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Ductus venosus blood flow velocity characteristics of fetuses with single umbilical artery

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KEYWORDS: Doppler; ductus venosus; single umbilical artery; umbilical vein

ABSTRACT

Objectives *Sonographic Doppler evaluation of the fetal ductus venosus has been proved to be useful in the evaluation of fetal cardiac function. The aim of this study was to investigate the ductus venosus blood flow profile in fetuses with single umbilical artery and to correlate it with the umbilical cord morphology.*

Methods *Fetuses at > 20 weeks' gestation with single umbilical artery who were otherwise healthy were consecutively enrolled into the study. The sonographic examination included evaluation of the following Doppler parameters: umbilical artery resistance index, maximum blood flow velocity of the ductus venosus during ventricular systole (S-peak) and atrial contraction (A-wave), ductus venosus time-averaged maximum velocity (TAMXV), and pulsatility index for veins (PIV). The cross-sectional area of the umbilical cord and its vessels were measured in all cases. The Doppler and morphometric values obtained were plotted on reference ranges.*

Results *A total of 88 fetuses with single umbilical artery were scanned during the study period. Of these 52 met the inclusion criteria. The S-peak velocity, A-wave velocity, and TAMXV were below the 5th centile for gestational age in 57.7%, 59.6%, and 57.7% of cases, respectively. The PIV was within the normal range in 80.1% of cases. The umbilical vein cross-sectional area of fetuses with single umbilical artery was above the 95th centile for gestational age in 34.6% cases.*

Conclusions *The ductus venosus blood flow pattern is different in fetuses with single umbilical artery from that in those with a three-vessel cord. This difference may be caused in part by the particular morphology of umbilical cords with a single artery. Copyright © 2003 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

The presence of a single umbilical artery (SUA), a condition that occurs only in humans, represents the most frequent fetal anomaly, with an incidence at delivery of approximately 1%[1].

Several studies have investigated the umbilical cord morphology and the Doppler blood flow characteristics of a number of fetal and extrafetal arteries in fetuses with SUA[2–6]. Persutte and Lenke[7] and others[8,9] noted that the SUA is usually larger than are the arteries of normal umbilical cords. Raio *et al.*[9] demonstrated that not only the artery but also the vein is larger in umbilical cords with SUA compared with those with three vessels. Abuhamad *et al.*[10] found that in fetuses with SUA the left artery is more commonly absent than is the right artery. Finally, Lacro *et al.*[11] reported that umbilical cords of fetuses with SUA are characterized by a lower number of coils compared with three-vessel cords.

Moreover, it has been reported that the arterial impedance to blood flow of an umbilical cord with SUA does not differ from that of a three-vessel umbilical cord due to compensatory dilatation of the single artery[2,3,7–9]. Sepulveda *et al.*[6] investigated the iliac artery and femoral artery waveforms in fetuses with SUA and found asymmetrical arterial blood flow patterns in the pelvic and lower extremities. Conversely, the Doppler flow characteristics of the venous compartment of fetuses with SUA have not yet been fully investigated.

In fetuses with a three-vessel cord, the Doppler flow characteristics of the fetal venous compartment have been

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extensively evaluated to identify fetuses at increased risk of hypoxia[12–15]. The assessment of the ductus venosus blood flow pattern has proved to be a valid indicator of fetal compromise due to cardiac dysfunction[12].

The purpose of this study was to investigate the blood flow characteristics of the ductus venosus of healthy fetuses with SUA.

METHODS

Consecutive patients referred for fetal sonographic evaluation at a gestational age > 20 weeks were considered eligible for the study. Inclusion criteria were: 1) absence of fetal structural abnormality; 2) normal karyotype; 3) intact membranes; 4) known gestational age; 5) normal amniotic fluid volume; 5) an umbilical cord with SUA.

The karyotype was considered normal depending on the results of chorionic villus sampling or amniocentesis or in the absence of neonatal phenotypic features suggestive of chromosomal abnormality. In patients with SUA and an otherwise structurally normal fetus, fetal karyotyping was not usually performed. Gestational age was determined by reliable recollection of the last menstrual period and by a sonographic examination within the first 20 weeks of gestation.

