# Uterine and Umbilical Artery Flow Velocity Waveform Analysis in Pregnancies Complicated by Chronic Hypertension or Preeclampsia

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**ABSTRACT: Using continuous wave Doppler ultrasound, we studied the umbilical and uterine flow velocity waveforms in 68 pregnant women who had chronic hypertension and/or preeclampsia. The systolic-diastolic (S/D) ratio was considered an expression of vascular resistance peripheral to the point of insonation. Abnormal umbilical artery S/D ratio (>95th percentile) alone or with abnormal uterine artery S/D ratio was associated with poor pregnancy outcome as judged by incidence of intrauterine growth retardation (IUGR), cesarean section rate, birth weight, perinatal morbidity and mortality, and prematurity. In patients with preeclampsia and abnormal Doppler values, pregnancy outcome was poor, whereas in those with normal Doppler values, pregnancy outcome approached normal. The same relationship was also found in patients with chronic hypertension. The sensitivity and specificity for the prediction of IUGR by the umbilical artery S/D ratio alone was 71% and 93%, respectively. The uterine artery S/D ratio alone yielded a 66% sensitivity and 64% specificity, and when both tests were taken into account, the sensitivity increased to 75% and the specificity to 100%. Abnormal umbilical and uterine artery S/D ratios were associated with 100% IUGR and 25% perinatal mortality. We conclude that in pregnant women with hypertensive disorders there is a significant difference in pregnancy outcome between those with normal and those with abnormal Doppler values. Umbilical artery S/D ratio alone is a better predictor of IUGR and poor pregnancy outcome than the uterine artery S/D ratio.**

DOPPLER ULTRASONOGRAPHY has been used for the diagnosis of peripheral vascular disease for a significant number of years.[1] Since the late 1970s and early 1980s when computer technology became available for real-time spectral analysis of the Doppler signal, this technology has been used with increasing frequency in the obstetric diagnosis of maternal and fetal disease.[2] The pulsatility index (PI = systolic velocity − diastolic velocity ÷ mean velocity), the resistance index (RI = systolic velocity − diastolic velocity ÷ systolic velocity), and the systolic-diastolic ratio (S/D = systolic velocity ÷ diastolic velocity) have been used by a number of investigators to evaluate the placental resistance and the uterine artery resistance in both normal pregnancies and those complicated by intrauterine growth retardation (IUGR) and hypertensive disorders.[3-5]

Campbell et al,[3] using pulsed wave Doppler ultrasound to evaluate the resistance of the uterine artery and umbilical artery, found that in pregnancies complicated by chronic hypertension and/or preeclampsia, uterine and umbilical artery resistance is elevated by means of a high pulsatility index or a high resistance index. Fleischer et al[4] studied women with hypertension and found a significant elevation of uterine artery resistance due to a high systolic-diastolic ratio. They calculated the uterine artery S/D ratio from signals obtained from the right and left uterine arteries in the parametrial area. Trudinger et al[5] studied uterine artery flow velocity waveforms (FVWs) by evaluating the systolic-diastolic ratio, obtaining the signals for analysis from the subplacental artery vessels after placental localization with real-time ultrasonography.

Although there are differences in the resistance values reported by these three groups, all authors have found that both increased uterine artery resistance and increased umbilical artery resistance correlate significantly with pregnancy outcome. The differences in the findings of the three groups may be due to the different methodology used.

