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Comparison study of harmonic imaging (HI) and fundamental imaging (FI) in fetal echocardiography

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Abstract: Objectives: To directly compare the quality of harmonic imaging (HI) and fundamental imaging (FI) in fetal echocardiography and to determine any differences in image quality between the two modalities. Methods: Fetal echocardiograms were performed with the use of FI and HI in 58 fetuses, image quality and visualization of left and right atria, left and right ventricles, mitral and tricuspid valves, aortic and pulmonary valves, left and right ventricular outflow tracts were evaluated and compared between FI and HI. Results: Mean HI scores were higher than mean FI scores (2.73 ± 0.43 vs 2.16 ± 0.69, $P < 0.001$)for all the cardiovascular structures evaluated. Compared with FI, HI improved the image quality and visualization of fetal cardiac structures in subjects with both good (2.73 ± 0.43 vs 2.88 ± 0.32, $P < 0.001$) and suboptimal (1.65 ± 0.41 vs 2.58 ± 0.47, $P < 0.001$) echocardiographic windows. The interobserver correlation coefficient for the grading scores was 0.74 ($P < 0.001$). Conclusions: harmonic imaging enhances and improves the image quality of fetal echocardiography; and has important potential role in cardiac imaging in the fetus.

Key words: Fetal echocardiography, Fundamental imaging (FI), Harmonic imaging (HI)
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INTRODUCTION

Harmonic imaging (HI) is one of the most important ultrasound imaging procedures developed recently, differing from fundamental imaging (FI) by transmitting ultrasound at one frequency and receiving it at two or more times the transmitted frequency. Clinical applications had documented that HI can enhance endocardial definition and improve imaging quality in adult subjects with limited transthoracic acoustic windows than FI (Thomas *et al.*, 1998; Kornbluth *et al.*, 1998; Yuan *et al.*, 1998). Fetal echocardiography is presently the definitive modality for commonly evaluating fetal cardiovascular structural morphology, fetal hemodynamics and fetal heart rhythms; and is playing a leading role in diagnosing congenital heart disease prenatally. Similar to transthoracic echocardiography in children and adults, the applications of fetal echocardiography also may be limited by poor acoustic windows. The use of HI in fetal echocardiography has not been previously evaluated. The purposes of the present clinical study were to directly compare the quality of HI and FI in fetal echocardiography and to determine any differences in image quality between the two modalities in fetuses of good acoustic and suboptimal windows.

MATERIALS AND METHODS

Study cohort

This group consisted of 58 consecutively pregnant women with gestation age of 16 – 41weeks (average 31.6 ± 6.4 weeks), 59 fetal echocardiograms were performed, one examination was follow-up. The referral reasons for fetal echocardiography were as follows: irregular fetal heart rhythm found by routine obstetrical ultrasound examinations, polyhydramnios, abnormal shape or size of fetal heart (abnormal 4 chamber-view), maternal history of pregnancy of fetus with congenital heart disease, maternal history of catching cold or taking medicines at the first trimester, maternal history of congenital heart disease, hereditary disease, metabolic diseases, and routine fetal echocardiographic screening.

Echocardiography

Two-dimensional echocardiography, M-mode, color M-mode and pulsed-wave Doppler were performed using GE LOGIQ 700 color Doppler flowing scanner. An M7c transducer with frequency of 4-7 MHz was used to obtain all routine fetal heart views including four-chamber view, long-axis view of left ventricle, short axis view of great vessels, aortic arch view, pulmonary artery-ductus arteriosis view and venous connections view.

All fetuses underwent both fundamental and harmonic imaging; the image quality of the mitral valve, tricuspid valve, aortic valve, pulmonary valve, left atria, right atria, left ventricle, right ventricle, left ventricular outflow tract and right ventricular outflow tract were evaluated.

Image analysis

The image quality of each cardiac structure was evaluated and graded on a scale of 1 to 3: 1 for poor image quality; 2 for fair image quality; 3 for good image quality (Kasprzak *et al.*, 1999) with fundamental and harmonic imaging by 2 independent, experienced echocardiographers. Each reviewer was blinded to the score of the other reviewer but not to the type of imaging modality.

