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The Use of a High Frequency Linear Transducer in the Assessment of Fetal Anatomy at the Routine 11 to 13 + 6-Week Scan among Chinese Population

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Abstract

Objectives: To determine if the use of high frequency linear transducer (HFLT) in addition to conventional curvilinear transducer (CCT) aids assessment of fetal cardiac and non-cardiac anatomy in the first trimester. Methods: Transabdominal CCT (4 - 8 MHz) followed by HFLT (9 MHz) was used to study prospectively the visualization rate of basic and optional anatomical structures according to international guidelines. McNemar and Chi-square test were used to compare correlated and independent proportions respectively. Postnatal outcomes were traced. Results: Comparing with CCT alone, additional use of HFLT did not improve the completion rate of basic anomaly screen (95.0% vs. 97.0%, $p = 0.5$) in the 101 women studied, but it improved the visualization rate of some optional structures including lens (57.4% vs. 73.3%), three-vessel view (3 VV) (17.8% vs. 48.5%), left ventricular outflow tract (17.8% vs. 51.5%), kidneys (8.9% vs. 47.5%), and umbilical artery (86.1% vs. 93.1%) (all $p < 0.05$). Favourable fetal position was associated with a better visualisation of four-chamber view and 3VV ($p < 0.05$). Conclusions: Our findings supported that the use of HFLT in addition to CCT does not improve the completion of basic anomaly screen, nor does it achieve a high visualisation rate of different cardiac views in the first trimester.

Keywords

Ultrasonography, First-Trimester, Transducter, Fetal, Anatomy

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1. Introduction

In the era of non-invasive prenatal testing (NIPT), all pregnant women should still be offered an ultrasound examination in the first trimester [1] with the benefits of early detection and exclusion of many major anomalies [2]-[4], some of which are either lethal or associated with severe handicap that may warrant the discussion of an earlier and safer termination of pregnancy with the pregnant women [5] [6]. Combining transvaginal approach with transabdominal sonography had increased the successful visualization rate of fetal anatomy from 72% to 86% [7]. However, the major challenge lies with the full visualization and examination of the fetal heart, which is achievable only in about 50% of cases, even with the additional use of transvaginal sonography without colour flow mapping [7]. Cultural preferences and misconception have also made transvaginal examination unacceptable to some women [8]. Transvaginal examination has also got a limitation of reduced flexibility in examining different scanning planes.

High radiofrequency is defined as 3 to 30 MHz [9], and linear transducer is one which transmits ultrasound beam in parallel orientation. In literature search, the first paper on the use of HFLT was published in 1981, reporting the use of HFLT in examining neonatal intracranial pathology [10]. HFLT have been used for the examination of smaller structures in radiology [11], internal medicine [12] and recently used more in obstetrics [13]-[16]. According to American Institute of Ultrasound in Medicine, a 3 - 5 mega Hertz (MHz) abdominal transducer will usually provide sufficient penetration while providing adequate resolution in most patients, however, in early pregnancy, HFLT with higher frequency like 5 MHz abdominal transducer may improve resolution while allowing adequate penetration [17]. Theoretically, the higher the frequency of a transducer is, the better the resolution of the sonographic images for superficial structures is. Besides, a linear transducer transmits ultrasound beam in parallel orientation, and thus provides reliable information throughout the insonated region. Nevertheless, a linear transducer offers a limited acoustic window and only minor adjustment of the width angle can be performed.

Early studies suggested that the use of a HFLT together with colour flow mapping allowed successful examination of fetal heart in 85% of patients [13], could be completed within an acceptable length of time [13], performed with high accuracy [14] [15] offered a high negative predicted value [13], and allowed differentiation of normal and abnormal cardiac findings in the first trimester [14]. However, a subsequent randomized trial showed that the use of a high-frequency (at 7.5 MHz) linear transducer alone without colour flow mapping did not improve visualization of cardiac anatomy [16], probably because of its limited penetration, given that the visibility of cardiac anatomy was inversely correlated with the transducer-heart distance [16].

We postulated that the use of a HFLT may help better examine fetal anatomy in the first trimester. The objective of the present study was to determine if the use of an abdominal HFLT in addition to a CCT can improve the visualization of fetal cardiac and non-cardiac anatomy at the 11 to 13 + 6 week scan in a low-risk population.