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**TABLE 1.** Comparisons of Clinical Parameters in Pregnancies With Abnormal and Normal Umbilical Artery Systolic-Diastolic (S/D) Ratios

| *Parameter* | *Abnormal Umbilical Artery S/D Ratio (n = 18)* | *Normal Umbilical Artery S/D Ratio (n = 50)* | P *Value* |
|---|---|---|---|
| Incidence of IUGR <10th percentile | 15 (71%) | 6 (12%) | <.0001 |
| Cesarean section rate | 17 (94%) | 25 (50%) | <.0001 |
| Proteinuria ($\bar{x}$ ± SE) | 2,914 ± 772 mg/24 hr | 1,089 ± 304 mg/24 hr | <.04 |
| Birth weight ($\bar{x}$ ± SE) | 1,560 ± 167 gm | 3,147 ± 107 gm | <.0001 |
| Mean arterial pressure ($\bar{x}$ ± SE) | 115 ± 0.32 MHz | 103 ± 2.68 MHz | <.004 |
| Gestational age at delivery ($\bar{x}$ ± SE) | 33.5 ± 1.03 wk | 38.2 ± 0.24 wk | <.0003 |
| Apgar <7 at 1 min | 10 (55%) | 8 (16%) | <.005 |
| Apgar <7 at 5 min | 4 (22%) | 0 ( 0%) | — |
| Perinatal mortality | 4 (22%) | 0 ( 0%) | — |
| Requiring admission to NICU | 13 (72%) | 4 ( 8%) | <.0001 |
| NICU stay (days $\bar{x}$ ± SE) | 48.30 ± 20.56 | 9.00 ± 2.48 | <.05 |

As more and more information becomes available, evidence suggests that evaluation of the umbilical artery and uterine artery resistance may be a clinically useful method of assessing both maternal-placental and fetal-placental compromise. We undertook this study to further evaluate continuous wave ultrasonic assessment of uteroplacental and fetal-placental blood supply in pregnancies complicated by chronic hypertension and/or preeclampsia.

## MATERIALS AND METHODS

We examined 68 pregnant women who came to the antenatal testing unit of our institution for evaluation of fetal well-being. A total of 165 Doppler examinations were done. Only the last examination before delivery was used for analysis. All patients were in the late second or in the third trimester of pregnancy. Thirty-six patients had chronic hypertension, seven had chronic hypertension with superimposed preeclampsia, and 25 had preeclampsia. The patients with preeclampsia and superimposed preeclampsia were analyzed as one group because the Doppler and clinical parameters were all similar. The diagnosis of chronic hypertension was made if the patient was known to be hypertensive before pregnancy or if her mean arterial pressure (diastolic + 1/3 [systolic-diastolic] blood pressure) was ≥90 torr on more than two occasions before 20 weeks' gestation.[6] The diagnosis of preeclampsia was based on the presence of hypertension, proteinuria, and edema in the absence of a history of chronic hypertension. Growth charts appropriate for our population were used to classify the infants.[7] Infants with birth weight ≤10th percentile were classified as small for gestational age (SGA). Doppler data were not used in the management of the patients. The study was approved by the Clinical Research Practices Committee, and all patients gave written informed consent.

The FVWs were obtained with the mother lying comfortably in a left lateral tilt. A continuous wave Doppler device operating at the frequency of 4 MHz was used. The device is equipped with a spectrum analyzer for on-line real-time flow velocity waveform analysis of the Doppler shift signal. The uterine artery FVWs (UtA FVWs) were obtained first. The signal was obtained by placing the Doppler transducer 2 to 3 cm medial to the anterior superior iliac spine. Subsequently, the transducer was pointed laterally and downward toward the parametrial area where the ascending branch of the uterine artery travels along the lateral uterine wall and gives off the arcuate branches. This landmark permits regional consistency and reproducibility of FVWs. Flow velocity waveform patterns were used to identify the proper signal. We believe that these flow velocity waveforms obtained by this method originate from the arcuate arteries or from the ascending branch of the uterine artery. When the appropriate waveforms were obtained, the systolic and diastolic velocities were measured with the use of electronic calipers on the frozen display. Two measurements were obtained from each side, and the mean of the four measurements (UtA S/D ratio) was used for analysis. The umbilical artery flow velocity waveforms (UA FVWs) were obtained by placing the transducer over the fetal small parts after their position was determined by Leopold's maneuvers. Pattern recognition was used to identify the fetal umbilical artery, and an effort was made to always include the umbilical vein in the opposite direction of the umbilical artery during periods of fetal apnea. Four measurements were obtained at four different angles to sample the signals from four different places on the umbilical cord in an effort to obtain representative measurements of a significant length of the cord. The peak systolic and the lowest end diastolic frequencies were measured with electronic calipers on the frozen display, and an S/D ratio was calculated. The intraobserver

