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Venous Doppler in the prediction of acid-base status of growth-restricted fetuses with elevated placental blood flow resistance

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Objective: This study was undertaken to test which venous Doppler parameter offers the best prediction of acid-base status at birth in pregnancies complicated by intrauterine growth restriction (IUGR) caused by placental dysfunction.

Study design: A prospective cross-sectional Doppler study of IUGR fetuses with abnormal umbilical artery Doppler and birth weight less than the 10th percentile. Absence of atrial systolic forward velocities in the ductus venosus (DV) (DV-RAV) and umbilical vein (UV) pulsations were noted and multiple venous indices were calculated for the inferior vena cava (IVC) and DV (IVC and DV preload index, peak velocity index [PVIV] and pulsatility index [PIV] and the DV S/a ratio). Doppler indices, UV pulsations, and DV- RAV were related to an umbilical artery cord pH <7.20, and a pH <7.00 and/or base deficit greater than -13 (severe metabolic compromise) in neonates delivered by cesarean section without labor.

Results: In 122 fetuses all venous Doppler indices were equally predictive of a pH <7.20, with the exception of the IVC PVIV. No Doppler index predicted severe metabolic compromise. Bayesian analysis of individual Doppler parameters showed comparable outcome prediction with the highest sensitivity for the IVC PIV (76%) and the highest specificity for DV-RAV (96%). Combined assessment of the IVC, DV, and UV provided the most accurate outcome prediction. Doppler abnormality in either vessel identified 89% of neonates with pH <7.20 (negative predictive value 92%) and 10 of 11 neonates with severe metabolic compromise. Prediction was most specific (84%) when Doppler parameters were abnormal in all 3 vessels.

Conclusion: IVC, DV, and UV Doppler parameters correctly predict acid-base status in a significant proportion of IUGR neonates. Combination, rather than single vessel assessment provides the best predictive accuracy. While the choice of Doppler index can be guided by operator preference, familiarity with the examination technique of all 3 vessels is encouraged to offer the highest flexibility in clinical practice.

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Currently the primary goal of antenatal surveillance in high-risk pregnancies is the early detection of fetal compromise secondary to hypoxemia. Therefore, antenatal surveillance tools that have been developed over the past 3 decades primarily focus on fetal responses to decreased oxygenation and deterioration of acid-base status. Abnormalities of placental and fetal blood flows are a prominent feature of intrauterine growth restriction (IUGR) caused by underlying placental dysfunction. The application of Doppler surveillance to the clinical management of IUGR pregnancies revealed that deterioration of the fetal circulatory status and acid-base balance are related. Elevation of umbilical artery blood flow resistance and enhanced perfusion of vital organs (''organ sparing'') are observed initially and may be accompanied by fetal hypoxemia.[1,2] Although arterial Doppler provides information on downstream distribution of cardiac output this information is incomplete without an evaluation of cardiac function.[3] Declining forward cardiac function is the hallmark of cardiovascular deterioration in IUGR fetuses and frequently is accompanied by progressive fetal acidemia.[4,5] This deterioration can be documented by examination of the inferior vena cava (IVC), ductus venosus (DV) (''precordial veins'') and umbilical venous flow velocity waveforms. As cardiac function declines, the failure to accommodate cardiac preload results in abnormal venous Doppler indices, absence or reversal of forward flow during atrial systole in the DV or umbilical venous pulsations.[5-7]

In contrast to the arterial system, precordial venous flow velocity waveforms have a complex triphasic flow pattern that reflects pressure changes in the right atrium throughout the cardiac cycle. Several venous Doppler indices are described for each precordial vein and are used in clinical practice.[8,9] In addition, qualitative waveform analysis of DV atrial systolic forward flow and umbilical venous pulsations are also used to define venous Doppler abnormality. Although venous Doppler surveillance is increasingly incorporated into the management of IUGR pregnancies, there is no uniform agreement whether there is a single venous Doppler parameter that most accurately predicts acid-base status at delivery. The object of this investigation was to examine the relationship between IVC, DV, and umbilical vein (UV) flow patterns in IUGR fetuses and acid-base status at birth.