A targeted sonographic evaluation of the umbilical cord was performed using a commercially available ultrasound machine (Sequoia 512, Acuson Co. CA, USA or Aloka 1700 Dyna view II, Aloka, Tokyo, Japan) equipped with a 3.5/3.75- or 5-MHz transducer. The presence of a SUA was confirmed and the cross-sectional area of the umbilical cord and its vessels were measured as described previously[9]. Briefly, the sonographic cross-sectional areas of the umbilical cord, the SUA and the umbilical vein were calculated at the maximum magnification. The ellipse function of the ultrasound machine was used in all cases and the best-fitting ellipse was placed over the umbilical cord and vessels. The measurements were performed at three different parts of a free-floating loop of the umbilical cord and the average of three measurements was taken for statistical purposes. Intra- and interobserver variability were 3.4% and 4.0% for the artery and 2.2% and 3.4% for the vein, respectively. Color Doppler was utilized to visualize the umbilical arteries as they coursed around the bladder and whether the missing artery was on the left or the right side was documented.

Pulsed Doppler interrogation of the umbilical artery and of the ductus venosus was performed at a power output of < 100 mW/cm^2 spatial peak temporal average and with a 100-Hz high-pass filter. The size of the sample volume was adapted to the vessel diameter. Flow velocity waveforms were recorded during fetal apnea and, when at least three consecutive waveforms showing a consistent pattern were obtained, the resistance index (RI) was calculated. Using color Doppler, the ductus venosus was identified either in a mid-sagittal longitudinal plane of the fetal trunk or in an oblique transverse plane through the upper abdomen. The median angle between the ultrasound beam and the direction of blood flow was 24° (range, 0–53°). Angle correction was performed in all cases and the following parameters were measured at the level of the isthmic portion of the ductus venosus: 1) peak velocity during ventricular systole (S-peak); 2) peak velocity during atrial contraction (A-wave); 3) time-averaged maximum velocity (TAMXV); 4) the pulsatility index for veins (PIV). The PIV was calculated as previously described (S-peak – A-wave/TAMXV).

Umbilical cord morphometric and Doppler values as well as ductus venosus Doppler values were plotted on reference ranges[14]. Each patient was included only once. When a patient underwent more than one examination, only the first one was considered for the purposes of this study.

The presence of a SUA was confirmed after delivery in all cases.

RESULTS

From January 1999 to April 2002 a total of 88 fetuses with SUA were identified. Of these, 33 cases were excluded because of the following reasons: gastrointestinal anomalies ($n = 7$), urogenital anomalies ($n = 6$), cardiovascular anomalies ($n = 3$), skeletal anomalies ($n = 5$), central nervous system anomalies ($n = 4$), multiple anomalies ($n = 6$), trisomy 18 ($n = 2$). Three cases were not included because the Doppler signal at the level of the ductus venosus was not clear. The clinical characteristics of the 52 patients included in the study are presented in Table 1.

The ductus venosus S-peak velocities, A-wave velocities and TAMXVs of the study population plotted on reference ranges[14] are displayed in Figures 1, 2 and 3, respectively. The S-peak velocity, A-wave velocity and TAMXV were below the 5th centile for gestational age in 29 (55.8%), 31 (59.6%) and 30 (57.7%) cases, respectively. Figure 4 shows the ductus venosus PIV of the study population plotted on reference ranges. The PIV of fetuses with SUA was above the 95th centile in 13 (25.0%) cases and above 2 SD from the mean for gestational age in 10 (19.2%) cases.

The umbilical cord and umbilical vein cross-sectional areas are presented in Figures 5 and 6, respectively. The umbilical cord cross-sectional area was below the 5th centile for gestational age in 19 (36.5%) cases. The umbilical vein cross-sectional area of fetuses with SUA was above the 95th centile for gestational age in 18 (34.6%) cases. The umbilical artery was above 12.6 mm^2

Table 1 Patient characteristics

Characteristic	*Value* (n = *52)*
Maternal age (years, mean ± SD)	29.7 ± 5.7
Gestational age at ultrasound (weeks, median (range))	32.4 (20.6–40.2)
Gestational age at delivery (weeks, median (range))	39.5 (33.2–42.0)
Nulliparous (*n* (%))	31 (59.6%)
Birth weight (g, median (range))	3210 (1975–4110)

