].

The results of this study show that it is possible to apply the Mod-MPI in fetal cardiac assessment with reproducible results. Clinical applications of this new method should be further evaluated.

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