Patients and methods

Patients with suspected IUGR were invited to participate in the study if they met the following criteria: (1) Sonographic estimated fetal weight was below the 10th percentile for gestational age using local reference ranges; (2) umbilical artery pulsatility index more than 2 SD above the gestational age mean; (3) singleton fetus with normal fetal anatomy and karyotype (confirmed either ante-or postpartum); (4) there was no indication for immediate delivery that precluded completion of the ultrasound examination; and (5) the absence of active labor before delivery. After informed written consent at enrollment, each patient underwent a uniform antenatal assessment protocol. To maintain a close temporal relationship between Doppler findings and delivery data and to remove the known effects of labor on acid-base status, we only included patients in the final analysis who had a Doppler examination 48 hours, or less, before delivery by cesarean section. The study protocol was approved by the Institutional Review Board.

All Doppler examinations were performed using 4, 5, or 8 MHz transducers (Acuson Sequoia 512, Mountain View, Calif, or Advanced Technology Laboratories HDI 5000, Phillips, Bothell, Wash) with an acoustic output of less than 100 mW/cm^2 and the high pass filter at 50 to 100 Hz. The IVC was examined between the renal veins and the diaphragm and the DV at the inlet portion. The free UV was examined at the estimated midportion of the umbilical cord. The angle of insonation was close to 0 degrees for the UV and below 30 degrees for all other venous Doppler measurements. The Doppler image was frozen when at least 5 consecutive uniform flow velocity waveforms with a high signal-to-noise ratio were obtained during a period of fetal rest and apnea. On the basis of our experience and that of others, this approach has a coefficient of variation less than 10%.[5,8,9]

For the IVC and the DV (the precordial veins), the time averaged maximum velocity and forward velocities during the ventricular systole (S-wave), ventricular diastole (D-wave), and atrial systole (a-wave) were measured. The highest forward velocities were used in the final analysis. The peak velocity index for veins (PVIV) and the pulsatility index for veins (PIV)[5] were calculated for the DV and the IVC. We applied a preload index previously reported for the inferior vena cava (IVC PLI)[10] and a second preload index reported for the ductus venosus (DV PLI).[11] In addition, the S/a ratio[4,7] was calculated for the DV for fetuses with antegrade flow during atrial systole. A diagrammatic summary of the calculation of venous Doppler indices is provided in Figure and Table I.

All venous indices were related to locally derived reference ranges[9] and converted into z-scores for statistical analysis. Elevation of the Doppler index greater than 2 SD from the mean was considered abnormal for the PVIV and PIV and DV PLI and S/a ratio. For the IVC PLI deviation greater than 2 SD below the mean was considered abnormal. In addition, qualitative waveform analysis was performed for the DV and the UV. Forward flow during the a-wave in the DV was described as antegrade or absent (including absent and reversed). The UV

flow profile was described as either constant or pulsatile (including mono-, bi-, or triphasic pulsations).

At birth, a blood sample was drawn from the umbilical artery of a double-clamped umbilical cord segment and sent for blood gas analysis. It is difficult to provide an accurate cutoff for acidemia, or significant metabolic compromise in blood gas samples obtained after delivery. We defined an umbilical artery pH <7.20 as abnormal and an umbilical artery pH <7.00 and/or a base excess below -13 as evidence of significant metabolic compromise. These cutoffs were chosen for several reasons. First, they correspond to the 2 SD and 4 SD range below the gestational mean using many reference ranges for nonlabored patients.[12,13] Second, these values are abnormal before the onset of labor and in particular a pH <7.00 is considered evidence of profound metabolic compromise by the American College of Obstetricians and Gynecologists.[14] Finally, the relationship between long-term outcomes in growth restricted fetuses has been investigated in relation to similar cutoffs.[15]

To elucidate the relationship between the venous Doppler parameters and acid-base status we first performed a receiver operator curve (ROC) analysis to identify those venous indices yielding a significant prediction and area under the curve. ROC statistics provide a measure of the efficiency of a diagnostic test. By convention, a useful screening test has an area under the curve greater than 0.5. The greater the area under the curve, the better the screening test. Next, the 2 Doppler indices with the highest predictive value in each venous vessels, absence, or reversal of the DV−wave and umbilical venous pulsations were examined for their prediction of acidemia with the use of the Bayesian analysis. For this analysis, the individual Doppler indices were categorized as abnormal by using local reference values. The venous parameters that provided the best combination of sensitivity, positive prediction, specificity, and negative prediction were then selected on the basis of the highest test efficiency and the lowest test bias. We then sought to determine how combined evaluation of vessels affects predictive accuracy. Finally, we assessed the accuracy of venous Doppler indices to identify significant metabolic compromise to refine our assessment of venous Doppler indices. Statistical analysis was performed with SPSS 10.0 (SPSS Inc, Chicago, Ill). A *P*-value $<.05$ was considered statistically significant.