2. Materials and Methods

Women with low risk pregnancies were recruited for the study from 1st June, 2014 to 31st September, 2014 during their scheduled appointment for nuchal translucency measurement which was a part of our universal Down screening program, at a gestation of 11 - 13 + 6 weeks when early anomaly screening can be performed. Low risk pregnancies were defined as pregnancies without any risk factors after routine antenatal evaluation including clinical examination and investigations. Our hospital was a major public one in Hong Kong with around 6000 deliveries per year. The study had been approved by local ethics committee. Written informed consent had been obtained from the patients. Detailed maternal information including age, history of laparotomy, and history of bleeding in the current pregnancy were recorded.

All ultrasound examinations were performed by two experienced operators (KY and KO) in our maternal-fetal medicine team. The ultrasound machine used was Voluson E8 (GE Healthcare, USA); the CCT used was the 4 - 8 mm C4-8-D H48681AS (Wide band two-dimensional abdominal convex transducer, FOV 75˚/ wide 95˚ for E8 Expert, 2 - 8 MHz, GE healthcare, USA); and the HFLT used was 9L-D H40442LM (Wide band abdominal linear transducer, FOV 43.0 mm, 3 - 8 MHz, mid-range of 5.5 MHz, GE Healthcare, USA).

The Mechanical Index (MI) and Thermal Index (TI) were set not to exceed 1, and both were recorded to ensure that exposure did not exceed safety limit. Duration of ultrasound exposure was no more than 10 minutes [18] [19].

2.1. Sonography with a HFLT

There were two modes: a) linear mode, and b) virtual convex mode, with the ultrasound beam transmitted in parallel and divergent orientations respectively. A linear mode allowed transmission of a straight ultrasound beam and thus the acoustic window was limited with a width equal to the size of the transducer footprint [20]. The region of interest could be magnified, and the depth, but not the width angle, could be adjusted. The penetration was up to 8 cm, and the acoustic window 43 mm. Compared to a CCT, the images generated by a HFLT looked differently initially, but with time operators were accustomed to viewing them.

2.2. Examination of the Fetal Structures

All ultrasound examinations were performed via the transabdominal approach using a CCT followed by a HFLT. For the HFLT, a virtual convex mode was used for an overview, and a linear mode was then used to focus on the areas of interest with adjustments of the depth and magnification.

Both the basic and optional fetal anatomical structures were examined according to the guidelines of the Fetal Medicine Foundation, London and ISUOG (International Society of Ultrasound in Obstetrics and Gynaecology) for early anomaly scan before 13 + 6 weeks [2].

Recommended basic anatomical structures included:

1) Skull: cranial bones, neck.
2) Brain: midline falx, choroid-plexus filled ventricles.
3) Cardiac regular activity. Symmetrical lung fields, no effusion or masses.
4) Stomach: hypoechoic structure in the left upper abdomen.
5) Abdominal wall with normal cord insertion and no umbilical defects.

Optional anatomical structures included:

6) Orbit and lens.
7) Facial profile: nasal bone, normal profile/mandible, intact lips.
8) Spine: vertebrae (longitudinal and axial), intact overlying skin.
9) Heart: Four chambers view: four symmetrical chambers, three-vessel view: visualization of the cross-sectional view of the pulmonary artery, aorta and superior vena cava, left outflow tract.
10) Kidneys: hyperechoic structure.
11) Bladder: hypoechoic structure in fetal pelvis.
12) The three-vessel cord.
13) Extremities: four limbs each with three segments, hands and feet with normal orientation.

The accuracy of all sonographic diagnoses at the early anatomy screening was ascertained by correlation with results from the subsequent mid-trimester anomaly scan and postnatal findings.

The main outcome measure was the completion rate of basic anatomy screen. We also assessed the rate of successful visualization of individual basic and optional structures (as above).

2.3. Statistical Analysis

Statistical analysis was performed using IBM Statistical Package for the Social Sciences, version 22.0 (SPSS Inc., Chicago [IL], US). Differences in two independent and correlated proportions were analyzed with Pearson Chi-Square test and McNemar's test respectively. Logistic regression was used to examine the contribution of different factors (including CRL, fetal position and BMI) on successful visualization of fetal anatomy. P value < 0.05 was considered to be significant.

In a previous study, compared with transabdominal approach alone, a combined usage of both the transabdominal approach and the transvaginal approach improved the successful visualization of fetal anatomy at 11 - 14 weeks from 72% to 86% [7]. We postulated that the benefits offered by a transabdominal HFLT would be similar to the transvaginal approach. With a type I error of 0.5 and power 0.8, a sample size of at least 95 was required for the current study.

