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Umbilical artery half peak systolic velocity deceleration time throughout pregnancy and its role in fetuses with bradycardia

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KEYWORDS: blood flow velocity waveforms; bradycardia; Doppler ultrasound; fetal arrhythmia; half peak systolic velocity deceleration time; resistance indices; umbilical artery

ABSTRACT

Objectives *To describe a new technique for Doppler waveform quantification of the fetal umbilical artery, the half peak systolic velocity (h-PSV) deceleration time, which measures the time that it takes a single flow velocity waveform to halve its maximum systolic velocity. As this measurement is independent of fetal heart rate, its role in the evaluation of placental vascular resistance in fetuses with bradycardia was also explored.*

Methods *The umbilical artery impedance indices and the h-PSV deceleration time were measured in 532 normal singleton fetuses from 17 to 41 weeks of gestation. A nomogram was established and its usefulness in assessing fetuses with bradycardia was evaluated.*

Results *The relationship between umbilical artery h-PSV deceleration time and gestational age was best described by a linear formula* ($y = 6.5523x + 12.41$; $R^2 = 0.6346$)*, h-PSV deceleration time increasing by 6.6 ms per week. The correlation coefficients for the 95th, 50th and 5th centiles were 0.97, 0.98 and 0.98, respectively. Measurement of h-PSV deceleration time was reproducible, with interobserver and intraobserver variabilities of 10.7% and 7.4%, respectively. Among fetuses with bradycardia* ($n = 7$)*, the h-PSV deceleration time was above the 5th centile in all cases, suggesting normal placental function in spite of abnormally increased impedance indices obtained with traditional Doppler indices in six.*

Conclusions *The h-PSV deceleration time increases linearly during the second and third trimesters of pregnancy. As its measurement is reproducible and independent of heart rate, it may be useful in the assessment of well-being in fetuses with bradycardia.* *Copyright © 2007 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

Fetal assessment using Doppler blood flow velocity waveforms (FVWs) has become one of the most important methods for evaluating fetal well-being in high-risk pregnancies. This technique assesses the downstream impedance in uterine and umbilical–placental vascular beds, and has proved useful in the early detection of fetal compromise, thus reducing perinatal mortality[1–3]. There are, however, several factors that may affect the measurement of fetal FVWs, one of which is the fetal heart rate (FHR)[4,5]. Indeed, in fetuses with bradycardia the cardiac cycle is longer and the diastolic component is prolonged, which decreases the end-diastolic flow velocity leading to falsely increased impedance indices. In contrast, tachycardia leads to a decrease in such indices owing to shortening of the diastolic component of the FVW.

Abnormal FHR can be present in several fetal conditions including fetal tachyarrhythmia or bradyarrhythmia, during tocolysis with beta-agonists, in association with maternal fever or as an early sign of fetal distress. Among these, fetuses with bradycardia present difficulties when assessing well-being with cardiotocography because the fetal non-stress test largely depends on FHR analysis. We noticed that umbilical artery FVWs in fetuses with bradycardia are similar to those obtained from fetuses with normal FHR, but the last part of diastole is significantly different owing to the aforementioned factors. We therefore hypothesized that, in fetuses with bradycardia,

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measurement of the wavelength during the early part of diastole might provide a better estimation of the placental vascular resistance than the indices currently in use, which all involve the use of end-diastolic velocities.

The aim of this study was to describe a new method for assessing umbilical artery impedance indices with Doppler ultrasound, which may be useful in fetuses with bradycardia. We investigated a new measurement, the half peak systolic velocity (h-PSV) deceleration time, which evaluates the time that it takes a single FVW to halve its maximum systolic velocity. This value reflects the umbilical artery downstream resistance independently of the FHR, and could therefore represent a more accurate method for assessing fetal well-being when a pathological alteration of the FHR is present. We present the technique for measuring this parameter, report normal values throughout the second and third trimesters, and study its usefulness in the evaluation of fetuses with bradycardia.

