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# Comparison of the reproducibility of 2D doppler and 3D STIC in the measurement of fetal cardiac output

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## ABSTRACT

**Objectives: Two methods have been described to assess fetal cardiac output (CO). It has usually been calculated by using 2D ultrasound to measure the diameter of outflow valves and Doppler ultrasound to measure flow velocity through the valves. Recently CO has been assessed using 3D spatio-temporal image correlation (STIC) to measure stroke volume. We aimed to compare the reproducibility of these techniques. Methods: In 27 women with singleton pregnancies, examinations were performed in three gestational age groups: 13 - 15, 19 - 21 and >30 weeks of gestation. Each mother was scanned once. Using 2D pulsed wave Doppler the duration of flow and average flow velocity in systole were measured through aortic and pulmonary valves. We averaged values from three consecutive Doppler complexes. The outlet valve diameters were measured and the cardiac output was calculated for each valve. The measurements were repeated to assess reproducibility. In the same women, we acquired STIC volumes of the fetal heart. The volume measurements were made using the 3D Slice method by one observer. Using 2 mm slices the circumference of the ventricles was traced at the end of systole and diastole to calculate ventricular volume before and after contractions to calculate stroke volume and hence cardiac output. The measurements were repeated to assess reproducibility. Results: The root mean square difference of log (CO) of repeat measurements ranged between 0.12 and 0.21 using Doppler compared to 0.7 to 1.47 using STIC. The differences in reproducibility reached statistical significance for both sides of the heart at all but one gestation. Conclusions: We found that Doppler assessment of fetal cardiac output was more reproducible than measurement using STIC.**

**Keywords:** Cardiac Output; Fetal; STIC; 2D Doppler; Ultrasound

## 1. INTRODUCTION

Fetal cardiac output has been measured by various techniques using both 2D Doppler [1-3] and 3D ultrasonography [3-11]. Cardiac outflow has been estimated by using Doppler ultrasound to measure the average flow velocity across the aortic and pulmonary valves and 2D ultrasound to measure the valve diameters [3].

After the advent of 3D ultrasonography, Hamill *et al* suggested it might have advantages over 2D assessment of cardiac output. Using a single acquired volume analysed with STIC (spatio-temporal image correlation) and VOCAL (virtual organ computer aided analysis) they assessed ventricular volume at end diastole and end-systole to calculate stroke volume. They felt that these volume assessments would be more accurate than using 2D methods such as multiplanar assessment and Simpson's rule. They felt it might also avoid the variability that occurs with 2D measurements due to small changes in measurement of valvular diameter having a large effect on calculated cardiac output [6].

Uitttenbogaard *et al* [10] recently described calculation of cardiac output using 3D spatio-temporal image correlation (STIC) to provide cross-sectional slices of the heart based on Simpson's rule [12]. They provided reference ranges of cardiac output from 12 weeks until term in a longitudinal study of 63 fetuses and argued that because of the potential for errors in conventional 2D Doppler assessment of cardiac output calculations from STIC volumes were likely to become the method of choice for assessment of fetal cardiac function. Their study did not compare their method with Doppler assessment in the same fetuses so we aimed to compare directly the reproducibility of these techniques from 13 weeks until term.

## 2. MATERIALS AND METHODS

This was a cross-sectional observation study of women undergoing normal singleton pregnancy taking part in a larger study of fetal cardiac function [13]. When women attended the ultrasound department for routine dating or anomaly scans they were invited to take part in the study by coming for an additional research scan. In 27 women with singleton pregnancies, examinations were performed in three gestational age groups: 13 to 15, 19 to 21 and more than 30 weeks of gestation. The scans were arranged so that each woman attended for a single assessment of fetal cardiac function. The study was approved by the local research ethics committee.

Two-dimensional fetal echocardiography was performed using a Toshiba Aplio ultrasound machine. Examination of blood flow was made by Doppler assessment of the duration and average flow velocity in systole through the aortic and pulmonary valves. In order to make the measurements, the Doppler gate was reduced to its minimum size (1 mm) and placed centrally just beyond the outlet valve. The valves 'clicks' are evident in the Doppler flow and help to define the opening and closing of the valves. The ultrasound probe was placed so that the beam was as near to parallel as possible with the direction of blood flow and the offset was always less than 30˚. The machine settings were used to correct for the angle of insonation if the beam was not truly parallel.

There is a single peak of flow through the aortic and pulmonary valves, during cardiac systole and we measured the average velocity of systolic flow and the length of the ejection time ($t_{syst}$) as shown in **Figure 1**. For each measurement we used the average values from three consecutive Doppler complexes.

To measure the outlet valve diameter, the ultrasound beam was placed perpendicular to the valve to define the vessel borders clearly and the diameter measured three times between the valve leaflets, with the average value used for the calculations. The cross-sectional area of the outlet valve was calculated from the average measured diameter.