**TABLE 2.** Comparisons of Doppler Values Between SGA and AGA Infants and Between Patients With Preeclampsia (PE) and Those With Chronic Hypertension (CH)

| *Doppler Parameter* | *Condition* | $\bar{x} \pm SE$ | *Condition* | $\bar{x} \pm SE$ | P *Value* |
|---|---|---|---|---|---|
| Umbilical artery S/D ratio | SGA | 3.88 ± 0.33 | AGA | 2.33 ± 0.10 | <.0003 |
| | PE | 3.34 ± 0.24 | CH | 2.49 ± 0.15 | <.007 |
| Uterine artery S/D ratio | SGA | 3.49 ± 0.29 | AGA | 2.68 ± 0.15 | <.02 |
| | PE | 3.24 ± 0.24 | CH | 2.63 ± 0.15 | <.04 |

SGA = small for gestational age.
AGA = appropriate for gestational age.

coefficient of variation is 8%.

The uterine artery (UtA) and umbilical artery (UA) S/D ratios were classified as abnormal if they exceeded the 95th percentile of our normal population. Comparisons of various clinical and laboratory parameters were made by two-tailed Student's *t* test for independent groups and by the Mann-Whitney test when appropriate. For comparison of frequencies between groups, the chi-square test was used. Pearson's correlation was used to explore the relationship between the UA S/D ratio and birth weight. A *P* value of less than 0.05 was considered statistically significant.

## RESULTS

Analysis of the data according to UA S/D ratio reveals two distinct groups. When the UA S/D ratio was abnormal, the pregnancy outcome was poor, as judged by the incidence of IUGR, cesarean section rate, proteinuria, birth weight, mean arterial pressure, gestational age at delivery, perinatal mortality and morbidity, and Apgar scores at one minute and five minutes. The differences in these factors between the group with normal and the group with abnormal UA S/D ratios were highly significant (Table 1). The UA S/D ratio was abnormal in 18 patients; 17 of them (94%) had delivery by emergency cesarean section for fetal and/or maternal hypertensive complications and one by spontaneous vaginal delivery. Of the 50 patients whose UA S/D ratio was normal, only 11 (22%) had emergency cesarean section, 14 (28%) had cesarean section for obstetric indications not related to hypertension, and 25 (50%) had vaginal delivery. All of the 18 fetuses with abnormal UA S/D ratio were born alive, but four died in the postnatal period (22% perinatal mortality). In this group of infants, 13 (72%) required NICU admission for growth retardation, prematurity, or perinatal asphyxia, and stayed an average of 48 days. All 50 fetuses with normal umbilical artery S/D ratio were born alive and were discharged home in good health. Only four (8%) of these infants required admission to the NICU for prematurity and stayed an average of nine days. All were discharged home in good health.

When the patients were separated into groups according to fetal growth (small vs appropriate for gestational age) and hypertensive condition (preeclampsia vs chronic hypertension), comparisons of Doppler parameters showed significant differences (Table 2). Twenty patients with preeclampsia (63%) had a UtA S/D ratio above the 95th percentile, as compared with 11 (30%) of the patients with chronic hypertension. When the UtA S/D ratios for each patient were examined individually, 23 (72%) of the patients with preeclampsia had at least one uterine artery with an S/D ratio above the 95th percentile. Only 13 (36%) of the patients with chronic hypertension had at least one uterine artery with an abnormal S/D ratio. The mean UtA S/D ratio in patients with chronic hypertension was within the normal range, whereas in patients with preeclampsia it was above the 95th percentile (2.63 ± 0.18 vs 3.24 ± 0.21 [$\bar{x} \pm$ SE], $P < .04$).

