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Doppler flow velocity waveforms in late first- and early second-trimester fetuses: reproducibility of waveform recordings

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ABSTRACT

The objective of the study was to assess the reproducibility of Doppler flow measurements of the fetal umbilical vein and artery, descending and ascending aorta, mitral and tricuspid valve, pulmonary artery, inferior vena cava and ductus venosus in early pregnancy.

In a cross-sectional study, Doppler measurements were obtained in a total of 54 women at 11–16 weeks of gestation, at 2–5 different vascular sites, on 3–5 different occasions, at 5-min time intervals. The total variance in the various flow velocity parameters was partitioned in a between-subject and within-subject component by analysis of variance, and, from these calculations, coefficients of variation in waveform recording were calculated.

Flow velocity waveform recording was characterized by coefficients of variation in the range 2.2–5.7% except for the acceleration time (18.6–24.5%) and percentage reverse flow (8.8%).

In conclusion, our data suggest that fetal flow velocity waveforms in early pregnancy demonstrate good reproducibility in the individual subject, while all parameters depict larger variabilities for between-subject values. Acceleration time turned out to be poorly reproducible. If a single flow velocity waveform measurement is used for the future evaluation of clinical conditions in early pregnancy, one has to consider that normal values will display a rather wide range.

INTRODUCTION

Transvaginal and transabdominal Doppler ultrasonography are non-invasive methods of studying early human fetal cardiac and extracardiac hemodynamics[1,2]. Flow velocity waveforms obtained from different vascular sites are influenced by various factors, such as preload, afterload (including arterial pressure and vascular resistance), heart rate and the intrinsic contractile properties of both cardiac ventricles. It was suggested that a relatively low vascular resistance is present at cerebral level compared to umbilical artery level in the late first-trimester fetus[2,3]. With the increasing use of Doppler techniques to assess early fetal hemodynamics, it is necessary to define the reproducibility of flow velocity waveform data in early pregnancy, especially since cardiovascular changes during this period could have a marked influence on consistency of flow velocity measurements[3].

The aim of the present study was to assess the reproducibility of Doppler flow measurements in early pregnancy with respect to within-subject and between-subject variance.

MATERIALS AND METHODS

Study subjects

A total of 54 women with a normal singleton pregnancy consented to participate in the study. The study protocol was approved by the Hospital Ethics Committee. Gestational age varied between 11 and 16 weeks and was determined from the last menstrual period confirmed by ultrasonic measurement of the crown–rump length or biparietal diameter. Women were selected into three subgroups, namely 11–12 weeks, 13–14 weeks and 15–16 weeks of gestation, to guarantee a homogeneous distribution of study subjects and to assess possible differences between these groups. Each woman was included in this cross-sectional study only once.

Recording technique

A combined real-time and pulsed Doppler system (Hitachi EUB-450, Hitachi Medical Corporation, Tokyo) was used with a carrier frequency of 3.5 MHz (Doppler mode and transabdominal real-time) and 6.5 MHz (transvaginal real-time). The system operates at

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power outputs of < 100 mW/cm^2 spatial peak temporal average in both imaging and Doppler modes by manufacturer's specifications. Energy output levels from the transvaginal Doppler transducer are clearly situated in the lower regions for acoustic output of Japanese and American diagnostic ultrasound equipment[4], determined by the fact that the fetus is closer to the transducer with the transvaginal approach than with the abdominal approach, and lower energy levels are required to detect it.

The high-pass filter was set at 100 Hz. Depending on fetal size and position, a transvaginal or transabdominal approach was chosen. Doppler studies were performed by one examiner (P. A. S.), whereas the data analysis was carried out by an independent investigator (T. W. A. H.), who was aware which recordings belonged to each subject. Nine fetal vascular sites were examined: the umbilical artery and vein, descending aorta, inferior vena cava, ductus venosus, mitral and tricuspid valve, pulmonary artery and ascending aorta. The total examination period was limited to 30 min. Recordings were performed with the women in the semi-recumbent position and during fetal apnea. Depending on fetal position and accessibility of vascular structures, Doppler measurements were obtained at 2–5 different sites, on 3–5 different occasions, at 5-min time intervals. Each recording consisted of 3–5 technically acceptable waveforms. Doppler sample volume length was 0.1–0.3 cm. The angle between the Doppler cursor and the assumed direction of blood flow was always kept below 30°. Both sample volume length and angle insonation were kept the same at each vascular site for each woman. Flow velocity waveforms in the umbilical artery were obtained from a free-floating loop of the umbilical cord. Umbilical vein Doppler measurements were taken from the intra-abdominal part close to the cord insertion. Flow velocity waveforms at atrioventricular valve level were documented from the four-chamber view, whilst recordings from the ascending aorta were obtained from the five-chamber view[5,6]. The pulmonary artery waveform was obtained from the echocardiographic short-axis view[5]. Flow velocity waveforms from the lower thoracic part of the fetal descending aorta were recorded from a sagittal cross-section through the fetal trunk that displayed a major section of the fetal spine. Flow velocity waveforms from the inferior vena cava were obtained in a sagittal view, which included the fetal right atrium and right ventricle[7]. The sample volume was positioned over the inferior vena cava immediately proximal to the right atrium with special regard to the assumed direction of blood flow. Finally, the ductus venosus waveform recording was documented from a transverse cross-sectional scanning plane of the fetal abdomen by placing the sample volume immediately above the umbilical sinus[8].