METHODS

This study was approved by the local Institutional Review Board and all patients gave verbal consent for the examination. Unselected pregnant women at 17–41 weeks of gestation presenting to the Ultrasound Unit, San Juan de Dios Hospital, National Health Service, for routine obstetric ultrasound examination were recruited prospectively. Patients underwent a detailed ultrasound scan for fetal biometry and anatomical survey, amniotic fluid volume assessment and Doppler measurement of umbilical artery FVWs. The estimated fetal weight was determined by using measurements of the biparietal diameter, head circumference, abdominal circumference and femur length, and plotted against our fetal growth chart[6]. Umbilical artery impedance indices were plotted against previously published nomograms for fetuses at or below 22 weeks[7] and for those beyond 22 weeks[8]. All examinations were carried out by maternal–fetal medicine specialists using commercially available, high-resolution ultrasound equipment with color Doppler facilities (Sonoace 8000EX and Sonoace 8800MT; Medison, Seoul, Korea).

Umbilical artery FVWs were obtained during fetal apnea, absent fetal movements and at an isonation angle of less than 45° until a minimum of three similar FVWs were documented on the screen. The wave with the highest systolic velocity and least noise was selected for measuring the pulsatility index (PI), the resistance index (RI) and the systolic to diastolic (S/D) ratio using the built-in program software. Subsequently, the same FVW was used for measuring the h-PSV deceleration time, which was determined as follows. The first caliper was used to measure the maximum systolic velocity. The second caliper was then placed at the level of half the maximum velocity as previously determined by the first caliper. A perpendicular line was then drawn from the second caliper to the intersection with the spectral waveform, which measures the deceleration time in milliseconds (Figure 1). One of the authors (J.C.B.) performed 95% of the measurements. Interobserver and intraobserver variability was performed in a subset of 28 normal fetuses, and determined to be 10.7% and 7.4%, respectively. Information obtained on Doppler indices was available to the clinicians for subsequent prenatal care; however, the h-PSV deceleration time values were kept in the database and not reported to the attending physician.

Information on maternal demographics, antenatal course and perinatal outcome was obtained by reviewing the medical records and delivery reports. Fetuses that fulfilled the following criteria were used to develop the nomogram: singleton pregnancy; reliable gestational age according to first-trimester ultrasound examination; a single measurement per fetus; estimated fetal weight and birth weight between the 10th and 90th centiles; and normal FHR and umbilical artery impedance indices at

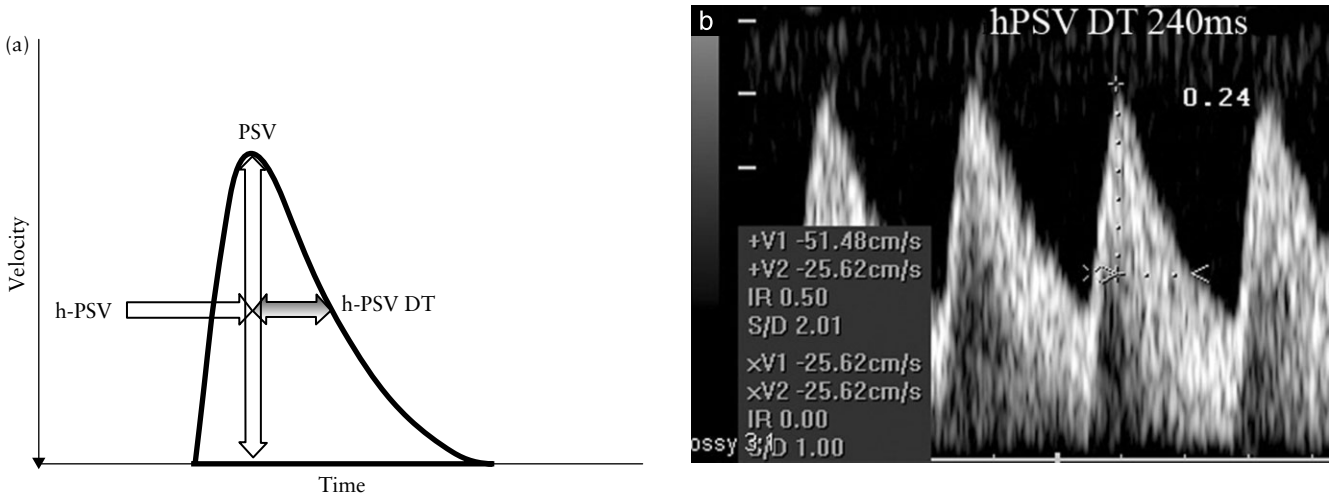

Figure 1 (a) Schematic representation of the half peak systolic velocity (h-PSV) deceleration time (DT). (b) Technique for measuring the h-PSV deceleration time in a normal fetus. The PSV was 51.4 cm/s and the h-PSV was 25.6 cm/s. The horizontal dotted line indicates the h-PSV deceleration time (240 ms).