Results

One hundred seventy-two patients were enrolled during the study period from January 1999 to April 2003. Fifty were excluded (15 stillbirths, 28 vaginal deliveries, and 3 lost to follow-up). In 4 patients, the quality of the flow velocity waveforms immediately preceding delivery was insufficient for analysis. In the remaining 122 patients, the Doppler examination was successful in the IVC in 113 fetuses (92.6%), the DV in 119 fetuses (97.5%), and the UV in all 122 fetuses. One hundred ten fetuses had a complete examination of all 3 veins, whereas in the remainder, the UV was examined with either 1 of the precordial veins.

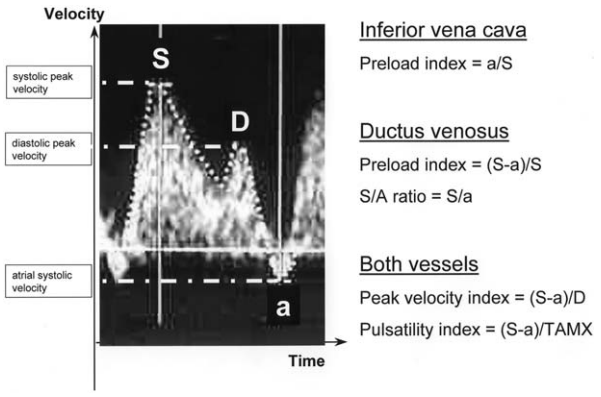

Figure A precordial venous flow profile is shown on the left to illustrate the components of the flow velocity waveform (S = systolic peak blood flow velocity, D = diastolic peak blood flow velocity, a = atrial systolic peak blood flow velocity, $TAMX$ = time averaged maximum velocity calculated from the area under the curve). The calculations for the various Doppler indices reported in the literature are displayed on the right.

Fifty-five patients (44.1%) had elevated umbilical artery pulsatility with forward end-diastolic velocity. In 23 (18.9%), end-diastolic velocities were absent and in 44 (36.1%) reversed. The distribution of abnormal venous Doppler findings is listed in Table II. Among all venous indices studied, the IVC PLI was most frequently abnormal, whereas absence of forward velocities during atrial systole in the DV was rare (n = 9).

The majority of patients (102, 83.6%) were delivered for fetal indications, whereas severe preeclampsia necessitated delivery in the remaining 20 (16.4%) patients. The median gestational age at delivery was 30.2 weeks' gestation and the median birth weight was 905 g. The median umbilical artery pH at delivery was 7.24. Thirty-six (29.5%) neonates had an umbilical artery pH <7.20 and 11 (9.0%) neonates had a pH <7.00 and/or base excess greater below -13. One hundred ten neonates (90.2%) were admitted to the neonatal intensive care unit primarily for management of prematurity-related complications and/or growth restriction. Perinatal and obstetric outcomes are summarized in Table III.

With the exception of the IVC PVIV, all venous Doppler indices produced a significant area under the curve in the ROC analysis for the prediction of a birth cord artery pH <7.20 (Table IV). However, the ROC curves for the various Doppler indices were not significantly different from each other, suggesting that there is no single Doppler index with superior efficiency. None

Table I Venous Doppler parameters

Venous Doppler indices	Calculation
IVC PLI	Peak velocity during atrial contraction / systolic peak velocity
PIV (calculated for IVC and DV)	(Systolic peak velocity - diastolic peak velocity) / time averaged maximum velocity
PVIV (calculated for IVC and DV)	(Systolic peak velocity - peak velocity during atrial contraction) / diastolic peak velocity
DV PLI	(Systolic peak velocity - diastolic peak velocity) / diastolic peak velocity
DV S/a ratio	Systolic peak velocity / peak velocity during atrial contraction
Qualitative waveform analysis	Description
DV - velocity during atrial systole	1. Forward 2. Absent, or reversed
Umbilical venous blood flow	1. Constant 2. Pulsatile (including mono-, bi-, and triphasic)