Among the 32 patients with preeclampsia, abnormal UA S/D ratio was associated with SGA infants in 86%; 71% of these infants required admission to the NICU and 21% died before discharge. When the UA S/D ratio was normal only 16% of the infants were SGA, 16% required admission to the NICU, and all were discharged home in good health. In the patients with chronic hypertension (n = 36) the results were similar (Fig 1).

In the group of patients who had preeclampsia, there was a highly significant negative linear correlation between the UA S/D ratio and the birth weight ($r = -0.74$, $P < .0001$). In patients with chronic hypertension but without preeclampsia, a negative linear correlation was also found between UA S/D ratio and birth weight, but this relationship was weaker ($r = -0.47$, $P < .005$).

Figure 2 shows the distribution of SGA and AGA infants and the perinatal mortality according to UA and UtA S/D ratio. When both UA and UtA were abnormal, all infants were SGA and the perinatal mortality was 25%. When both vessels were normal, the incidence of SGA was only 13%, and there was no perinatal mortality. The combination of abnormal UA S/D ratio and

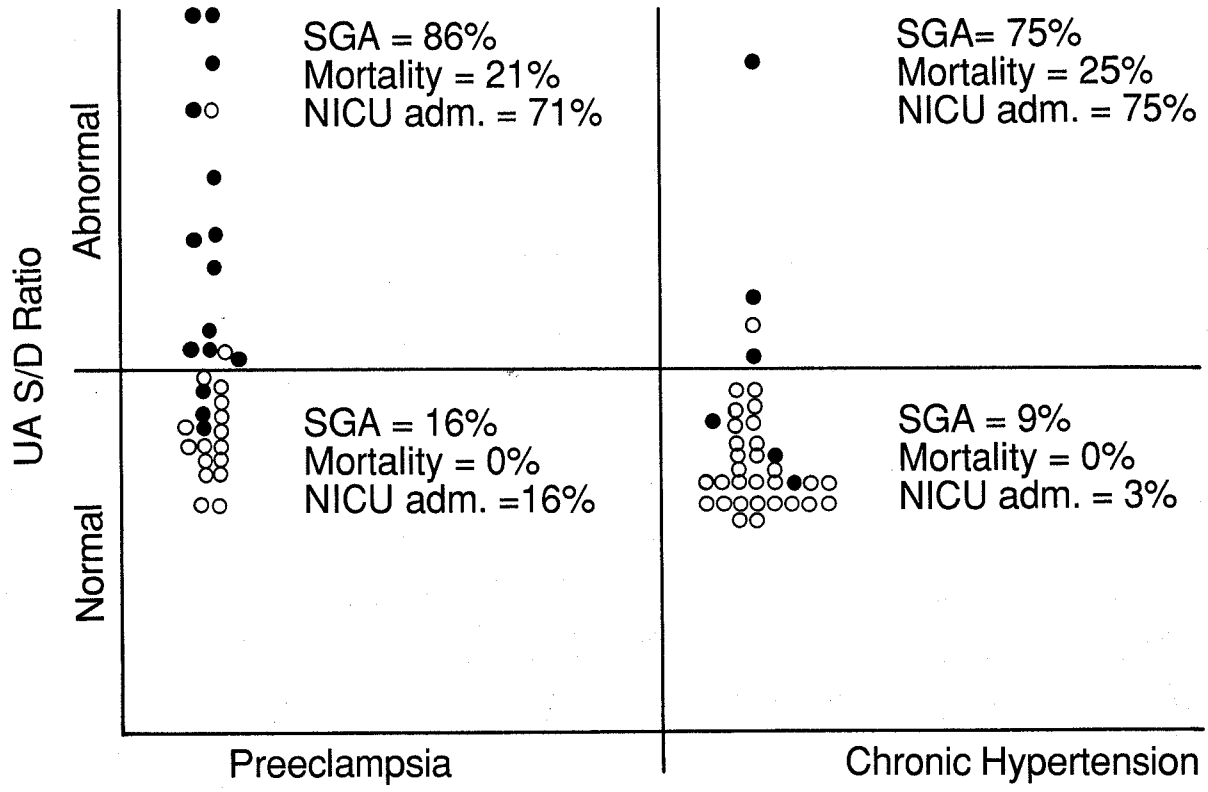


**FIGURE 1.** Distribution of patients according to UA S/D ratio and hypertensive condition. Solid circles represent infants who were small for gestational age; open circles represent infants appropriate for gestational age.

normal UtA S/D ratio was associated with a 50% incidence of SGA and 17% perinatal mortality. When the UA S/D ratio was normal, regardless of the UtA S/D ratio value, the incidence of SGA fetuses was very small and perinatal mortality was 0%.

Thirty-eight of the patients had diastolic notching in the uterine artery FVW; 21 of them (55%) were preeclamptic and the rest (45%) had chronic hypertension. The presence or absence of notching did not influence the results because when there was notching of the uterine artery, the uterine artery S/D ratio was also above the normal range in 87% of our patients.