Table 1 Half peak systolic velocity deceleration time (in ms) according to gestational age ($n = 532$)

GA (weeks)	N	Centile				
		5^{th}	10^{th}	50^{th}	90^{th}	95^{th}
17	16	106	107	120	149	164
18	17	111	112	127	157	172
19	17	115	117	133	165	180
20	22	120	122	140	173	188
21	27	124	127	147	182	196
22	25	129	132	153	190	204
23	20	133	137	160	198	212
24	21	138	142	167	206	220
25	30	142	147	174	214	227
26	21	147	152	180	222	235
27	19	151	157	187	230	243
28	22	156	162	194	238	251
29	19	160	167	200	246	259
30	17	165	172	207	255	267
31	22	169	176	214	263	275
32	21	174	181	220	271	283
33	19	178	186	227	272	291
34	22	183	191	234	287	298
35	19	187	196	240	295	306
36	30	192	201	247	303	314
37	16	196	206	254	311	322
38	22	201	211	260	319	330
39	23	206	216	267	327	338
40	28	210	221	274	336	346
41	17	215	226	280	344	354

GA, gestational age.

the time of the ultrasound evaluation. Pregnancies complicated by fetal structural anomalies, oligohydramnios, hypertension or diabetes were also excluded from the analysis.

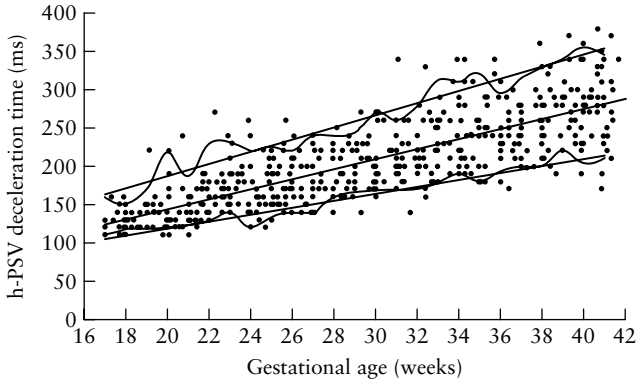

Figure 2 Umbilical artery half peak systolic velocity (h-PSV) deceleration time according to gestational age in 532 normal singleton fetuses. The regression line and smoothed and non-smoothed 5^{th} and 95^{th} centiles are shown ($y = 6.5523x + 12.409$ ($R^2 = 0.6346$)).

RESULTS

The h-PSV deceleration time was obtained from umbilical artery FVWs in 1108 fetuses. Of these, 532 complied with the inclusion criteria and were used to develop the nomogram (Table 1). Figure 2 displays the plotted values, the regression line and the smoothed and non-smoothed 5^{th} and 95^{th} centiles according to gestational age. The best correlation was obtained with a linear formula ($y = 6.5523x + 12.41$; coefficient of determination $R^2 = 0.6346$; correlation coefficient $R = 0.7966$), resulting in a linear trend with an increase of 6.6 ms per week. The correlation coefficients for the 95^{th}, 50^{th} and 5^{th} centiles were 0.97, 0.98 and 0.98, respectively.

We additionally measured the h-PSV deceleration time in seven fetuses with bradycardia, defined as a persistent FHR below 100 beats per min[9]. Relevant

Table 2 Clinical cases of fetal bradycardia

Case	GA (weeks)	Pathology	FHR (bpm)	Umbilical artery Doppler			GA at delivery (weeks)	Birth weight (g)	Apgar scores (1, 5 min)	Remarks	Survival
				S/D	PI	h-PSV deceleration time (ms)					
1	23	AV block, maternal lupus	55	9.52	2.58	190	40	4020	8, 8	Pacemaker at birth. Demise at 9 months	No
2	34	Cardiac isomerism	85	4.96	1.77	260	36	3600	3, 6	Hydrops, NND	No
3	32	Sinus bradycardia	82	7.84	1.76	190	40	3320	8, 9	Sinus bradycardia	Yes
4	34	AV block	50	4.52	1.55	400	40	3600	8, 9	Pacemaker at birth	Yes
5	39	Rhabdomyomas, AV block, atrial flutter	69	3.26	1.21	330	39	3050	9, 9	Rhabdomyomas	Yes
6	20	Complex cardiac defect, ventriculomegaly	71	8.78	2.30	140	23	—	0, 0	IUD at 23 weeks	No
7	22	AV block, craniosynostosis	65	9.71	2.16	285	32	—	0, 0	IUD at 32 weeks	No

AV, atrioventricular; FHR, fetal heart rate; GA, gestational age; h-PSV, half peak systolic velocity; IUD, intrauterine death; NND, neonatal death; PI, pulsatility index; S/D, systolic to diastolic ratio.

