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Presence of pulsations and reproducibility of waveform recording in the umbilical and left portal vein in normal pregnancies

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ABSTRACT

Reproducibility and inter-observer variability of intra- and extra-abdominal umbilical venous flow velocity and left portal venous flow velocity as well as heart-synchronous waveform pulsations in these vessels were studied in 23 women at 34–38 weeks of normal pregnancy.

Limited reproducibility, expressed by large intra-patient coefficients and limits of agreement between two observers, was established for all standardized recording sites. Pulsations, defined as negative venous deflections of at least 10% of the mean velocity, were demonstrated at all locations ranging from 19.6% of the measurements at the free-floating loop of the umbilical vein to 78.4% of the measurements at the left portal vein.

The present study shows that the limited reproducibility of venous flow velocity waveforms should be taken into consideration, and that the presence of pulsations can be demonstrated in normal late pregnancy.

INTRODUCTION

An increasing number of reports has appeared on flow velocity waveform recording in the umbilical vein in normal pregnancies as well as in pathological conditions. Waveform velocities have been obtained from either the free-floating loop[1–4] or the intra-abdominal part of the umbilical vein[5–9]. Sparse information is available on the reproducibility of umbilical venous flow velocity waveforms. Reproducibility of waveform recordings depends not only on the exact location of the Doppler sample volume, the sample size and interrogation angle, but also on fetal variables such as breathing movements. Lately, heart-synchronous pulsations have been observed in the umbilical venous flow waveform in the small-for-gestational-age fetus[1] and in fetuses with non-immune hydrops[2] in late pregnancy, and in normally developing fetuses during the late first trimester of pregnancy[3]. In a pilot study in our own center, occasional pulsations have been observed in normal fetuses in the umbilical vein and in its extension, the left portal vein, as late as the third trimester of pregnancy.

The objective of the present study was twofold:

(1) To determine the reproducibility and inter-observer variability of intra- and extra-abdominal umbilical venous flow velocity waveforms and left portal venous flow velocity waveforms; and

(2) To investigate the existence of heart-synchronous waveform pulsations relative to these recording levels.

MATERIALS AND METHODS

A total of 23 women consented to participate in the study. Gestational ages varied between 34 and 38 weeks (mean 36 weeks). Pregnancy duration was determined from the last menstrual period and confirmed by ultrasound measurements of the fetal crown–rump length or fetal biparietal diameter. All pregnancies were uncomplicated. All women gave birth to a healthy infant with a birth weight between the 10th and 90th centiles[10]. Each woman was included in the study once. All participants were non-smokers.

Pulsed wave Doppler ultrasound recordings were obtained using the Hitachi EUB-450, manufactured by Hitachi Medical Corporation, Tokyo, Japan (real-time and Doppler carrier frequency 3.5 MHz; high pass filter 100 Hz).

Doppler studies were performed with the woman in the semirecumbent position and during fetal apnea, because fetal breathing movements modulate venous blood flow velocity waveforms[11]. The sample volume length was between 0.4 and 0.5 cm. Maximal flow velocity waveforms were obtained from four standardized locations:

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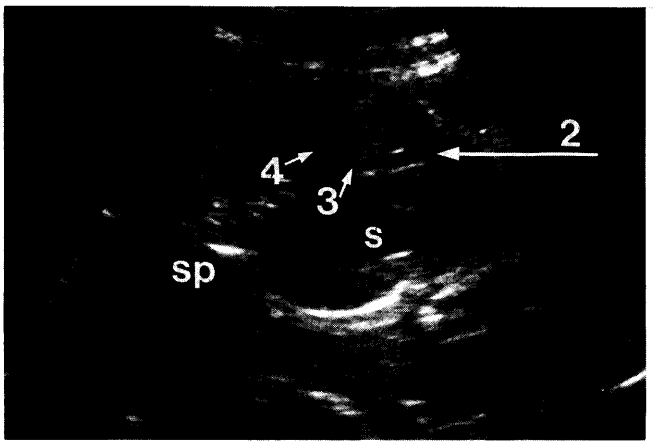