Table 3 demonstrates the sensitivity, specificity, and predictive values of the two measurements individually and in combination.

## COMMENT

The use of Doppler ultrasound appears to be useful in the evaluation of circulatory changes taking place in the uteroplacental and fetoplacental circulations. Normal development of the uteroplacental and fetoplacental circulation results in two low resistance vascular systems.[8] Pathology studies of the subplacental vessels in human pregnancy complicated by preeclampsia have shown the existence of limited trophoblastic invasion and poor vascular development.[9] This in turn is associated with increased vascular resistance. Poor vascular development of the placenta has been associated with abnormal flow velocity waveforms in human umbilical artery, and embolization of the placenta in sheep resulted in abnormal umbilical artery flow velocity waveforms.[10,11]

In this study, we found significant differences in the severity of the disease and its complications according to flow velocity waveform values. Normal and abnormal umbilical artery S/D ratios divided the patients into two distinct groups—one group with clinical and laboratory parameters that approached normal, with a pregnancy outcome as good as that of a normal pregnancy, and another group with abnormal clinical and laboratory parameters and poor pregnancy outcome. These results are in agreement with those of others.[3-5]

**TABLE 3.** Sensitivity, Specificity, Postitive Predictive Value (PPV), and Negative Predictive Value (NPV) of Various Doppler Parameters for Prediction of SGA Fetuses

| *Doppler Parameters* | *Sensitivity* | *Specificity* | *PPV* | *NPV* |
|---|---|---|---|---|
| Umbilical artery S/D ratio | 71 | 93 | 83 | 90 |
| Mean UA S/D ratio | 66 | 64 | 45 | 81 |
| Mean UA and UA S/D ratio | 75 | 100 | 100 | 86 |