The stroke volume was calculated as the time averaged velocity × output time × cross-sectional area of the outlet valve, and the cardiac output as the stroke volume × heart rate.

In the same women, we acquired STIC volumes of the fetal heart using a Voluson 730 (GE Medical Systems) ultrasound machine. The mean number of STIC volumes for each fetus was 5 with a range from 3 to 7. The STIC acquisition time was 7.5 seconds. A short acquisition time was used to limit degradation of the volumes due to fetal movement during capture. The volumes were stored and the clearest two analysed by one observer using the 3D Slice method described by Uittenbogaard with the GE post processing software [10]. We used multiple 2 mm slices (**Figure 2**) and calculated the volume by a sum of the areas traced each multiplied by the thickness (2 mm). The circumference of the ventricles was traced

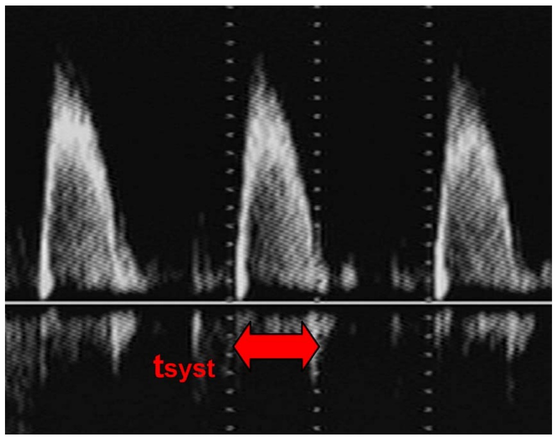


**Figure 1.** Doppler waveform of an outlet valve showing measurement of the length of the ejection time $t_{(syst)}$.

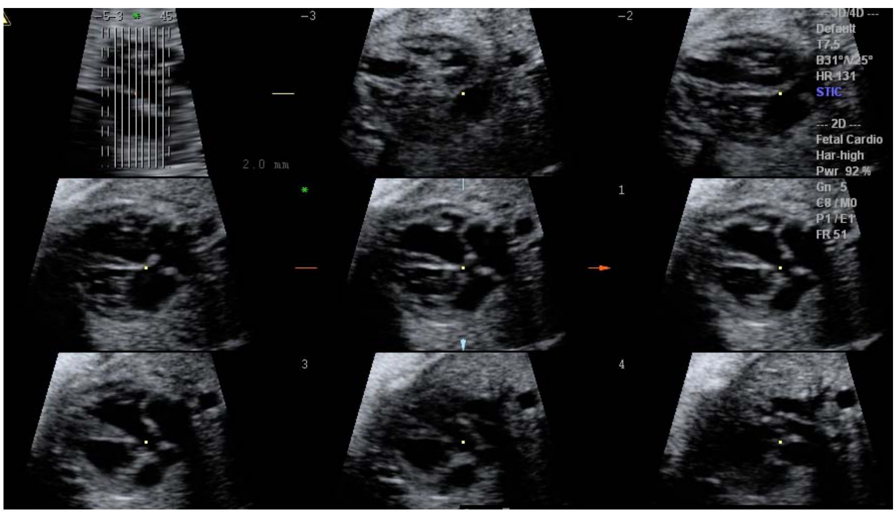


**Figure 2.** Images of 2 mm slices obtained from STIC volume.

 

at the end of systole (just before opening of the atrio-ventricular valves) and the end of diastole (just after closure of the atrio-ventricular valves) to calculate ventricular volume before and after contractions to calculate stroke volume and hence cardiac output. We followed Uittenbogaard's technique by tracing ventricular contours on the echogenic side of the endocardial border and considered papillary muscles to be part of the ventricular cavity. The measurements were repeated on a separately acquired STIC volume to assess reproducibility.

## 3. RESULTS

We included 10 women in the 13 week - 15 week gestational period, 8 women between 19 week - 21 weeks and 9 women after 30 weeks of gestation. All fetuses had biometric measurements within the normal range for gestation at the time of the scan. For each gestation and technique.

We calculated the root means square of the differences in repeat measurements and these are shown in **Table 1**. Using 2D echocardiography, the root mean square difference (rms) of log (cardiac output) across the gestational age group 13 to 15 weeks was 0.18 on the left and 0.17 on the right side. The rms across the 19 to 21 weeks group was 0.16 on the left and 0.21 on the right whereas the respective values in the >30 weeks gestation group were 0.12 and 0.14 using 2D echocardiography. Doppler measurements were achieved in 26 of the 27 fetuses examined.

The rms for the STIC method at 13 to 15 weeks was 0.70 for the left ventricle and 1.07 for the right. on the left and right sides in the 13 to 15 weeks gestation group, At 19 to 21 weeks it was 1.47 and 1.39 and at >30 weeks it was 0.62 and 0.9 for the left and right ventricles respectively. Volume measurements were not possible with STIC in 2 fetuses (8%), one in the 13 to 15 week gestational group and the other in the 19 to 21 week group as the clarity of the views in the captured volumes were suboptimal.