Table II Distribution of abnormal venous Doppler findings

	IVC PLI	IVC PVIV	IVC PIV	DV PLI	DV S/a	DV PVIV	DV PIV	DV RAV	UV pulsation
Abnormal	65 (53.2)	35 (28.7)	60 (49.1)	48 (39.7)	46 (37.7)	54 (44.3)	56 (45.9)	9 (7.4)	44 (36.1)
Median (range)	2.98 (−1.9-11.1)	0.82 (−2.2-31.4)	2.08 (−2.1-12.4)	1.57 (−2.4-13.9)	1.21 (−1.4-61.0)	1.67 (−2.3-15.3)	1.75 (−8.2-31.5)	-	-

RAV, Reversal or absence of forward flow during atrial systole.

of the Doppler indices were identified as efficient tests for the prediction of severe metabolic compromise. For further analysis we selected 2 representative Doppler indices for each precordial vein that had the largest ROC area. These were the DV S/a ratio and PLI, as well as the IVC PLI and PIV.

In the Bayesian analysis, all individual venous Doppler parameters were predictive of an umbilical artery pH <7.20. IVC Doppler indices had higher sensitivity (74%-76%), but lower specificity than DV Doppler indices (specificities 66% and 70%). Umbilical venous pulsations provided the best combination of sensitivity (61%), specificity (74%), positive predictive value (50%), and negative predictive value (82%) and therefore had the highest test efficiency (Table V). Although absence of forward flow during atrial systole had the highest specificity overall for the prediction of a low umbilical artery pH, the sensitivity was low (Table III). None of the venous Doppler parameters were significant predictors of severe metabolic compromise. There were no statistically significant differences between individual venous Doppler parameters in the prediction of an umbilical artery pH <7.20. However, an elevation of the IVC PIV identified the highest proportion of neonates with severe metabolic compromise (8/11, Table V). On the basis of the Bayesian analysis, the IVC PIV, DV S/a ratio, and umbilical venous pulsations were selected for further testing.

Combined assessment of Doppler parameters in multiple venous vessels resulted in improved predictive accuracy. Generally, specificity and negative predictive values were highest when all 3 veins had abnormal parameters, or if Doppler index elevation in any of the precordial veins was associated with umbilical venous pulsations (Table IV). An elevated DV S/a ratio accompanied by UV pulsations had 50% sensitivity, but 83% specificity in the prediction of an umbilical artery pH <7.20 at birth and identified 5 of the 11 neonates with significant metabolic compromise (Table VI). When all 3 veins were examined and abnormal Doppler parameters were observed in any of the vessels, sensitivity was highest (89%), with a modest fall in specificity (48%), but a negative predictive value of 92% (Table VI). Such a combination of findings also identified the highest proportion of neonates with significant metabolic compromise. Again, predictive efficacies for various combinations of venous Doppler parameters were not significantly different from each other.

Comment

IUGR caused by placental dysfunction is associated with characteristic changes in arterial and venous waveform patterns that are related to the stage of fetal disease and gestational age.[1,4,5] Doppler surveillance uses the