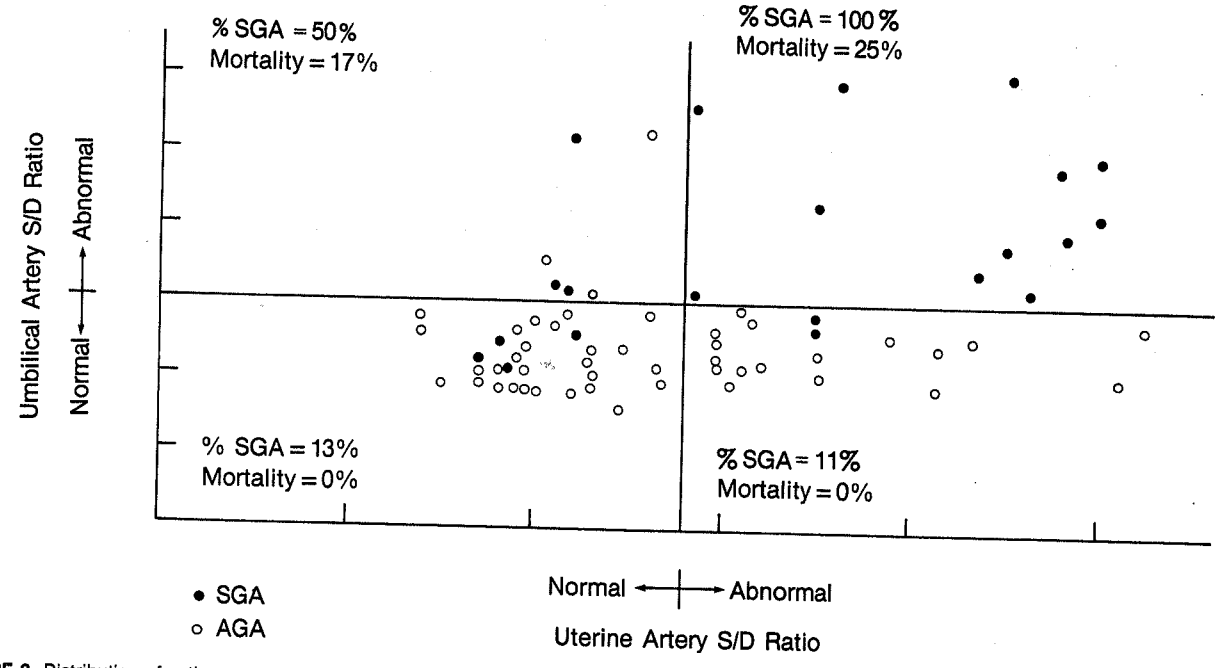


**FIGURE 2.** Distribution of patients according to Doppler values. Solid circles represent infants small for gestational age, and open circles, those appropriate for gestational age.

In pregnancies with SGA fetuses the UA and UtA FVWs were likely to be abnormal, whereas in pregnancies with AGA fetuses the Doppler values were likely to be normal. A similar relationship exists between Doppler values and the presence or absence of preeclampsia. The UA S/D ratio relates better to severity of maternal disease and to perinatal outcome because in the majority of the patients with abnormal UA S/D ratio the UtA S/D ratio is also abnormal and the clinical condition severe. When both UA and UtA FVWs were abnormal, poor pregnancy outcome was a certainty. When only the UtA FVWs were abnormal the most common problem was premature delivery for maternal indications, but the perinatal outcome approached that of normal patients.

Preeclampsia and chronic hypertension are clinical conditions that in themselves predispose to poor pregnancy outcome. The clinical significance of Doppler FVW analysis in these groups becomes apparent by its ability to identify the patients who will be adversely affected by preeclampsia or chronic hypertension. This ability can be a useful clinical adjunct in the management of such patients.

It has been speculated that early development of preeclampsia with prolonged duration leads to pathologic flow velocity waveforms in both the uterine and umbilical arteries, whereas acute development with short duration affects only the uterine artery.[12] Unsuccessful attempts at trophoblastic invasion of the spiral and radial arteries leads to increased uterine artery resistance, and has been strongly associated with preeclampsia and intrauterine growth retardation.[9] Our data support this speculation, since the majority of the patients with abnormal UtA FVWs have normal UA FVWs. In some of our patients who had longitudinal follow-up (unpublished data), the uterine artery FVWs were abnormal for weeks before the development of UA FVW changes. There are cases, however, in which the UA FVWs are abnormal and the UtA FVWs normal in the presence of preeclampsia. This certainly does not fit into the mechanism mentioned, and it may be suggestive of a different pathogenetic mechanism originating from the fetus.

In summary, our report confirms the clinical significance of uterine and umbilical artery flow velocity waveform analysis in patients with chronic hypertension and/or preeclampsia. Hypertensive patients with normal FVW analysis have pregnancy outcome comparable to that of uncomplicated pregnancies, whereas abnormal FVWs are associated with poor maternal and fetal outcome.

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