Detection of umbilical venous constriction by Doppler flow measurement at midgestation

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KEYWORDS: Doppler velocimetry; hypercoiled cord; hypocoiled cord; umbilical ring constriction; umbilical venous pulsation

ABSTRACT
Objectives To investigate whether umbilical venous velocity and venous velocity pulsation are associated with umbilical vein diameter, umbilical ring diameter and umbilical cord coiling index at midgestation.
Methods Two hundred and eighty pregnant women were enrolled in the study at between 18 and 24 weeks of gestation. The diameter of the umbilical cord and internal diameter of the umbilical vein in a free loop and at the ring, and the umbilical coiling index, were measured using ultrasonography. Umbilical venous velocities were measured by Doppler ultrasonography at the umbilical ring and a free loop of the cord.
Results All variables were successfully measured in 92% of the patients. There were negative correlations between the diameters of the umbilical ring and of the umbilical vein at the ring and the venous velocity at the umbilical ring. The venous velocity at the umbilical ring was significantly higher and the umbilical ring diameter was significantly lower in fetuses with umbilical venous pulsation at the free loop. Significant correlations were observed between the venous velocity and amplitude of pulsation. Venous pulsations at the free loop were frequently observed in fetuses with a hypercoiled cord.
Conclusion High venous velocity and increased venous pulsation at the umbilical ring may be associated with umbilical cord constriction. Copyright © 2010 ISUOG. Published by John Wiley & Sons, Ltd.

INTRODUCTION
Hypercoiled cord and constriction at the umbilical ring are often observed in stillborn fetuses, and the prenatal assessment of these pathological conditions has been addressed in several studies. An extremely coiled cord at the umbilical ring is associated with sudden fetal death. However, few fetuses in which hypercoiled cord is diagnosed antenatally are actually compromised during pregnancy or delivery. Unfortunately, there is no method for assessing the likelihood of fetal compromise in fetuses with hypercoiled cord.

The purpose of this study was to investigate whether umbilical venous velocity and velocity pulsation are associated with umbilical vein diameter, umbilical ring diameter and umbilical cord coiling index (UCI) at 18–24 weeks' gestation.

PATIENTS AND METHODS
Two hundred and eighty women with uncomplicated pregnancy underwent ultrasound examination at between 18 and 24 weeks of gestation between March 2008 and March 2009. Only cases of singleton pregnancy with no detectable fetal structural abnormalities were included in the study. Ultrasound examinations were performed with a Sonovista color FD machine (Mochida Inc., Tokyo, Japan) equipped with a multifrequency transabdominal transducer (3.5 and 5.0 MHz). Gestational age was determined by a sonographic examination prior to 14 weeks of gestation. Informed consent was obtained in writing from all patients before scanning. Sonographic measurements were performed to determine the external diameter of the umbilical cord and maximum internal diameter of the umbilical vein in a free loop (Figure 1a), and the maximum internal diameter of the umbilical ring and internal diameter of the umbilical vein at the ring (Figure 1b). The antenatal UCI was calculated by measuring the distance between two adjacent coils of the umbilical artery from the right outer surface of the vascular wall to its next twist (antenatal UCI = 1/distance in cm). All cases were stratified by UCI.

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Cases with UCI above the 90th percentile were classified as hypercoiled cord, cases with UCI below the 10th percentile as hypocoid cord and the others as normocoiled cord.

Maximum umbilical venous velocities (Vmax) were measured by Doppler ultrasonography with angle correction within 60° at the umbilical ring and free loop of the umbilical cord (Figures 1c and d). The presence of umbilical venous pulsation (UVP) was defined visually as a velocity variation synchronized with the fetal heart rate. The amplitude of pulsation waves between the maximum and minimum velocities (UVPa) was measured when pulsation was visualized (Figure 1d).

The relationship among these parameters was evaluated after standardization using the Z-score, defined as (measurement value – mean)/SD. Z-scores for measurements of each of the diameters and for UCI were calculated according to regression formulae against gestational age, and for venous velocities the Z-scores were calculated using the overall mean and SD.

The examiners were two obstetricians (J.H. and T.M.) who are well trained in ultrasound scanning. When all measurements could not be obtained within 10 min, the examination was defined as unsuccessful. Each measurement was performed two or more times and the values were averaged. In a convenience sample of patients who were not included in the main study analysis, intra- and interobserver variation in measurements of the umbilical ring diameter and venous velocity were assessed using the coefficient of variation with 95% confidence intervals (CI).

The data were entered into a computerized data analysis program (StatView for windows, SAS Institute, Inc., Cary, NC, USA). Continuous variables were compared using independent sample t-test for means. Categorical variables were reported as percentages and compared using the chi-square test. Multiple comparisons were made using an analysis of variance and the Bonferroni post-hoc test. Statistical significance was defined as P < 0.05.