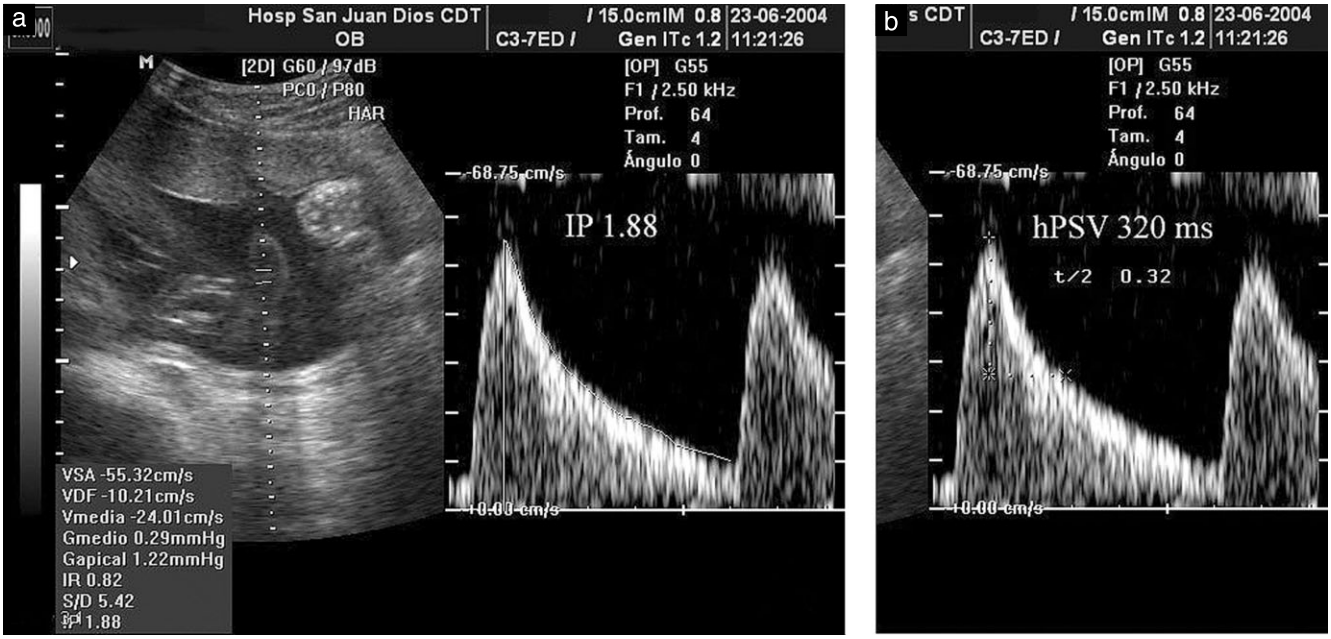

Figure 3 Pulsatility index (PI) (a) and half peak systolic velocity (h-PSV) deceleration time (b) in a fetus with bradycardia (Case 1, Table 2) at 31 weeks of gestation. The PI of 1.88 is abnormally increased (normal value, < 1.51) whereas the h-PSV deceleration time of 320 ms is above the 95th centile suggesting low resistance in the umbilical–placental territory.

clinical details from these cases are presented in Table 2. The umbilical artery impedance indices were abnormally increased in six of the seven cases (86%), whereas h-PSV deceleration time measurements showed no values below the 10th centile, suggesting low downstream resistance at the time of evaluation (Figures 3 and 4). Moreover, in two of the seven (29%) cases the h-PSV deceleration time was prolonged (Figure 4), reflecting increased ventricular filling consistent with the Frank-Starling mechanism[10]. Figure 5 shows the correlation between the h-PSV deceleration time and the PI. In normal fetuses, there was an exponentially inverse correlation ($y = 202.11x^{-1.0685}$) with a coefficient of determination of 0.7581. The correlation in the seven fetuses with pathological bradycardia is also shown, indicating that the vast majority had an abnormal PI but a normal or prolonged h-PSV deceleration time.