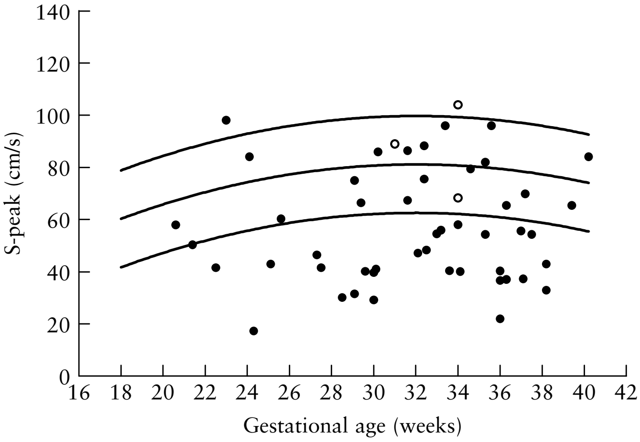

Figure 1 Maximum blood flow velocities of the ductus venosus during ventricular systole (S-peak) of fetuses with single umbilical artery plotted on reference ranges[14]. Lines represent the 5th, 50th and 95th centiles for gestational age. ●, appropriate for gestational age fetuses; ○, fetuses with intrauterine growth restriction.

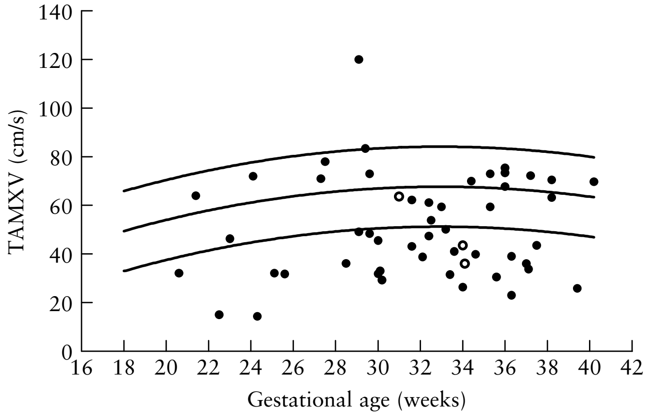

Figure 3 Time-averaged maximum velocities (TAMXV) of the ductus venosus of fetuses with single umbilical artery plotted on reference ranges[14]. Lines represent the 5th, 50th and 95th centiles for gestational age. ●, appropriate for gestational age fetuses; ○, fetuses with intrauterine growth restriction.

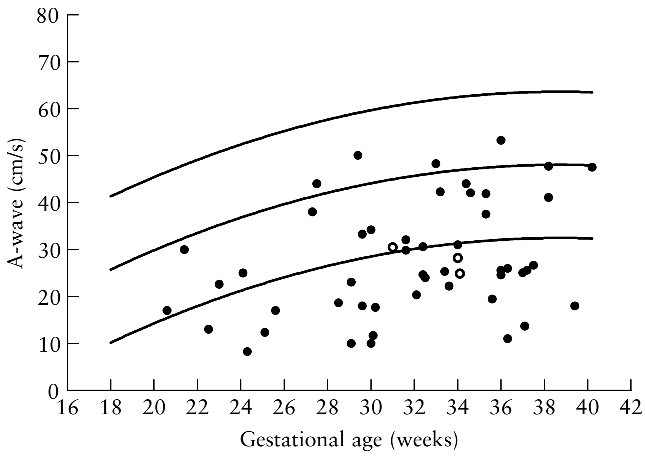

Figure 2 Maximum blood flow velocities of the ductus venosus during atrial contraction (A-wave) of fetuses with single umbilical artery plotted on reference ranges[14]. Lines represent the 5th, 50th and 95th centiles for gestational age. ●, appropriate for gestational age fetuses; ○, fetuses with intrauterine growth restriction.