RESULTS

Full measurements were successfully obtained in 258 of 280 fetuses (92%). There were significant correlations...
between gestational age (in days) and each of the diameters measured: the umbilical cord \( r = 0.454, \ P < 0.0001 \), umbilical vein at the free loop \( r = 0.529, \ P < 0.0001 \), umbilical ring \( r = 0.275, \ P < 0.0001 \) and umbilical vein at the umbilical ring \( r = 0.186, \ P < 0.01 \), though the venous velocity was not found to correlate with gestational age in our study group. The UCI significantly decreased with advancing gestation according to the equation:

\[
\text{mean UCI} = (0.00004 \times \text{GA}^2) - (0.0162 \times \text{GA}) + 1.9546, \quad r^2 = 0.0625,
\]

where GA is gestational age in days. The intra- and interobserver variations (95% CI) were 7.4 (5.0–9.9)% and 8.7 (6.3–11.1)% for the venous velocity \( n = 12 \), and 2.2 (1.2–3.2)% and 2.6 (1.4–3.8)% for the umbilical ring diameter \( n = 17 \), respectively.

Analysis of the relationships between the Z-scores of umbilical vein and ring diameters and umbilical venous velocities showed no significant correlations except for those between the diameter of the umbilical ring and of the umbilical vein at the ring, and Vmax at the umbilical ring, both of which showed a negative correlation (Figure 2).

The values of Z-scores of the measured parameters according to the presence or absence of UVP in the umbilical ring and in a free loop of the umbilical cord are shown in Table 1. UVPs were present at the umbilical ring in 36% of fetuses and at the free loop in 15% of fetuses. Vmax at the umbilical ring was significantly higher in fetuses with UVP present at the umbilical ring and in those with UVP present at the free loop of the umbilical

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**Table 1. Z-scores of each variable and umbilical venous pulsation at the umbilical ring and free loop**

<table>
<thead>
<tr>
<th></th>
<th>UVP at umbilical ring</th>
<th>UVP at free loop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absent ( (n = 165 \ (64%)) )</td>
<td>Present ( (n = 93 \ (36%)) )</td>
</tr>
<tr>
<td><strong>Umbilical ring</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ring diameter</td>
<td>( 0.02 \pm 1.05 )</td>
<td>(-0.12 \pm 0.90 )</td>
</tr>
<tr>
<td>Vein diameter</td>
<td>( 0.09 \pm 0.99 )</td>
<td>(-0.14 \pm 1.01 )</td>
</tr>
<tr>
<td><strong>Free loop</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cord diameter</td>
<td>( 0.08 \pm 0.99 )</td>
<td>(-0.13 \pm 1.02 )</td>
</tr>
<tr>
<td>Vein diameter</td>
<td>( 0.07 \pm 0.103 )</td>
<td>(-0.10 \pm 0.93 )</td>
</tr>
<tr>
<td>Coiling index</td>
<td>(-0.23 \pm 0.97 )</td>
<td>(-0.19 \pm 1.05 )</td>
</tr>
<tr>
<td>Vmax</td>
<td></td>
<td></td>
</tr>
<tr>
<td>At umbilical ring</td>
<td>(-0.26 \pm 0.86 )</td>
<td>(0.47 \pm 1.05^* )</td>
</tr>
<tr>
<td>At free loop</td>
<td>(-0.07 \pm 0.98 )</td>
<td>(0.13 \pm 1.02 )</td>
</tr>
</tbody>
</table>

Data are given as mean ± SD Z-score. *Statistically significant by t-test \( P < 0.01 \). Vmax, maximum venous velocity.

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Table 2 Z-scores of maximum venous velocities and frequencies of umbilical venous pulsation (UVP) at the umbilical ring and the free loop stratified by coiling index

<table>
<thead>
<tr>
<th>Coiling index</th>
<th>&lt; 10th percentile (hypocoiled)</th>
<th>Normal (n = 205)</th>
<th>&gt; 90th percentile (hypercoiled)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 26)</td>
<td></td>
<td>(n = 27)</td>
</tr>
<tr>
<td>Z-score of Vmax</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At umbilical ring</td>
<td>0.39 ± 1.13</td>
<td>-0.04 ± 0.94</td>
<td>-0.04 ± 1.16</td>
</tr>
<tr>
<td>At free loop</td>
<td>0.78 ± 1.56*</td>
<td>-0.13 ± 0.85</td>
<td>0.21 ± 1.00</td>
</tr>
<tr>
<td>UVP present</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At umbilical ring</td>
<td>13 (30)</td>
<td>68 (33)</td>
<td>12 (44)</td>
</tr>
<tr>
<td>At free loop</td>
<td>6 (23)</td>
<td>22 (11)</td>
<td>10 (37)†</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD or n (%). *Statistically significant difference from normal by ANOVA and Bonferroni post hoc test (P < 0.01). †Statistically significant difference from normal by chi-square test (P < 0.01). Vmax, maximum venous velocity.

![Figure 3](image-url) Scatter plots showing correlation between maximum venous velocity and amplitude of pulsation: (a) at the umbilical ring (r = 0.487, P < 0.001) and (b) at the free loop (r = 0.287, P < 0.001).