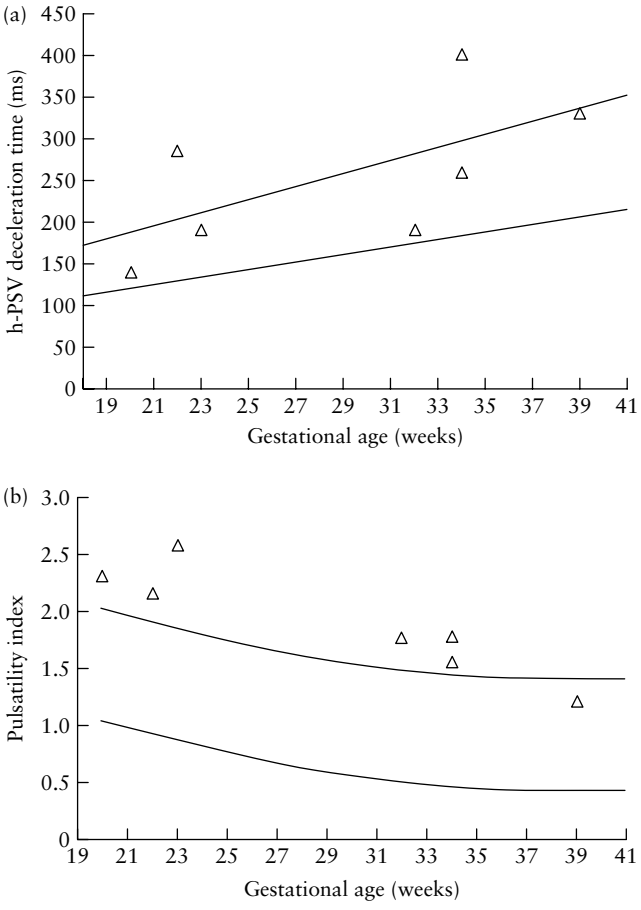

Figure 4 Half peak systolic velocity (h-PSV) deceleration time (a) and pulsatility index (PI) (b) in seven fetuses with bradycardia. Lower and upper lines represent 5th and 95th centiles, respectively. All fetuses had h-PSV deceleration time values above the 5th centile, whereas six of the seven had PI values above the 95th centile, falsely suggesting increased placental vascular resistance.

DISCUSSION

Yarlagadda *et al.* studied 149 normal pregnancies and noted that up to 18% of the variability of umbilical artery impedance indices can be attributed to the effect of FHR[5]. They demonstrated that FHR is inversely correlated to umbilical artery impedance indices and suggested a complex correction system, which unfortunately is difficult to incorporate into routine clinical practice. Although these changes have little significance in the normal fetus, they become highly relevant whenever the baseline FHR is abnormal, especially in cases complicated by pathological fetal tachyarrhythmias or bradyarrhythmias[9]. This study describes a new parameter for Doppler waveform quantification, the h-PSV deceleration time, which is based on deceleration

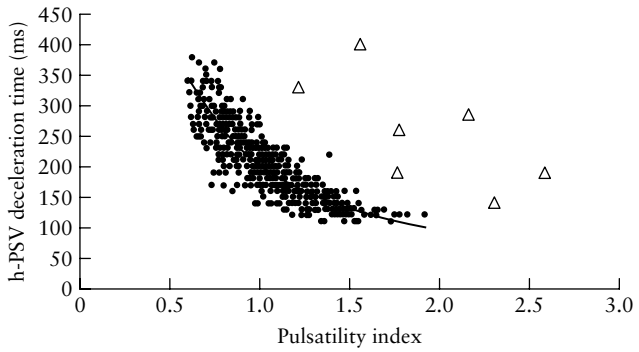

Figure 5 Relationship between half peak systolic velocity (h-PSV) deceleration time and pulsatility index in 532 normal singleton fetuses (•) and in seven fetuses with bradycardia (△). Note that values from bradycardic fetuses are shifted to the right of the curve ($y = 202.11x^{-1.0685}$ ($R^2 = 0.7581$)).

characteristics of the umbilical artery FVWs obtained by Doppler ultrasound examination and, therefore, independent of the FHR.