Table III Perinatal characteristics

Characteristic	N (%)	Mean/ median	±SD/ range
Maternal age		28	±5.5
Maternal race			
- White	84 (68.9)		
- African American	38 (31.1)		
Maternal disease	31 (25.4)		
Hypertension	20 (16.4)		
Thrombophilia	2 (1.6)		
Lupus erythematosus	2 (1.6)		
Miscellaneous	7 (5.7)		
Substance abuse	5 (4.1)		
Preeclampsia	55 (45.1)		
Severe/HELLP	21 (17.3)		
Indication for caesarean delivery			
Nonreassuring NST	28 (22.9)		
Nonreassuring BPS (≤6)	26 (21.3)		
Non-reassuring Doppler	24 (19.7)		
Oligohydramnios	7 (5.7)		
Absent growth near term	8 (6.6)		
Placental abruption	3 (2.5)		
Documented lung maturity			
- Breech presentation	4 (3.3)		
- Refusal of VBAC	2 (1.6)		
Severe preeclampsia	20 (16.4)		
Gestational age at delivery		30.2	24.0-38
Birth weight (g)		905	420-2260
Birth weight percentile			
>10	3 (2.5)		
<10 and >5	9 (7.4)		
<5 and >3	73 (59.8)		
<3	37 (30.2)		
5 min Apgar <7	12 (9.8)		
Cord artery blood gas			
pH		7.24	6.91-7.41
po_2		16	4.0-62.1
pco_2		53.1	31.0-93.0
Hco_3		23	11.4-28.0
Base excess		−4.3	−18.0-2.1

Data are presented as numbers and percentage of all patients (in parentheses) or median, mean, SD, and range.
VBAC, Vaginal birth after cesarean section; *HELLP*, syndrome of hemolysis, elevated liver enzymes, and low platelets; *NST*, nonstress test; *BPS*, biophysical profile score.

Table IV ROC characteristics of venous Doppler indices in the prediction of a cord artery pH <7.20

Doppler index z-scores	Area under the curve	95% CI	*P*-value
IVC PLI	0.676	0.559-0.792	.0033
IVC PVIV	0.558	0.445-0.672	.3287
IVC PIV	0.660	0.553-0.767	.0075
DV PLI	0.681	0.571-0.790	.0025
DV S/a	0.681	0.570-0.793	.0024
DV PVIV	0.667	0.557-0.778	.0052
DV PIV	0.657	0.545-0.768	.0088

evaluation of these waveform patterns to assess the severity of the fetal condition. Doppler abnormalities of the umbilical circulation or in the cerebral vessels are characteristic in the early stages and frequently accompany fetal hypoxemia, whereas deterioration of venous flows is a late finding more commonly associated with fetal acidemia.[4,5,7,16] On the basis of the assumption that metabolic and hemodynamic deterioration coincide, abnormal venous Doppler findings have been suggested as a surrogate marker for fetal acidemia and an indication to deliver IUGR fetuses.[7,17] Although the issue that venous Doppler parameters may differ in their ability to predict fetal acidemia in IUGR fetuses has been previously raised by Rizzo et al,[8] several approaches to evaluate venous flow velocity waveforms are currently in use. This study tests the relationship between qualitative and quantitative venous Doppler parameters and acid-base balance at birth in a large cohort of fetuses with IUGR caused by increased placental blood flow resistance.

Because Doppler evaluation is most relevant in the setting of placental insufficiency,[1] we only evaluated small fetuses with elevated placental blood flow resistance. This explains the high incidence of absence or reversal of umbilical artery end-diastolic velocities and the degree of venous Doppler abnormalities. Because venous Doppler abnormalities are specific to severe fetal growth restriction, our patient selection has the advantage that differences in venous Doppler parameters are more likely to be detected if they are truly significant. In contrast to Rizzo et al[8] and Hecher et al[16] who used cordocentesis to evaluate fetal acid-base status, we believe that the current state of art no longer requires it. Therefore, we related venous Doppler parameters to umbilical cord artery samples obtained at birth in the absence of labor. This required the exclusion of a sizeable proportion of patients initially screened at study entry. With the cutoffs that we used to define an abnormal prelabor acid-base status, our rate of abnormal results was comparable to the rate of acidemia in previous investigations by Rizzo et al.[8] Reference ranges for the venous Doppler indices that were derived by various authors differ significantly in their normal distribution.[5,7,8,10,17] To avoid the possible confounding effect of these discrepancies, we used reference ranges for venous Doppler indices that were derived from the local population. To test the role of qualitative waveform

Table V Individual abnormal venous Doppler parameters in the prediction of acidemia at birth