Figure 1 Ultrasound scan of fetal abdomen illustrating the intra-abdominal recording sites: 2, the intra-abdominal part of the umbilical vein at the entrance into the abdomen; 3, the umbilical sinus; 4, the left portal vein between the right portal vein and the umbilical sinus; s, stomach; sp, spine

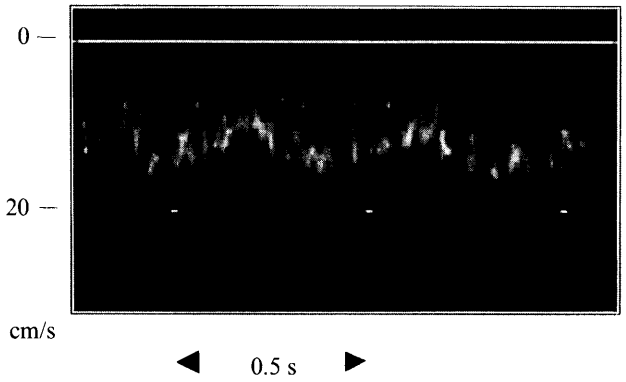

Figure 2 Venous flow velocity waveform at the umbilical sinus (location US)

(1) The free-floating loop of the umbilical vein (location FL-UV);

(2) The intra-abdominal part of the umbilical vein at the entrance into the abdomen (location IA-UV);

(3) The umbilical sinus (location US); and

(4) The left portal vein between the right portal vein and the umbilical sinus (location PV) (Figure 1).

The position of the vessel at location FL-UV and location PV allowed interrogation angles of less than 10°. Recordings at locations IA-UV and US were only accepted if the interrogation angle was less than 30°. The examination time never exceeded 60 min.

All measurements were performed by two investigators in a fixed, standard order:

(1) First measurement by T.W.A.H.;

(2) Measurement by I.P.v.S.; and

(3) Second measurement by T.W.A.H.

Inter-observer variability was defined as the variability between the two measurements by observer 1 and the measurement by observer 2. The intra-patient variability, which depended on the biological variation within the individual patients and the measurement error by observer 1, was defined as the variability in flow velocity between the first and second measurements by observer 1.

Umbilical venous blood flow velocity waveforms were recorded on hard copies. These hard copies were shuffled in a random order, and the presence or absence of pulsations was documented independently by the two investigators. Umbilical venous pulsations were defined as at least three consecutive negative deflections of the venous waveform, each comprising at least 10% of the mean velocity and synchronous with the fetal heart rate (Figure 2). The fetal heart rate was established by correlating the time intervals from consecutive umbilical arterial and venous pulsations. The occurrence of umbilical venous pulsations was only accepted if both investigators agreed about its presence. In all recordings displaying pulsations, maximal velocity (cm/s), minimal velocity (cm/s) and mean velocity (cm/s) were determined for three cardiac cycles from the maximum frequency envelope. In the case of waveforms without pulsations, the mean velocity was analyzed at three different measuring points on the maximum frequency envelope in the continuous flow velocity waveform.

For analysis of the Doppler recordings, a microcomputer (Olivetti M24, Olivetti B.V., Leiden, The Netherlands) was used, linked to a graphical tablet. The waveform analysis was performed by one examiner (I.P.v.S.).

Statistical analysis

Analysis of variance for repeated measurements was used to assess systematic differences in mean velocities between the three successive measurements. To assess the observer agreement, limits of agreement between the observers were calculated[12]. Limits of agreement were defined as the range in which approximately 95% of the differences between observer 1 and observer 2 were situated. On the basis of the measurements carried out by observer 1, intra- and inter-patient variance components were determined by standard analysis of variance. The prevalence of pulsations was compared between the two observers (T.W.A.H. 1 vs. I.P.v.S. and T.W.A.H. 2 vs. I.P.v.S.), between the first and second measurement of observer 1 (T.W.A.H. 1 vs. T.W.A.H. 2) and between all four locations, by McNemar's test. Fisher's two-tailed exact test was used to assess associations in the presence of pulsations between the different locations. A value of $p < 0.05$ was considered statistically significant.