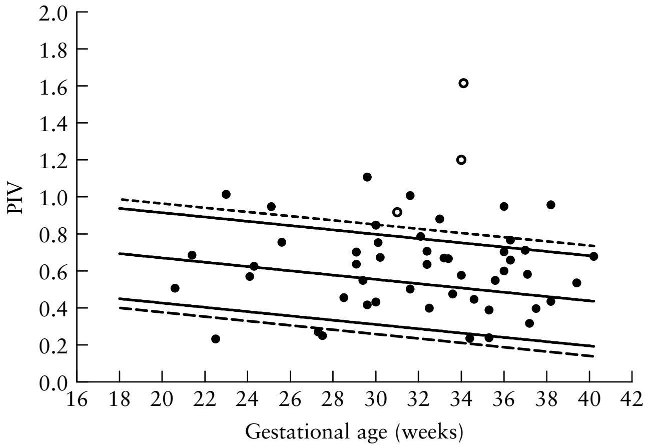

Figure 4 Pulsatility indices for veins (PIV) of fetuses with single umbilical artery plotted on reference ranges[14]. Lines represent the 5th, 50th and 95th centiles for gestational age. Dashed lines represent the ± 2 SD lines. ●, appropriate for gestational age fetuses; ○, fetuses with intrauterine growth restriction.

(corresponding to a diameter of 4 mm, used to define an adaptive dilatation of the SUA)[3,7,8] in 35 (67.3%) cases. The umbilical artery RI was within the normal range in 51 (98.1%) cases.

Intrauterine growth restriction occurred in three fetuses in the third trimester. In one of these fetuses the umbilical artery RI was above the 95th centile for gestational age.

The left umbilical artery was absent in 41 (78.8%) cases.

DISCUSSION

This study shows that, in otherwise healthy fetuses with SUA, the ductus venosus blood flow pattern is different when compared with that of fetuses with a three-vessel cord. The blood flow through the ductus venosus is influenced by both the cardiac function and the umbilical and placental circulation. Therefore, the reduced blood flow velocity throughout the entire cardiac cycle at the level of the ductus venosus in fetuses with SUA has to be interpreted with caution because these hemodynamic characteristics could be the consequence of the particular umbilical cord anatomy and not due to cardiac dysfunction.

Umbilical cords with SUA present a number of morphological differences in comparison to three-vessel umbilical cords[1]. The present study has demonstrated that umbilical cords with SUA are characterized not only by an adaptive dilatation of the artery, as previously reported by others[7,8], but also by an increased caliber of the vein. This is in keeping with a previous study conducted by our group on a different population, in which 11 of 22 fetuses with SUA had an umbilical vein area > 2 SD from the mean for gestational age[9]. Moreover, Lacro *et al.*[11] reported that umbilical cords with SUA are characterized by a lower number of vascular coils than are three-vessel cords and there may even be absence of coils. Reynolds[16] proposed

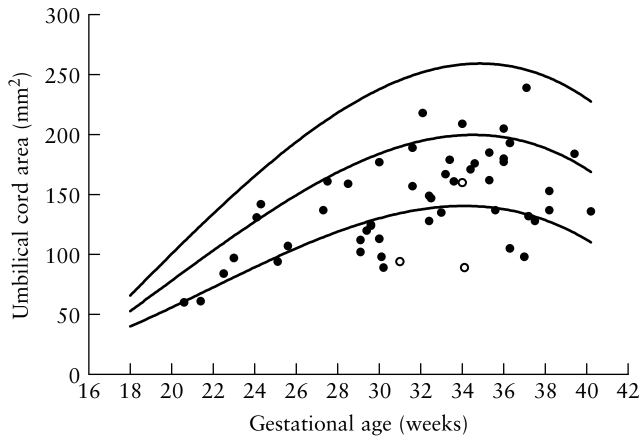

Figure 5 Umbilical cord cross-sectional areas of fetuses with single umbilical artery plotted on reference ranges[21]. Lines represent the 5th, 50th and 95th centiles for gestational age. ●, appropriate for gestational age fetuses; ○, fetuses with intrauterine growth restriction.