Doppler result	N	pH < 7.20 (n = 36)	Sens	Spec	PPV	NPV	Test efficiency	LR (95% CI)	*P*-value
IVC PLI	65	25	74	49	39	82	57	1.9 (1.1-3.4)	.0371
IVC PIV	60	26	76	57	43	85	59	2.4 (1.3-4.6)	.0018
DV PLI	48	20	56	66	42	77	63	1.4 (1.1-2.2)	.0410
DV S/a	46	21	58	70	46	80	66	1.7 (1.1-2.5)	.0045
DV RAV	9	6	17	96	67	52	72	4.6 (1.2-17.2)	.0217
UV pulsations	44	22	61	74	50	82	70	1.9 (1.3-2.9)	.0003
		pH < 7.00 +/or Base excess below-13 (n = 11)							
IVC PLI	65	6	60	43	9	92	42	1.1 (0.5-2.4)	NS
IVC PIV	60	8	80	50	13	96	52	2.5 (0.7-8.6)	NS
DV PLI	48	5	50	61	10	93	60	1.2 (0.6-2.3)	NS
DV S/a	46	5	50	62	11	93	61	1.3 (0.7-2.4)	NS
DV RAV	9	2	20	94	22	93	87	4.4 (0.8-7.2)	NS
UV pulsations	44	6	60	66	14	95	66	1.7 (0.8-3.6)	NS

All tests are Fishers exact tests.
Sens, Sensitivity; *Spec*, specificity; *PPV*, positive predictive value; *NPV*, negative predictive value; *LR*, Likelihood ratio.

Table VI Combination of abnormal venous Doppler parameters in the prediction of acidemia at birth

Abnormal Doppler result	N	pH < 7.20 (n = 36)	Sens	Spec	PPV	NPV	Test efficiency	LR (95% CI)	*P*-value
IVC PIV, DV S/a and pulsatile UV	26	14	41	84	54	76	71	1.4 (1.1-1.9)	.0067
IVC PIV and DV S/a	37	17	50	74	46	77	68	1.5 (1.1-2.1)	.0179
IVC PIV and UV pulsations	30	16	47	82	53	78	71	1.5 (1.1-2.2)	.0027
DV S/a and UV pulsations	30	17	50	83	57	79	72	1.7 (1.2-2.4)	.0009
Either vein abnormal	77	32	89	48	42	91	60	4.7 (1.8-12.4)	.0009
IVC PIV, or DV S/a abnormal	65	29	85	53	45	89	63	4.0 (1.7-9.5)	.0009
IVC PIV abnormal, or UV pulsations	73	32	89	52	44	92	63	5.4 (2-14.2)	.0009
DV S/a abnormal, or UV pulsations	59	25	70	61	42	83	63	2.4 (1.3-4.5)	.003
		pH < 7.00 +/or Base excess below-13 (n = 11)							
IVC PIV, DV S/a and pulsatile UV	26	4	36	78	15	92	72	1.2 (0.8-1.9)	NS
IVC PIV and DV S/a	37	5	46	68	14	92	66	1.7 (0.5-2.2)	NS
IVC PIV and UV pulsations	30	5	46	75	17	93	72	1.4 (0.8-2.4)	NS
DV S/a and UV pulsations	30	5	46	75	17	93	72	1.4 (0.8-2.4)	NS
Either vein abnormal	77	10	91	40	13	98	45	5.8 (0.8-44.2)	NS
IVC PIV, or DV S/a abnormal	65	10	90	45	15	98	50	6.9 (0.9-52.2)	NS
IVC PIV abnormal, or UV pulsations	73	10	91	43	14	98	48	6.7 (0.9-50.8)	NS
DV S/a abnormal, or UV pulsations	59	7	64	53	11	93	54	1.9 (0.6-6.1)	NS

analysis, we also included umbilical venous pulsations and absent, or reversed DV a-wave in our analysis.

In this large cohort of fetuses with severe IUGR (one third had a birth weight below the third percentile), the UV was the easiest vessel to examine satisfactorily, followed by the DV and then the IVC. Approximately 40% of the population had abnormal venous parameters. In the precordial veins, Doppler abnormality was associated with an increasing gradient between systole and a-wave. This relationship is most frequently abnormal when the IVC is analyzed by using the PLI. Rarely, forward flow during atrial systole is lost or even reversed in the DV. With exception of the IVC PVIV, all venous Doppler parameters, including DV a-wave reversal and umbilical venous pulsations, provide significant prediction of a low umbilical artery pH at birth without any apparent differences between individual venous Doppler parameters. Clinically, IVC Doppler indices and umbilical venous pulsations performed better by identifying a higher proportion of infants with significant metabolic compromise. In this population preselected by abnormal umbilical artery, Doppler velocimetry combined assessment of precordial veins and the UV improves prediction of acid-base status at birth without any apparent clinical and statistical difference between individual complications. Although, absence, or reversal of the

DV a-wave is the most specific indicator of a low umbilical artery, it is a finding that is too rare to be clinically useful. Our results raise several important aspects for venous Doppler surveillance in IUGR pregnancies.