3. Results

A total of 101 Chinese pregnant women participated in the study. The age of women ranged from 22 to 39 (median 31) (**Table 1**). Eleven patients (10.9%) had a BMI of more than or equal to 25, 22 patients (21.8%) aged 35

Table 1. Characteristics of pregnancies assessed by the routine 11 - 13 + 6 week ultrasound scan.

Characteristics	Median (range) or n (%)
Maternal age	31 (22 - 39)
Age ≥ 35	22 (21.8%)
Gestational age (weeks + days)	12 + 3 (11 + 2 to 13 + 5)
Crown rump length	62.3 (46.3 - 80.3)
CRL (45 - 64 mm)	68 (67.3%)
CRL (65 - 82 mm)	33 (32.7%)
Nuchal translucency	1.7 (0.93 - 2.84)
Body mass index ≥ 25	11 (10.9%)
Gravida	
1	43 (42.6%)
2	43 (42.6%)
3	15 (14.9%)
Parity	
0	59 (58.4%)
1	39 (38.6%)
2	3 (3.0%)
Unfavourable fetal position	6 (5.9%)

or above, and 43 (42.6%) patients were primigravida. Ultrasound examinations were performed between 11 + 2 weeks and 13 + 5 weeks' gestation, with a fetal CRL of 46.3 - 80.3 (median, 62.3) mm. Sixty-eight fetuses (67.3%) belonged to Group 1 with CRL of 45 - 64 mm. Six (5.9%) of the fetuses remained in unfavourable or deep position for morphology screening during the examinations (**Table 1**). During subsequent mid-trimester anomaly examinations, normal anatomical structures were found in all except two scans, with one of them showing mild renal dilatation, and the other displaying a small renal cyst in the fetus. At birth, no significant congenital abnormalities were found.

3.1. Visualization of Fetal Anatomical Structures According to CRL

Using a combination of the HFLT and the CCT, a full examination of the fetal basic anatomy was achieved in 98 (97.0%) of the fetuses (**Table 2**). There were no significant differences in percentages of successful visualization of basic anatomy screen or all individual fetal structures between Group 1 (CRL of 45 - 64 mm) and Group 2 (CRL of 65 - 82 mm) except for facial profile.

3.2. Visualization of Fetal Anatomical Structures with or without HFLT

The additional use of HFLT did not increase the successful completion rate of basic anatomical screen, but increased the successful visualisation rate of some optional anatomical structures including lens (57.4% vs. 73.3%, $p < 0.001$), three-vessel view (17.8% vs. 48.5%, $p < 0.001$), left ventricular outflow tract (17.8% vs. 51.5%, $p < 0.001$), umbilical artery (86.1% vs. 93.1%, $p = 0.016$) and kidneys (8.9% vs. 47.5%, $p < 0.001$) (**Table 3**) (**Figures 1-5**).

3.3. Factors Affecting Visualization of Fetal Heart

Compared to an unfavourable fetal position, a favourable one during examination was associated with a higher visualization rate of four chamber view (66.7% vs. 99.0%, $p < 0.001$), and three-vessel view of the fetal heart (51.6% vs. 0%, $p = 0.014$) (**Table 4**).

Table 2. Successful visualization (n (%)) of fetal anatomical structures according to crown-rump length (CRL).

	Total N = 101	CRL (45 - 64 mm) N = 68	CRL (65 - 82 mm) N = 33	p value
Skull/neck†	101 (100%)	68 (100%)	33 (100%)	Not applicable
Brain†	101 (100%)	68 (100%)	33 (100%)	Not applicable
Orbit	91 (90.1%)	63 (92.6%)	28 (84.8%)	0.218
Lens	74 (73.3%)	50 (73.5%)	24 (72.7%)	0.932
Facial profile	96 (95.0%)	67 (98.5%)	29 (87.9%)	0.021*
Spine	99 (98.0%)	67 (98.5%)	32 (97.0%)	0.598
Four chambers view/chest†	98 (97.0%)	66 (97.1%)	32 (97.0%)	0.980
Three-vessel view	49 (48.5%)	32 (47.1%)	17 (51.5%)	0.674
Left ventricular outflow tract	52 (51.5%)	32 (47.1%)	20 (60.6%)	0.201
Stomach†	101 (100%)	68 (100%)	33 (100%)	Not applicable
Abdominal wall†	101 (100%)	68 (100%)	33 (100%)	Not applicable
Umbilical artery	94 (93.1%)	63 (92.6%)	31 (93.9%)	0.810
Kidneys	48 (47.5%)	29 (42.6%)	19 (57.6%)	0.159
Urinary bladder	100 (99.0%)	67 (98.5%)	33 (100%)	0.484
Extremities†	100 (99.0%)	68 (100%)	32 (97.0%)	0.149
Anatomy check†	98 (97.0%)	66 (97.1%)	32 (97.0%)	0.500

*statistically significant ($p < 0.05$). †anatomy check according to ISUOG guidelines in first trimester scan [2].