Statistical analysis

Scores for the fundamental and harmonic images of each structure were averaged for the 2 reviewers, and the average scores were compared between fundamental and harmonic imaging with the Wilcoxon sighed rank test. The overall quality of the acoustic windows for fetal echocardiography for each study was evaluated and graded as either good or suboptimal. Interobserver agreement was assessed with the Spearman rank correlation coefficient. $P < 0.05$ was considered statistically significant.

RESULTS

Fifty-nine fetal echocardiograms were performed on 58 fetuses. One fetal echocardiogram was follow-up study. There were 54 fetuses with normal rhythms and normal cardiac structures, four with fetal arrhythmias, one with ventricular septal defect. The mean harmonic imaging scores were higher than the mean fundamental imaging for all the structures evaluated (Table 1). The image quality was considerably improved when harmonic imaging was used both in four-chamber view (Fig. 1) and in short-axis view of great vessels (Fig. 2).

Fig. 1 Comparision of fundamental imaging (A) and harmonic imaging (B) in a 4-chamber view in a fetus with suboptimal echocardio-graphic windows. The endocardium, ventricular septum, atrio-ventricular valves, left and right ventricular chambers are much better defined with harmonic imaging than with fundamental imaging

Fig. 2 Comparision of fundamental imaging (A) and harmonic imaging (B) in a short axis view of great vessels in a fetus with suboptimal echocardiographic windows. The aortic valves, pulmonary valves, pulmonary arteries, right ventricular outflow tract and left atrium are pretty better delineated with harmonic imaging than with fundamental imaging

Table 1 Comparison of FI and HI scores for all evaluated cardiac structures

$n = 59$	FI score	HI score	P
LA	2.20 ± 0.66	2.75 ± 0.40	< 0.001
RA	2.19 ± 0.66	2.75 ± 0.42	< 0.001
LV	2.22 ± 0.68	2.75 ± 0.39	< 0.001
RV	2.21 ± 0.38	2.76 ± 0.38	< 0.001
MV	2.20 ± 0.68	2.75 ± 0.41	< 0.001
TV	2.19 ± 0.68	2.75 ± 0.40	< 0.001
AV	2.14 ± 0.67	2.73 ± 0.46	< 0.001
PV	2.06 ± 0.74	2.64 ± 0.53	< 0.001
LVOT	2.11 ± 0.70	2.72 ± 0.44	< 0.001
RVOT	2.08 ± 0.74	2.64 ± 0.51	< 0.001

Data are presented as mean ± SD. FI, Fundamental image; HI, Harmonic image. LA, Left atrium; RA, Right atrium; LV, Left ventricle; RV, Right ventricle; MV, Mitral valve; TV, Tricuspid valve; AV, Aortic valve; PV, Pulmonary valve; LVOT, Left ventricular outflow tract; RVOT, Right ventricular outflow tract.

Twenty-eight fetuses had good echocardiographic windows and 31 had suboptimal acoustic windows. In either group of fetuses with good echocardiographic windows or group of fetuses with suboptimal echocardiographic windows, harmonic imaging improved visualization of the fetal cardiac structures than that obtained with fundamental imaging (Table 2 – Table 4). The interobserver correlation coefficient for the grading scores was 0.74 ($P < 0.001$).

Table 2 Comparison of FI and HI scores for fetuses with good acoustic windows

$n = 28$	FI score	HI score	P
LA	2.75 ± 0.40	2.88 ± 0.32	< 0.05
RA	2.75 ± 0.40	2.89 ± 0.31	< 0.05
LV	2.75 ± 0.40	2.89 ± 0.31	< 0.05
RV	2.75 ± 0.40	2.89 ± 0.31	< 0.05
MV	2.77 ± 0.40	2.89 ± 0.31	< 0.05
TV	2.75 ± 0.42	2.89 ± 0.31	< 0.05
AV	2.70 ± 0.44	2.89 ± 0.31	< 0.01
PV	2.66 ± 0.51	2.88 ± 0.32	< 0.01
RVOT	2.68 ± 0.48	2.88 ± 0.32	< 0.01
RVOT	2.68 ± 0.53	2.84 ± 0.36	< 0.01

Abbreviations as in Table 1.