The IVC is a direct tributary of the fetal heart, whereas the DV traverses the liver and is capable of changes in caliber and flow patterns in response alterations in fetal oxygenation and hepatic shunting.[10,18] There has been a theoretical argument that the IVC provides a more accurate depiction of the deteriorating fetal preload condition and therefore acid-base status,[4,8,10] whereas others maintain that the DV is superior in this respect.[5,16] Our results show that there are no clinically relevant appreciable differences between these vessels and that quantitative and qualitative umbilical venous Doppler waveform analysis is equally effective in the prediction of acid-base status at birth. It is of note that the predictive accuracy of Doppler index elevation in a single vessel was lower than that reported by Rizzo et al.[8] This may be due to the higher prevalence of acidemia in their patient collective and an adjusted cutoff level for an abnormal venous Doppler index that is based on their ROC analysis. We used both a categorical cutoff for the cord artery pH value and a 2 SD cutoff to define an abnormal Doppler index. However, the results of Hecher et al[16] also observed that the relationship between venous indices and cord pH may show a wide range of variation despite a significant decline in the median pH. These findings suggest that study methodology and normal biologic variation both account for the lower predictive accuracy observed in this study. These limitations in prediction are overcome when precordial veins and umbilical venous flow are examined in combination. Such an approach will identify the majority of neonates with an umbilical artery pH <7.20 as well as those with severe metabolic compromise. This improved accuracy appears to be primarily because of the validation of umbilical venous pulsations.

Umbilical venous pulsations are considered the ultimate reflection of increased central venous pressure observed in the late stages of fetal compromise and therefore also show a significant relationship with acid-base status. However, umbilical venous pulsations may have several causes, including oligohydramnios, alterations in placental afterload, changes in DV diameter, and fetal breathing patterns.[7,18-20] In our high-risk group of patients, the vast majority of fetuses with umbilical venous pulsations also had elevated precordial venous Doppler indices. Therefore, predictive accuracy was not significantly altered when the UV was examined in combination with any precordial vein. It is likely that this combination will be more effective in the prediction of acid-base balance in a lower-risk cohort, in which the number of fetuses with more "benign" causes for umbilical venous pulsations will be greater. In this setting the combined assessment of any precordial vein in combination with the UV is mandatory to prevent a false suspicion of fetal acidemia on the basis of isolated venous pulsations.

Finally, our data also suggest that there are several causes underlying the deterioration of acid-base status in IUGR fetuses. Cardiovascular and metabolic deterioration coincide in a significant proportion and can be effectively assessed with venous Doppler analysis. Other causes such as maternal factors, (sub)-acute alterations in placental perfusion,[21] accelerating decline in transplacental transport mechanisms, and fluctuations in cardiac lactate metabolism may be less well reflected. In this context the most comprehensive assessment of fetal acid-base balance may require combined assessment of venous Doppler and biophysical parameters.[1] Once these relationships have been clarified further, a randomized comparison of traditional monitoring tools, venous Doppler either in isolation or integrated with biophysical parameters is necessary to fully ascertain the merits of these surveillance methods in IUGR fetuses with placental dysfunction.[1]

Conclusion

Doppler ultrasound of the IVC, DV, and the UV predicts a low umbilical artery pH at birth in a significant proportion of fetuses with severe IUGR. Although individual Doppler parameters are predictive, combined assessment of precordial veins and the UV achieves better predictive accuracy. The choice of precordial vein and Doppler index can be largely guided by operator preference although familiarity with the examination technique of all 3 venous vessels offers the highest flexibility in clinical practice. All 3 veins should be evaluated, whereas any Doppler index can be used.

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