Table 3. Comparison of successful visualization (n (%)) fetal anatomical structures after addition of high frequency linear transducer (HFLT) to conventional currvilinear transducer (CCT).

	CCT	CCT_HFLT	P-value
Skull/neck†	101 (100%)	Not applicable	Not applicable
Brain†	101 (100%)	Not applicable	Not applicable
Orbit	88 (87.1%)	91 (90.1%)	0.250
Lens	58 (57.4%)	74 (73.3%)	<0.001*
Facial profile	96 (95.0%)	96 (95.0%)	1.0
Spine	99 (98.0%)	99 (98.0%)	1.0
Four chambers view/chest†	96 (95.0%)	98 (97.0%)	0.500
Three-vessel view	18 (17.8%)	49 (48.5%)	<0.001*
Left ventricular outflow tract	18 (17.8%)	52 (51.5%)	<0.001*
Stomach†	101 (100%)	Not applicable	Not applicable
Abdominal wall†	101 (100%)	Not applicable	Not applicable
Umbilical artery	87 (86.1%)	94 (93.1%)	0.016*
Kidneys	9 (8.9%)	48 (47.5%)	<0.001*
Urinary bladder	100 (99.0%)	100 (99.0%)	1.0
Extremities†	100 (99.0%)	100 (99.0%)	1.0
Anatomy check†	96 (95.0%)	98 (97.0%)	0.500

*statistically significant ($p < 0.05$), McNemar test. †basic anatomy check according to ISUOG guidelines in first trimester scan [2].

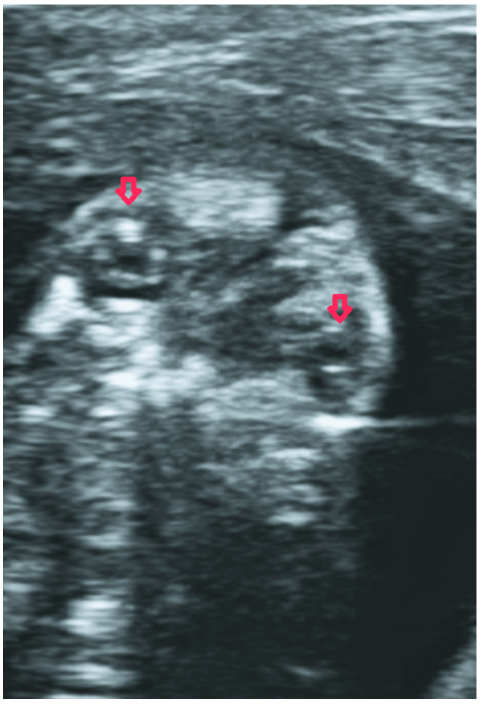

Figure 1. Transverse ultrasound image obtained using a high frequency transabdominal linear transducer showing two orbits and lens (arrows) at 12 weeks' gestation.

Figure 2. Transverse ultrasound image obtained using a high frequency transabdominal linear transducer showing three-vessel view [pulmonary artery (PA), aorta (Ao) and superior vena cava (SVC)] at 13 weeks' gestation.