DISCUSSION

Although the venous diameters and velocities in the umbilical cord should also be assessed during the third trimester to identify high-risk fetuses with umbilical venous constriction, our study period (18–24 weeks' gestation) was selected because measurement of velocities at the umbilical ring is more difficult with advancing gestational age. The size and flow velocity of the umbilical cord were successfully measured in most of the subjects enrolled in the study.

Congestion in the umbilical vein due to hypercoiled cord causes reduced compliance, which enhances the induction of velocity pulsation. The main origin of venous pulsation at the umbilical ring is the neighboring umbilical artery. The umbilical ring tightens around the three vessels, thus reducing compliance at this point and facilitating the transmission and induction of a pulse in the vein. The UVP was more frequently observed at the umbilical ring (36%) than at the free loop (15%) in the current study. Furthermore, not only was Vmax higher in fetuses with UVP than in those without at both the...
umbilical ring and the free loop, but a significant correlation was also observed between Vmax and UVPa. These results suggest that umbilical venous pulsations occur more often in umbilical veins that are narrow, as indicated by higher venous flow velocity, in fetuses such as those with hypercoiled cord and umbilical ring constriction.

There was a significant negative correlation between the diameter of the umbilical ring and Vmax at the umbilical ring. This result suggests that umbilical ring constriction increases venous velocity. However, there was no difference in umbilical ring diameter between fetuses with and without UVP at the umbilical ring, whereas Vmax was significantly higher in fetuses with UVP than without. Skulstad et al.2,3,9 also found, in their evaluation of umbilical venous velocity and umbilical ring constriction, that since it was a very short section of the vein that was narrowed, the diameter was difficult to assess with confidence. They therefore recommended velocity measurement as a better method for identifying strictures. Our results support a similar conclusion.

A coiled umbilical cord with the support of Wharton's jelly is thought to be more resistant to torsion, stretch and compression. However, an extremely coiled cord is less flexible and more prone to kinking and torsion during labor, potentially leading to fetal hypoxia and poor perinatal outcome.10-13. Degani et al.5 found that the antenatal UCI is higher than the postnatal UCI (0.44 ± 0.11 vs. 0.28 ± 0.08, P < 0.001). Furthermore, the antenatal UCI is lower in the third trimester than in the second trimester.16. We found that the 90th, 50th and 10th percentiles of the UCI were 0.578, 0.370 and 0.226, consistent with previous work.13. Whereas ring constriction and UVP are often observed in pathological fetuses owing to hypercoiled cord, there were no significant correlations between the degree of umbilical coiling and occurrence of UVP at the umbilical ring in this normal population at midgestation.

Previous observations at the free loop have indicated that umbilical coiling does not significantly influence arterial Doppler measurements, while hypercoiled cord could be associated with venous blood flow pulsatile patterns in severe circulatory compromise. Predanic et al.19 noted that increased umbilical coiling was strongly associated with increased umbilical vein blood flow, and suggested that a direct correlation between increased cord coiling and increased venous flow could be explained by a ‘piston’ or pulsometer effect. In our study, UVP at the free loop was frequently observed not only in fetuses with hypercoiled cord, but also in fetuses whose venous velocity at the ring was high. Therefore, we think that UVP at the free loop can originate from both hypercoiled cord and a narrow umbilical ring.

Our study is limited by its cross-sectional design. Acharya et al.19 demonstrated in a longitudinal study that fetuses with high umbilical venous velocity at the umbilical ring in the first half of pregnancy can subsequently have lower velocity, and vice versa in the second half of pregnancy. Interestingly, they hypothesized that a varying degree of constriction is a physiological method of regulating umbilical venous pressure in the cord and the placenta. Umbilical venous constriction at the umbilical ring is a dynamic process and is not permanent.19. Though dynamic processes of the umbilical ring could not be evaluated in this study, we believe that some fetuses may maintain high umbilical venous velocities owing to permanent narrowing of the umbilical vein caused by severe hypercoiled cord, complex cord entanglement or complicated kinking.

The current series included one case in which there was intrauterine fetal death due to an umbilical ring constriction with a hypercoiled cord. Ultrasound examination at 20 + 5 weeks indicated a vein diameter of 3.6 mm (±1.7 SD) at the free loop, a vein diameter of 3.0 mm (±0.7 SD) at the umbilical ring, a UCI of 0.78 (±2.5 SD), and Vmax of 15 cm/s (±0.2 SD) and 49 cm/s (+4.0 SD) at the free loop and the umbilical ring, respectively, with strong venous pulsation. When the mother presented with a lack of fetal movement at 22 + 5 weeks, no fetal heart beat could be detected. Umbilical ring constriction with hypercoiled cord was observed after delivery. We hypothesize that in this case there was permanent narrowing at the umbilical ring due to hypercoiled cord. If sonographic findings indicate only high venous velocity at the umbilical ring, the constriction at the ring might be temporary. However, if findings of umbilical constriction with hypercoiled cord are detected, permanent narrowing of the umbilical ring should be considered.

In conclusion, our results suggest that fetuses with high umbilical venous velocity and increased umbilical venous pulsation at the ring are associated with cord constriction.

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