RESULTS

Technically unacceptable flow velocity waveforms were obtained in four women due to persistent fetal breathing or fetal position, leaving data from 19 women for further analysis. Among these 19 women (57 measurements), successful recording of flow velocities was achieved at locations FL-UV and US in 98% (56/57) and at locations IA-UV and PV in 96% (55/57).

Table 1 Mean maximum velocity ± standard deviation (cm/s) measured by two observers at the four different locations: FL-UV, free-floating loop of the umbilical vein; IA-UV, intra-abdominal part of the umbilical vein at the entrance into abdomen; US, umbilical sinus; PV, left portal vein between the right portal vein and the umbilical sinus

	FL-UV	*IA-UV*	*US*	*PV*
T.W.A.H. 1	14.4 ± 3.3	18.6 ± 7.0	15.3 ± 2.4	14.0 ± 3.4
I.P.v.S.	15.6 ± 2.8	20.7 ± 5.0	17.3 ± 2.6	14.8 ± 3.1
T.W.A.H. 2	15.8 ± 2.9	17.9 ± 5.3	17.2 ± 3.4	14.1 ± 2.5
p value	$p = 0.32$	$p = 0.048$	$p = 0.013$	$p = 0.59$

Mean maximum velocities were significantly higher at location IA-UV as compared with locations FL-UV, US and PV (Table 1). For the mean velocities at location IA-UV and US, the overall test for differences in mean values between the three successive measurements was statistically significant ($p = 0.048$ and $p = 0.013$). No such differences could be documented for the mean velocities at locations FL-UV ($p = 0.32$) and PV ($p = 0.59$). Table 2 shows the intra-patient variation. Limits of agreement are presented in Table 3. For the analysis of the incidence of pulsations, the data of the three repeated measurements were pooled, and therefore no adjustment was made for the fact that, from each woman, three measurements were used. The presence of pulsations was demonstrated at location FL-UV in 19.6% (11/56), at location IA-UV in 32.7% (18/55), at location US in 76.8% (43/56) and at location PV in 78.4% (42/55) of measurements. This led to significant differences in the incidence of pulsations between locations FL-UV and US ($p = 0.002$), between locations FL-UV and PV ($p = 0.0018$), between locations IA-UV and US ($p = 0.0039$) and between locations IA-UV and PV ($p = 0.0034$). The Fisher's exact test revealed a significant association between the occurrence of pulsations at locations FL-UV and IA-UV ($p = 0.0003$) and between locations IA-UV and US ($p = 0.0047$).

Correlation coefficients between arterial and venous pulsations at locations US and PV were 0.71 and 0.74, respectively ($p < 0.001$).

Table 2 Intra-patient variation relative to the four different recording sites: FL-UV, free-floating loop of the umbilical vein; IA-UV, intra-abdominal part of the umbilical vein at the entrance into the abdomen; US, umbilical sinus; PV, left portal vein between the right portal vein and the umbilical sinus

Location	*Mean*	*SD*	*Coefficient of variation* (%)
FL-UV	15.1	3.5	23.2
IA-UV	18.3	3.6	19.7
US	16.3	2.3	14.2
PV	14.1	2.2	15.6

Table 3 Mean difference and limits of agreement (the range within which approximately 95% of the differences between observer 1 and observer 2 lie) relative to the four locations: FL-UV, free-floating loop of the umbilical vein; IA-UV, intra-abdominal part of the umbilical vein at the entrance into the abdomen; US, umbilical sinus; PV, left portal vein between the right portal vein and the umbilical sinus

Location	*Mean difference*	*p value*	*Limits of agreement*
FL-UV	1.18	0.03	−5.05, 7.34
IA-UV	2.06	0.01	−7.99, 12.13
US	1.88	0.04	−3.28, 7.05
PV	0.67	0.47	−7.74, 9.08

DISCUSSION

In most studies Doppler flow velocity waveforms were obtained from the free-floating loop of the umbilical vein and no account was taken of the waveform reproducibility at this or any other location along the umbilical vein.

Our data suggest differences in flow velocity at different standardized recording locations. Data from the intra-abdominal part of the umbilical vein at the entrance into the abdomen were similar to those reported by van Lierde and colleagues[9], but lower than those collected by Griffin and co-workers[6] and Erskine and associates[7] with velocities ranging between 20 and 50 cm/s. This may have been due to the higher insonation angle (30–60°) and variable Doppler sample positioning in the latter studies.