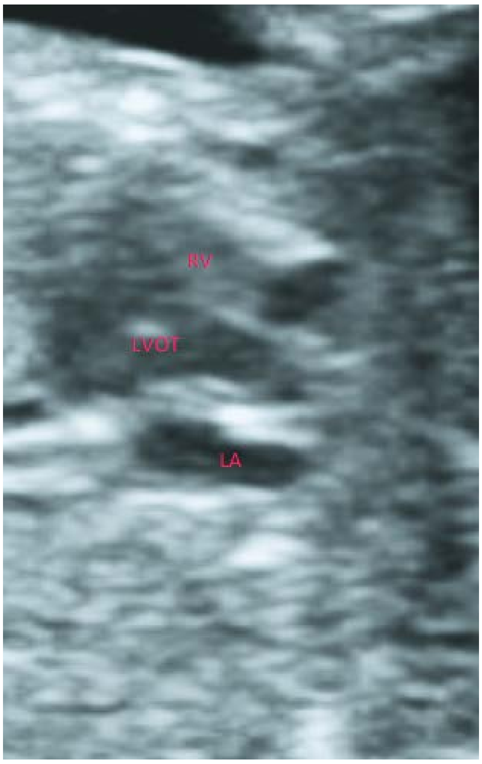

Figure 3. Oblique transverse ultrasound image obtained using a high frequency transabdominal linear transducer showing left ventricular outflow tract (LVOT) between right ventricle (RV) and left atrium (LA) at 13 weeks' gestation.

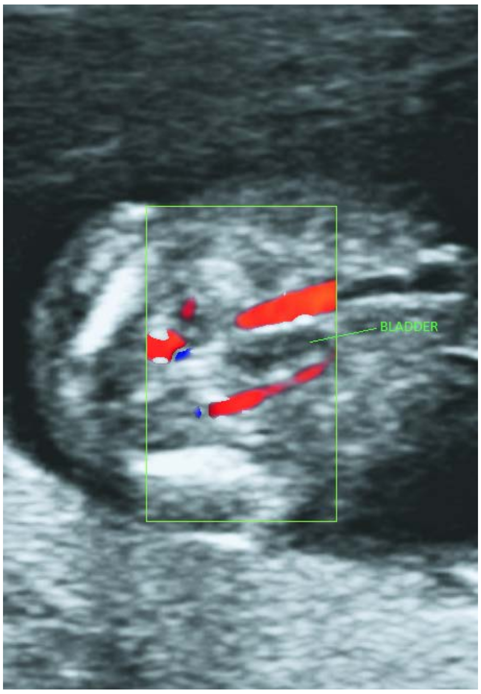

Figure 4. Transverse ultrasound image obtained using a high frequency transabdominal linear transducer showing two umbilical arteries with color flow (red) beside urinary bladder at 12 weeks' gestation.

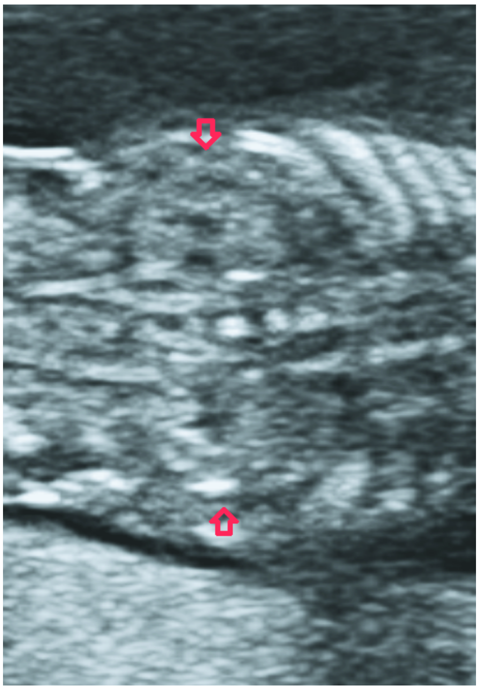

Figure 5. Coronal ultrasound image obtained using a high frequency transabdominal linear transducer showing two normal fetal kidneys (arrows) at 13 weeks' gestation.

Table 4. Succesful visualization (n (%)) of the four-chamber view, three-vessel view and left ventricular outflow tract of the fetal heart with respect to fetal position and body mass index (BMI).

	Four-chamber view	Three-vessel view	Left ventricular outflow tract
Favourable fetal position (N = 95)	94 (99.0%)	49 (51.6%)	50 (52.6%)
Unfavourable fetal position (N = 6)	4 (66.7%)	0 (0%)	2 (33.3%)
Chi-square test p-value	<0.001*	0.014*	0.359
BMI < 25 kg/m^2 (N = 90)	88 (97.8%)	44 (48.9%)	47 (52.2%)
BMI ≥25 kg/m^2 (N = 11)	10 (90.9%)	5 (45.5%)	5 (45.5%)
Chi-square test, p value	0.205	0.830	0.672

*statistically significant ($p < 0.05$).

There were no differences in the visualization rates of different cardiac views between low and high BMI (< and ≥25 kg/m^2) (**Table 4**).