Table 3 Comparison of FI and HI scores for fetuses with suboptimal echocardiographic windows

$n = 31$	FI score	HI score	P
LA	1.71 ± 0.42	2.65 ± 0.43	< 0.001
RA	1.69 ± 0.40	2.63 ± 0.46	< 0.001
LV	1.71 ± 0.42	2.63 ± 0.41	< 0.001
RV	1.69 ± 0.40	2.65 ± 0.39	< 0.001
MV	1.69 ± 0.42	2.61 ± 0.44	< 0.001
TV	1.68 ± 0.42	2.63 ± 0.43	< 0.001
AV	1.63 ± 0.39	2.58 ± 0.52	< 0.001
PV	1.52 ± 0.42	2.44 ± 0.59	< 0.001
LVOT	1.60 ± 0.40	2.58 ± 0.48	< 0.001
RVOT	1.53 ± 0.41	2.45 ± 0.55	< 0.001

Abbreviations as in Table 1.

Table 4 Comparison of FI and HI scores for fetuses withgood and suboptimal echocardiographic windows

	Suboptimal windows	Good windows	P
FI	1.65 ± 0.41*	2.73 ± 0.43†	< 0.001
HI	2.58 ± 0.47*	2.88 ± 0.32†	< 0.001

* $P < 0.001$; † $P < 0.001$

DISCUSSION

Fetal echocardiography is a commonly performed and valuable image modality used to diagnose fetal congenital cardiovascular malformations and fetal arrhythmias prenatally (Oberhansli *et al*., 2000). Similar to transthoracic echocardiography in children and adults, the applications of fetal echocardiography also may be limited by poor acoustic windows, such as with maternal obesity, abdominal wall scar tissue, hysteromyoma, hypamnios, placental hemangioma, fetal spine as well as gas in fetal digestive tract. This clinical study demonstrated that, compared with fundamental imaging, application of harmonic imaging improves image quality and visualization of cardiac structures in fetuses with either good or suboptimal echocardiographic windows. Similar improvement in cardiac visualization with the use of harmonic imaging compared with fundamental imaging in patients with limited echocardiographic windows had been well documented in investigations of adult subjects (Main *et al*., 1999). The following three important aspects may explain the mechanisms (Spencer *et al*., 1998). First, there is improvement in lateral resolution because the reflected harmonic beam width is smaller. Another important mechanism of improved imaging quality with harmonic imaging is reduction of clutter. Clutter in an ultrasound image is often due to the imaging of off-axis objects. It is generally accepted that a beam with high sidelobe content will cause more clutter to occur in an image because more of the energy is off-axis. The sidelobe level for a reflected beam decreases with increasing harmonic number. Because the sidelobe level is lower for harmonic imaging, there is less clutter in the harmonic image. Finally, it had been speculated that there is a gradual decrease in length of reflected pulses with increasing harmonic number, this leads to slight improvement in axial resolution as well as the harmonic image (Ward *et al.*, 1997). In pediatric and adults patients with poor echocardiographic windows, some other alternative cardiac imaging modalities such as transesophageal echocardiography (TEE), contrast echocardiography, magnetic resonance imaging (MRI) and cardiac catherterization are available (Rocchi *et al.*, 1999). However, the alternative cardiac imaging methods for fetuses are very much limited for various technical reasons and safety concerns, and therefore fetal echocardiography remains the commonest used and leading standard imaging method available now.

As denoted in some adult studies, we found some thin memberous structures such as atrioventricular and semilunar valves that appear thicker and hyperechogenic with harmonic imaging than with fundamental imaging.

The most important goal of any new imaging technology is to enhance diagnostic capability and diagnosis accuracy, therefore eventually to improve patient care and medication. Though the question of whether application of harmonic imaging improves diagnostic accuracy in fatal echocardiography is beyond the scope of this investigation. However, these questions remain important in the evaluation of the utility of new medical imaging technologies, so further clinical study is warranted.

The main limitation of this study is that we failed to blind the reviewers to the type of imaging modality because of overall changes in background contrast and gray scale observed with harmonic imaging; also, the focus mark of fundamental imaging is different from that of harmonic imaging. Another limitation is the grading scale system we used, which is subjective and only semiquantitative. However, the two reviewers have rich experience in fetal echocardiography and we averaged the scores of their assessment, so we believe this limitation has minor impact on our results.

CONCLUSIONS

Harmonic imaging enhances and improves the image quality of fetal echocardiography in fetuses with good and suboptimal acoustic windows. Harmonic imaging is a useful adjunct to fundamental imaging, and so has important potential application value in fetal echocardiography.

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