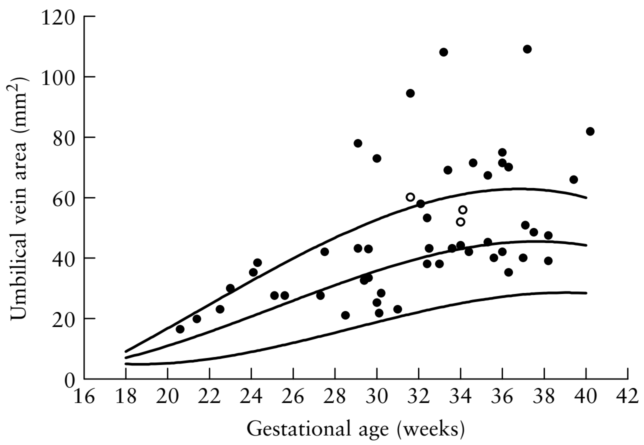

Figure 6 Umbilical vein cross-sectional areas of fetuses with single umbilical artery plotted on reference ranges[21]. Lines represent the 5th, 50th and 95th centiles for gestational age. ●, appropriate for gestational age fetuses; ○, fetuses with intrauterine growth restriction.

that the presence of vascular coils plays a central role in determining the blood flow from the placenta to the fetus. This agrees with the study by Di Naro *et al.*[17], who found a correlation between the umbilical coiling index and both the blood flow volume and the blood flow velocity in the umbilical vein. Finally, Bäz *et al.*[18] described an abnormal A-wave of the ductus venosus blood flow in the presence of an abnormally coiled three-vessel umbilical cord with normal placental vascular resistance.

Ductus venosus blood flow velocity during atrial contraction (i.e. A-wave), which is highly correlated to the severity of hypoxemia and acidemia in severely growth-restricted fetuses[12,15], was below the 5th centile in a very high proportion of healthy fetuses with SUA in the present study. This suggests that, in fetuses with SUA, the blood flow from the placenta to the fetal heart has hemodynamic characteristics different from those of fetuses with three-vessel cords. Hecher *et al.*[14] proposed assessment of the blood flow return to the heart using the PIV, an angle-independent index that takes into account the three-phasic shape of venous blood flow waveforms. In fetuses with SUA the PIV was within the normal range in most cases, indicating normal right ventricular function. Conversely, in all growth-restricted fetuses we found a PIV > 95th centile for gestational age, indicating that this parameter is useful in fetuses with SUA as it is in those with a three-vessel cord.

It remains to be explained why the ductus venosus blood flow velocities are reduced in fetuses with SUA. It has been demonstrated that flow velocity of the umbilical arterial blood to the placenta affects flow velocity of the venous system and vice versa[19]. Di Naro *et al.*[17] showed that a decreased velocity in the venous system is usually found in fetuses with growth restriction. In deteriorating intrauterine growth-restricted fetuses with brain-sparing, due to an increase of both right ventricular afterload and venous return from the superior vena cava, the right ventricular pressure increases leading to a reduction of the A-wave or its reversal in the ductus venosus. The majority of the fetuses in our study were normally grown without evidence of increased placental resistance or cardiac dysfunction. Therefore, the reduced blood flow velocity in the ductus venosus might be simply the consequence of a reduction in umbilical vein blood flow velocity. According to Poiseuille's law the three factors that might influence blood flow are the caliber of the vessel, the blood flow velocity and the viscosity of the blood. Lees *et al.*[20] demonstrated that the most important parameter influencing the umbilical vein blood flow in normal fetuses is the umbilical vein cross-sectional area. The increase of the umbilical vein cross-sectional area seen in our fetuses with SUA may lead to a decreased pressure gradient between right atrium and umbilical vein, which in turn reduces the driving force through the ductus venosus. Moreover, umbilical cords with SUA are characterized by a reduced number of arterial coils[11]. Reynolds[16] postulated that each arterial coil that surrounds the umbilical vein increases slightly and in an additive fashion the venous pressure, satisfying all requirements of a pulsometer pumping system.

Another possible cause for a larger umbilical vein diameter could be an interposed resistance (e.g. a venous stricture at the abdominal wall). Extreme constrictions could be associated with lower pressure in the intra-abdominal portion of the umbilical vein and a correspondingly lower perfusion pressure at the level of the ductus venosus. Further studies on the morphology of the intra-abdominal part of the umbilical vein of fetuses with SUA are required to test this hypothesis.

In conclusion, the hemodynamic pattern of the venous return of fetuses with SUA is characterized by a reduced blood flow velocity through the ductus venosus, although the well-being and growth of the fetus are maintained. This alteration seems to be attributable to the peculiar morphology of umbilical cords with SUA rather than being the consequence of fetal cardiac dysfunction. Prudence should be exerted in interpreting ductus venosus Doppler parameters in fetuses with SUA.

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