4. Discussion

Our study showed that the additional use of a HFLT did not significantly increase the completion rate of basic anatomical screen basing on the ISUOG guidelines on first trimester scan [2] as the completion rate had already been achieved in 95% using a CCT alone, compared with 98% for the combined use of CCT and HFLT (p value = 0.500) (**Table 3**). Although the combined use of HFLT and CCT improved successful examination of some optional anatomical structures including lens, three-vessel view, left ventricular outflow tract, umbilical artery and kidneys, the final success rate of cardiac examination was just around 50% which was not high. Our findings on cardiac assessment was similar to a previous study by Votini *et al.* that using HFLT alone without colour flow mapping did not improve cardiac assessment [16]. Our result on success rate on cardiac assessment was also similar to the study by Ebrashy *et al.* that the fetal heart was not properly visualized in 42% using both transabdominal and transvaginal sonography without colour flow mapping [8]. On the other hand, our success rate was much lower than the figures of 84% - 98% reported by other studies on sonography with addition of colour flow mapping [13]-[15].

In a previous study [13], one major reason for failure of cardiac assessment in a HFLT examination is probably long transducer-object distance which can be caused by thick abdominal wall, anterior placenta, retroverted uterus or deep fetal position. In the present study, we found that unfavourable fetal position could be another contributing factor for failure to obtain the three-vessel view. According to our experience, visualization of the three-vessel view in the first trimester is facilitated by placing the transducer over the left anterior or right posterior part of the fetal chest so that the direction of the ultrasound beam is perpendicular to the courses of the two great vessels, and hence making use of the posterior enhancement effect given by the transonic areas of the three vessels. Our observation was consistent with the ultrasound image of the three-vessel view published in the article by Souka *et al.* [7] although the rationale was not stated there explicitly. When the fetal position remain unfavourable despite various manoeuvres, it is less easy to slide a linear transducer over the maternal abdomen without causing discomfort to the patient as compared to a curvilinear transducer, and thus limiting an ability to "look around the corner" [20].

In contrast to a previous study in 2004 [7], CRL in general did not affect the visualisation rate of various anatomical structures. Compared to Group 1 (CRL 45 - 64 m), the higher non-visualization of facial profile in Group 2 (CRL 65 - 82 mm) was probably due to the persistent prone position of the fetuses during examinations.

In clinical practice, when screening basic anatomy based on ISUOG guideline in the routine 11 - 13 + 6 week scan [2], using a CCT alone is probably good enough, and the addition of a HFLT gives no additional benefits. When examination of optional anatomical structures is required for medium or high risk group of fetuses, and it cannot be achieved by using a transabdominal CCT, the additional use of vaginal approach is preferred [7]. Using a transabdominal HFLT is an alternative if transvaginal approach is not accepted by the woman or does not give an optimal imaging. If early fetal echocardiography is required, adding colour flow mapping to 2D mode is preferred [16] to a HFLT examination as the benefits of the latter is likely to be small from the findings of a previous [16] and the present studies. Training [13] [14], and a longer examination time of more than 10 minutes [13] can improve the successful rate.

Although the sample size of the present study was small, it was powerful enough to demonstrate significant improvement in the visualization rate of some optional anatomical structures after using HFLT and exclude a moderate (14% as described in our sample size calculation) improvement in the completion of basic anatomical screen. Another limitation was that the present study did not explore the effect of HFLT on assessing congenital anomalies. Further studies are needed. Further studies are also required to investigate the usefulness of a HFLT with colour flow mapping to examine normal and abnormal fetal heart in high risk groups. In particular, whether "I-shaped" sign in the three vessel view which raises suspicion of cardiac anomaly, especially d-transposition of the great arteries, can be found in the first trimester as in the mid-trimester [21]. After the implementation of universal first trimester combined screening for Down syndrome, there is an increasing demand for earlier echocardiogram with more frequent detection of a thick nuchal translucency, tricuspid regurgitation or an abnormal ductus venosus flow pattern [4] [22]-[25].

5. Conclusion

In conclusion, our results supported that the use of HFLT in addition to CCT do not improve completion rate of basic anomaly screen in the first trimester. Although the combined approach can improve visualization of some optional structures, the visualisation rate of different cardiac views is probably not high. Our findings on cardiac assessment fit into the current knowledge that using HFLT alone without colour flow mapping do not improve cardiac assessment [16]. When examination of optional anatomical structures cannot be achieved by using a transabdominal CCT, using a transabdominal HFLT is an alternative if transvaginal approach is not accepted by the woman or does not give an optimal imaging.

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