Doppler FVW impedance indices, such as the PI, RI and S/D ratio, are used extensively to examine blood flow in all vascular territories. Some investigators have reported the use of other indices, such as the systolic angle, maximal peak in systole, time-to-peak velocity, time–velocity integral and time-averaged maximum velocity[11–13]. However, the latter methods have had limited use in the evaluation of placental vascular resistance. According to our experience, the h-PSV deceleration time has several advantages over the traditional umbilical artery impedance indices. First, it provides an easy technique for measuring a single parameter, which is also independent of the isonation angle. Thompson *et al.* described 12 different indices for assessing umbilical artery vascular resistance, one of which was the diastolic time that measures the total diastolic phase[14]. The h-PSV deceleration time described in this report is similar, although it only measures the first component of diastole where the deceleration time is usually linear. Second, the h-PSV deceleration time is independent of the FHR, as it is an intrinsic measurement of each waveform. Therefore, the information provided by this measurement may be useful in the evaluation of fetoplacental function in cases in which the FHR is altered.

As part of the present study, the potential role of this new technique in the evaluation of fetuses with bradycardia was examined. In a study of seven such fetuses, we found that simultaneous recording of Doppler impedance indices and the h-PSV deceleration time values showed conflicting results. As expected, the PI, RI and S/D ratio were affected by the decelerated FHR. On the other hand, the h-PSV deceleration time suggested intact placental function at the time of evaluation. This proved to be the case as determined by the follow-up of these pregnancies; all the liveborn infants had normal growth and were born in good condition except for the bradycardia. We therefore suggest that the traditional Doppler umbilical artery impedance indices may provide misleading information for the subsequent management of these pregnancies, which can be corrected by using the h-PSV deceleration time instead.

Our study has shown that the h-PSV deceleration time is a single, absolute and quantitative value. It is independent of the isonation angle and does not require correction with any other measurement. Doppler impedance indices currently in use, on the other hand, require the measurement of several velocities from each waveform, including the maximum systolic velocity, the end-diastolic velocity and the mean velocity, each of which is subject to individual variability. In contrast, the h-PSV deceleration time may provide a single and, therefore, more precise measurement (Table 3). Although measurement of the h-PSV deceleration time currently requires placement of two calipers and one horizontal line, it usually takes less than 10 s to obtain the result. In addition, automated measurements may make the measurement considerably easier in the near future.

Another difference between the h-PSV deceleration time and the Doppler impedance indices is that the former is measured on the axis of the abscissa whereas the PI, RI and S/D ratio are measured on the axis of the coordinates, where the end-diastolic velocity is the most important value. This changes the intuitive interpretation of the results. Instead of measuring end-diastolic velocity, analysis of the h-PSV deceleration time measures wavelength; narrow waves represent higher downstream resistance and wider waves represent lower downstream resistance and, therefore, better blood flow to the placenta. Indeed, the h-PSV deceleration time curve increases linearly in relation to gestational age, which is in keeping with data that show a continuous decrease of vascular resistance in the umbilical artery as pregnancy progresses[1–3,12]. Based on our experience, the measurement described in this report is easy to perform, highly reproducible and accurate in measuring

Table 3 Comparison between the half peak systolic velocity deceleration time (h-PSV) and conventional Doppler indices

Variable	*h-PSV deceleration time*	*Conventional indices**
Fetal heart rate	Independent	Dependent
Insonation angle	Independent	Independent
Validity in bradycardia	Very probable	No
Measurement unit	Milliseconds	None
Values	Continuous	Limited in absent or reversed end-diastolic flow
Measurement plane	Abscissas	Coordinates
Regression with gestational age	Linear	Parabolic
Increased placental resistance	Decreases	Increases
Difficulty in measurement	Low	Low

*Pulsatility index, resistance index and systolic to diastolic ratio.

downstream impedance in cases with an abnormal FHR pattern.

There are, however, some limitations to our technique; the h-PSV deceleration time cannot be measured when the S/D ratio is less than 2, which may be a physiological phenomenon at the end of pregnancy owing to the progressive decrease in placental impedance. This can also be the case when there is severe tachycardia, with a subsequent increase in the end-diastolic velocity, and the FVWs are so close that the S/D ratio is below 2. In addition, this technique is not accurate in cases of irregular rhythm as the varying stroke volume will also prevent the application of our methodology. Other methods of evaluation are required in these special situations.

In summary, the h-PSV deceleration time increases linearly during the second and third trimesters of pregnancy. As its measurement is reproducible and independent of heart rate, it may be useful in the assessment of well-being in fetuses with bradycardia. Whether it can be used as a method complementary to the traditional umbilical artery Doppler indices in the evaluation of placental function in fetal growth restriction needs further investigation.

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