Measurement of umbilical venous flow velocities just inside the fetal abdomen (location IA-UV) may not be ideal since the waveform patterns at this location were less consistent as a result of the cranial-to-caudal course of the vessel. Moreover, the acquisition of waveforms at this location may be difficult as a result of obstruction of the Doppler beam by the lower limbs. There is no clear explanation for the systematic differences in flow velocity at location US. It is unlikely that the systematic differences in mean velocity at both locations IA-UV and US resulted from fetal movements, since these movements occur at random.

The higher mean flow velocity at the intra-abdominal location of the umbilical vein in comparison with the free-floating loop and the umbilical sinus may be explained by a difference in vessel diameter at the entrance of the umbilical vein into the abdomen. To our knowledge, no data are available on vessel diameter at this level.

Large coefficients of variation for recordings were established at all four measuring points. Since a systematic variation could be demonstrated for obtaining Doppler flow velocities at locations IA-UV and US, coefficients of variation from these locations should not be interpreted. For location FL-UV, large coefficients of variation were also reflected by the wide range of variation in data from both observers. This is an impor-

tant finding, for this measurement is often performed and is easy to obtain. Apparently, standardization of sample volume placement in this study was not precise enough. A large intra-patient variance may also be attributed to the normal biological variation of umbilical blood flow.

Location PV seemed to be the most reliable recording site for obtaining venous flow velocity waveforms. The clinical significance of this measurement, however, has not yet been established.

The presence of pulsations in the umbilical vein in the absence of fetal breathing is considered to be abnormal[1,2], except in early pregnancies[3]. Umbilical venous pulsations have been observed in small-for-gestational-age fetuses and during fetal bradycardia and tachycardia[2] as well as in non-immune hydrops[1]. These findings have been attributed to an increased reverse flow into the inferior vena cava during atrial contraction. In fetal lambs, umbilical vein pulsations have been established following cord occlusion[13,14]. It has been suggested that in normal conditions the pulsations in the venae cavae, which are modulated by cardiac cycle length and respiratory movements, are not large enough to be propagated via the ductus venosus to the umbilical vein. However, in our study, umbilical venous pulsations were demonstrated in normal late pregnancies. This is supported by studies in normal fetal sheep, in which minimal flow pulsations have been observed in the umbilical vein as well as increased pulsatility under conditions which modulate the amplitude of phasic flow pattern in the inferior vena cava[15].

Our study demonstrated umbilical venous and left portal venous pulsations in normal pregnancies. The venous pulsations at locations US and PV were shown to be synchronous with fetal heart rate. The incidence of venous pulsations were more or less equal for the umbilical sinus and left portal vein. This is in contrast with a recent report[16] in which a monophasic continuous flow pattern in the umbilical vein, as well as in the portal venous system, has been described. Under normal circulatory conditions, most of the veins are compressed by surrounding tissues. This compression causes resistance, to damp out the pulsations. Backward transmission of pulses occurs to some extent in the normal circulation. Pulsatile flow patterns have been reported for the ductus venosus and inferior vena cava, resulting from right atrial contraction and relaxation[17]. It seems plausible that pulsations in venous vessels further from the heart, such as the umbilical sinus and left portal vein, are caused by the same mechanism.

The fact that no association existed between the presence of pulsations at locations US and PV is probably due to the variability in propagation of the pulsations. It is our impression, therefore, that the significant associations between locations FL-UV and IA-UV and between locations IA-UV and US are probably coincidental.

It can be concluded that the occurrence of umbilical venous pulsations should be interpreted with caution. We demonstrated that umbilical venous and left portal venous pulsations even occurred in normal late pregnancy. Difficulty in standardizing the recording site as well as the individual variations in umbilical venous flow velocity may be responsible for the large intra-patient coefficients of variation and limits of agreement between observers. The left portal vein seems to be the most reliable recording site for obtaining flow velocity waveforms. In future studies the limited reproducibility of umbilical venous blood flow velocity waveforms should be taken into consideration.

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