Data analysis

During each recording, at least three consecutive, optimal flow velocity waveforms were documented on hard copies. A microcomputer (Olivetti M24; Olivetti BV, Leiden, The Netherlands) linked to a graphics tablet was used for analysis of the Doppler recordings.

For all recorded waveforms, the time-averaged velocity was calculated. For the umbilical artery and descending aorta, the pulsatility index was determined[9]. Waveforms obtained in the descending aorta, inferior vena cava, ductus venosus, pulmonary artery and ascending aorta were also analyzed for the peak systolic velocity. In the latter two vessels, the acceleration time was also calculated. The peak systolic/diastolic ratio was determined in the inferior vena cava. Finally, at atrioventricular level, the E-wave and A-wave peak velocities and their ratios were calculated for both the mitral and tricuspid valves.

Statistical analysis

Total variance was partitioned into a between-subject and a within-subject component, assuming a random-effects model. The coefficient of variation in waveform recording was defined as the between-subject component or within-subject component as a percentage of the mean value. To test the homogeneity of variances in the subgroups, Cochran's C test was applied (maximum variance/sum (variances)).

RESULTS

Data are presented in Tables 1 and 2. In this early pregnancy period, success rates of Doppler recording varied for different vessels. Umbilical artery flow velocity waveforms were obtained in all 22 women studied, resulting in 88 recordings, whilst Doppler measurements in the pulmonary artery only succeeded in 16 out of 25 women studied, with 61 recordings as a result.

Since the test for homogeneity of variances demonstrated no significant differences in standard deviations between or within the subgroups 11–12, 13–14 or 15–16 weeks of gestation, all data from the 54 participating women were combined. Mean values for the different parameters at each vascular site are shown in Tables 1 and 2, together with the between-subject and within-subject standard deviation, calculated by taking the square root of the respective variance components.

Flow velocity waveform recording in early pregnancy was characterized for almost all studied parameters by within-subject coefficients of variation in the range 2.2–5.7%. Percentage reverse flow showed a slightly higher coefficient of variation compared with the other parameters (8.8%). Only the acceleration time as a parameter demonstrated significantly higher values: 24.5% and 18.6% for the pulmonary artery and ascending aorta, respectively.

DISCUSSION

Although Doppler studies are frequently used to describe fetal hemodynamics, it is surprising that very few studies

Table 1 Reproducibility data of Doppler velocity waveform recording at umbilical and extracardiac levels in 11–16-week-old normal fetuses

Vessel	*Women studied (n)*	*Successful recordings/waveforms obtained*	*Flow velocity parameter*	*Mean*	*Between-subject SD (coefficients of variation)*	*Within-subject SD (coefficients of variation)*	*Reliability (%)*
Umbilical vein	17	53/159	TAV	8.6	1.7 (19.8%)	0.3 (3.5%)	96.4
Umbilical artery	22	88/271	TAV	11.9	5.4 (45.4%)	0.6 (5.0%)	98.9
			PI	2.1	0.6 (28.6%)	0.08 (3.8%)	98.4
Descending aorta	21	83/252	TAV	16.6	6.4 (38.6%)	0.7 (4.2%)	98.8
			PI	2.3	0.5 (21.7%)	0.1 (4.3%)	96.4
			PSV	38.1	9.5 (24.9%)	0.9 (2.4%)	99.1
Inferior vena cava	17	65/199	TAV	12.3	3.9 (31.7%)	0.7 (5.7%)	96.8
			PSV	23.5	7.0 (29.8%)	0.7 (3.0%)	98.9
			peak S/D ratio	1.7	0.2 (11.8%)	0.09 (5.3%)	80.2
			% reverse flow	19.4	5.6 (28.9%)	1.7 (8.8%)	91.3
Ductus venosus	18	69/222	TAV	28.5	7.2 (25.3%)	1.0 (3.5%)	94.5
			PSV	37.2	8.3 (22.3%)	1.0 (2.7%)	98.5
			peak S/D ratio	1.2	0.06 (5.0%)	0.03 (2.5%)	79.3