We found that Doppler assessment of fetal cardiac output was more reproducible than measurement using STIC as the rms values are much higher in the latter method. We demonstrated that this reached statistical significance ($p < 0.05$) in all but one of the gestation groups on both left and right sides of the heart (**Table 1**). Between 13 weeks - 15 weeks the probability approached statistical significance for the right side of the heart at the 5% level ($p = 0.08$) and achieved significance for left heart measurements.

## 4. DISCUSSION

Rizzo *et al.* determined the stroke volume of normal fetuses at 20 weeks - 22 weeks and 28 weeks - 32 weeks and growth restricted fetuses at 26 weeks - 34 weeks of gestation and reported that there is a good agreement between 2D Doppler and 4D STIC measurements. They obtained the outlet valve measurements between the open aortic and pulmonary valves. They calculated the time velocity integral by placing the Doppler gate distal to the outlet valve leaflets with an angle of insonation < 20 and used recordings from six consecutive waveforms.

They reported that the 4D STIC method was less operator dependent and was more time efficient than the 2D Doppler but they also noted that fetal movement and reduced amniotic fluid might affect the quality of the cardiac volume acquisition [3].

Uittenbogaard *et al.* [14] reported fetal cardiac volumetry in both *in-vivo* and *in-vitro* settings. They used the volume datasets from fetuses between 16 and 30 weeks of gestation and a miniature balloon model. Volume calculations were performed using the 3D Slice method and they reported that measurement errors in the fetus decreased with increasing operator experience and that the reliability was better for stroke volume than for ejection fraction. They noted that there was variation in measurement of the end-systolic and end-diastolic volumes which became more noticeable in calculating the ejection fraction as it included three volume measurements.

Measurement of the volume of the fetal cardiac ventricle has been described by Messing *et al.* [7] using 4D STIC combined with the inversion mode after 20 weeks of gestation. They used this to calculate stroke volume and ejection fraction and reported that their intra and

**Table 1.** Root mean square (rms) of repeat measurements of cardiac output in right and left ventricles assessed by 2D Doppler or 3D STIC.

| | Right ventricle | | | Left ventricle | | |
|---|---|---|---|---|---|---|
| Gestation | 2D Doppler (rms) | 3D STIC (rms) | probability (p value) | 2D Doppler (rms) | STIC (rms) | probability (p value) |
| 13-15 weeks (n = 10) | 0.17 | 1.07 | 0.083 | 0.18 | 0.7 | 0.003 |
| 19-21 weeks (n = 8) | 0.21 | 1.39 | 0.001 | 0.16 | 1.47 | 0.001 |
| >30 weeks (n = 9) | 0.14 | 0.9 | 0.000 | 0.12 | 0.62 | 0.000 |

 

interobserver agreement reached 96%. Their method was not suited to use in early gestation since it was not possible to use their method in fetal heart volumes under 20 weeks of gestation whereas fetuses >37 weeks of gestation posed different problems of unfavourable fetal position and relative oligohydramnios.

Molina *et al.* [8] have established reference intervals for stroke volume and cardiac output using the VOCAL technique in pregnancies at 12 weeks - 34 weeks of gestation. Their values for cardiac output were lower than previous reports which used 2D Doppler techniques. They also reported that the reproducibility of volume measurements is poor in the first trimester and in late gestation when the myocardium appears thicker. Similar techniques using VOCAL have been described by Simioni *et al.* [11] from 20 weeks - 34 weeks of gestation with the intra- and interobserver agreement reaching 95%.

Ventricular volume, stroke volume, cardiac output and ejection fraction have been evaluated from 19 to 42 weeks of gestation by Hamill *et al.* [6] with 4D ultrasound using both STIC and VOCAL techniques. They commented on the limitations of using a computer generated dataset, the learning curve involved and the significant amount of time needed to analyse the data.

When compared directly we found that cardiac output calculation by 2D Doppler was more reproducible than the 4D STIC slice method described by Uittenbogaard [10]. In the latter method, we found the volumes were difficult to acquire and analyse at early and late gestations for the same reasons mentioned in previous studies. Fetal movement artefacts affected measurements in early pregnancy (13 weeks - 15 weeks subgroup) and fetal position caused shadowing of the heart after 30 weeks. Uittenbogaard *et al.* [10] were only able to acquire STIC volumes in 71% of women attempted and they excluded fetuses examined after 30 weeks as they only had three technically acceptable datasets. In addition, the process was time consuming and accurate tracing of the ventricular borders was difficult introducing errors into calculation of stroke volume and hence cardiac output. Our data do not support their suggestion that their technique will become the method of choice for assessing fetal cardiac function.

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