TAV, time-averaged velocity; PSV, peak systolic velocity; PI, pulsatility index; S/D systolic/diastolic velocity; SD, standard deviation

Table 2 Reproducibility data of Doppler velocity waveform recording at atrioventricular and outflow tract levels in 11–16-week-old normal fetuses

Vessel	*Women studied (n)*	*Successful recordings/waveforms obtained*	*Flow velocity parameter*	*Mean*	*Between-subject SD (coefficients of variation)*	*Within-subject SD (coefficients of variation)*	*Reliability (%)*
Mitral valve	21	86/269	TAV	8.9	1.6 (18.0%)	0.5 (5.6%)	90.6
			E-wave	20.4	3.3 (16.2%)	1.0 (4.9%)	91.8
			A-wave	37.1	3.7 (10.0%)	0.9 (2.4%)	93.9
			E/A ratio	0.6	0.05 (8.3%)	0.02 (3.3%)	80.0
Tricuspid valve	23	94/286	TAV	9.6	1.6 (16.7%)	0.5 (5.2%)	90.5
			E-wave	23.0	3.7 (16.1%)	1.0 (4.3%)	93.4
			A-wave	40.9	4.6 (11.2%)	0.9 (2.2%)	96.6
			E/A ratio	0.6	0.05 (8.3%)	0.02 (3.3%)	79.3
Pulmonary artery	16	61/185	TAV	11.9	2.7 (22.7%)	0.6 (5.0%)	95.7
			PSV	34.4	7.2 (20.9%)	1.1 (3.2%)	97.5
			acceleration time	29.4	12.3 (41.8%)	7.2 (24.5%)	74.8
Ascending aorta	17	71/217	TAV	13.6	2.2 (16.2%)	0.7 (5.1%)	91.3
			PSV	42.1	6.2 (14.7%)	1.3 (3.1%)	96.1
			acceleration time	36.1	9.4 (26.0%)	6.7 (18.6%)	66.3

TAV, time-averaged velocity; E, early filling phase; A, atrial contraction phase; PSV, peak systolic velocity; SD, standard deviation

have been performed on the reliability of the measurements. Kenny and colleagues[10] and Al-Ghazali and colleagues[11] reported a good reproducibility both for cross-sectional diameter measurements and Doppler velocities at fetal outflow tract level in advanced pregnancy, whereas Beeby and associates[12] documented poor reliability for diameter and Doppler measurements at atrioventricular valve level.

To our knowledge, this is the first study on early pregnancy Doppler measurements with a description of waveform reproducibility. Our data suggest that fetal flow velocity waveforms in early pregnancy are well reproducible in the individual woman. As expected, most parameters demonstrated much larger variabilities for between-subject values than for within-subject values. Poor reproducibility was established for the acceleration time. At cardiovascular level, these data are similar to our observations in late pregnancy, demonstrating reproducible flow velocity waveforms at both atrioventricular and outflow tract levels[5,6]. An explanation for the relatively lower reproducibility of the acceleration time could be found in the poorly traceable steep ascending limb of the waveform by hand. Moreover, several reports have appeared about the effect of sampling site on acceleration time measurements[13,14]. In this study, these limitations led to high between-subject as well as high within-subject variance components.

Relatively low variance components between- and within-subjects were documented both at atrioventricular level (E/A ratio) and at the level of the ductus venosus and inferior vena cava (peak systolic/diastolic ratio). In terms of relative differences, these parameters show very

constant values. Moreover, their mean value is, in fact, a combination of two measurements with their own variabilities.

The same applies for the percentage reverse flow which is calculated from a combination of three separate measurements, i.e. integrals of systolic and early diastolic forward flow and late diastolic retrograde flow. Our results demonstrate that in early pregnancy a higher variance exists for percentage reverse flow compared with other parameters, as reflected by a within-subject coefficient of variation of 8.8%. An increase of percentage reverse flow has recently been described as an important parameter in the evaluation of fetal growth retardation[7,15]. Since the within-subject variance is rather high, repeated measurements might improve the reliability of the parameter and, therefore, increase the clinical applicability.

In conclusion, flow velocity waveforms obtained in late first- and early second-trimester fetuses display a good reproducibility. All parameters demonstrate, in our judgement, acceptable coefficients of variation for within-subject variance, except for the acceleration time which turned out to be poorly reproducible.

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