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The Relationships of Umbilical Venous Volume Flow, Birthweight and Placental Share in Monochorionic Twin Pregnancies With and Without Selective Intrauterine Growth Restriction

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This study was conducted to investigate the relationship among umbilical venous volume flow, birthweight and placental share in monochorionic twins with or without selective growth restriction. Having excluded cases complicated with twin-to-twin transfusion syndrome and one co-twin suffering intrauterine fetal death, a total of 51 monochorionic twin pregnancies were divided into two groups as with (group 1) and without (group 2) selective intrauterine growth restriction. Umbilical venous volume flow was calculated by multiplying the umbilical vein cross-sectional area by half of the maximal velocity around mid-trimester. The placentas were cut along the vascular equator into two individual placental masses. The discordance of birthweight was calculated as [(birthweight of larger twin—birthweight of smaller twin)/birthweight of larger twin × 100%]. The discordances of umbilical venous volume flow and placental share were calculated in a similar fashion. The median umbilical venous volume flow discordances (68.4% and 15.3% in groups 1 and 2 monochorionic twins, respectively) were similar and correlated well with the placental share discordances (66.6% and 18.5% in groups 1 and 2 monochorionic twins, respectively) but not with the birthweight discordance (28.6% and 6.4% in groups 1 and 2 monochorionic twins, respectively) in both groups. We concluded that the umbilical venous volume flow discordance reflects the placental share discordance rather than the birthweight discordance in monochorionic twin pregnancies.

■ **Keywords:** monochorionic twin pregnancy, intrauterine growth restriction, umbilical venous volume flow, placental share

Monochorionic twins (MCs) are at a very high risk of complications; the well-being of one fetus critically depends on that of the other because of the almost ever-present vascular anastomoses (Taylor, 2006). Selective intrauterine growth restriction (sIUGR) occurs in about 12% of twin pregnancies (Gonsoulin et al., 1990; Gratacos et al., 2004; Sebire et al., 1997), and the risk of neurological damage may be greater in monochorionic twins than in dichorionic twins (Bejar et al., 1990; Gonsoulin et al., 1990). Selective intrauterine growth restriction (sIUGR) is a unique problem to MCs (Chang, 2007) and unequal placental sharing has been found to be the primary contributor to birthweight discordance and sIUGR in MC pregnancies (Chang et al., 2008; Fick et al., 2006). There were several studies conducted to determine the placental share in MC pregnancies before delivery (Chang et al., 2008; Fick et al., 2006; Quintero et al., 2005). We have previously found that the abnormal umbilical artery (UA) Doppler of the sIUGR twin would indicate a more unequal placental share (Chang et al., 2009); nevertheless, there is so far no antenatal parameter that can be used to estimate the placental share in MCs.

Umbilical vein blood flow has been known to reflect the placental circuit (Acharya et al., 2005) and has been reported as relatively constant when adjusted for placental

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weight (Link et al., 2007). The aim of our study was to determine the degree of discordance of umbilical venous volume flow (UVVF), birthweight and placental share in MCs with and without sIUGR.

Study Design

This was a prospective study to evaluate the UVVF and placental share of MCs with and without sIUGR, which was approved by the local institutional ethics committee. SIUGR was defined as an estimated fetal weight below the 10th percentile in one twin of MCs (group 1) (Hadlock et al., 1991; Russell et al., 2007) and in this study, fetal weight discordance between the twins was used as an approximation to the diagnosis of sIUGR. Combination of discordance > 25% and birthweight < 10th percentile were defined as MC twin with sIUGR (Acosta-Rojas et al., 2007). MCs with two survivors and no IUGR, which were delivered at our institution during the same period of time, were used as control subjects (group 2). For comparison, control twins were identified as the smaller twin (smaller) or the larger twin (larger). In cases of TTTS, the ratio of intertwin UVVF could be altered by significant intertwin transfusion (Gratacos et al., 2002; Ishii et al., 2007; Yamamoto et al., 2007). As a result, pregnancies with signs of TTTS, as defined by severe oligohydramnios in one twin (maximum vertical pocket of amniotic fluid, < 2 cm) and polyhydramnios in another twin (maximum vertical pocket, > 8 cm) (Quintero et al., 1999), were not included in this study.

We used the color Doppler mode to determine the maximum flow velocity in the umbilical vein (Gerada et al., 2006). Pulsed and color Doppler was detected by a multi-frequency sector array transabdominal transducer (Voluson 730 Pro, GE Medical Systems, Milwaukee, WI, USA). The system operates at output intensities of < 100 mW/cm spatial peak temporal average in both imaging and Doppler mode and the highpass filter was set at 100 Hz. Angle correction was used if the vein was not displayed vertically on the screen, and the maximum angle of insonation was less than 45 degrees. The Doppler gate was positioned to completely cover the diameter of the vessel and a relatively small sample volume length compared to the lumen of the umbilical vein during an absence of fetal breathing and body movements. The umbilical vein area was calculated using the inner diameter of the umbilical vein as follows: area = $\pi \times$ (diameter/2) $\times$ (diameter/2). The Doppler velocity waveforms were obtained from the straight portion of the intra-abdominal UV before the first portal branch (Acharya et al., 2005). The 2D color Doppler presentation of the umbilical cord was carefully examined to find the color spot with the maximum velocity because maximum velocity in the vein can only be obtained with a zero angle of insonation (Gerada et al., 2006). Assuming a parabolic flow profile, the mean velocity was equal to half the maximum velocity (Bellotti et al., 2001). Then, calculation of UVVF (mL/min) was achieved using the equation: 0.5Vmax (cm/s) $\times \pi \times$ (UV diameter (cm)/2) $\times$ (UV diameter (cm)/2) $\times$ 60 (Gerada et al., 2006). To avoid inter-observer variation, scanning was carried out by a single investigator (YL Chang). And, to reduce error due to a solitary measurement, Vmax of the umbilical vein and each vessel diameter were measured three times and the mean of the three measurements was used to calculate the UVVF.

The UVVF was further normalized by estimated fetal weight as UVVF/kg, with the estimated fetal weight calculated using the Hadlock equation (Hadlock et al., 1991). In the comparison group without IUGR, the locations of the cord insertion were recorded at the time of sonographic examination, with the small twin marked as twin A and the larger twin as twin B. Because the estimated larger twin might not actually be the heavier twin after delivery, fetal positions were further confirmed upon delivery.

An estimated time of occurrence of UVVF in MCs was around the gestational age of 20 weeks, coinciding with when a routine biometry scan was performed to detect major anomalies. In those cases referred from other hospitals that went beyond the mid-trimester, the first visit's scan was chosen to be included in this study. Each woman was assessed for the UVVF study only once.

The placenta was routinely examined after delivery: following draining of the blood from the umbilical vessels, the placenta was washed to remove all the clots, and the cotyledons and membranes were inspected to ensure there were no missing cotyledons. The vascular equator was defined as a border drawn in the middle of the avascular zone on the chorionic fetal surface when there was no intertwin vascular anastomosis, or on the anastomosis points where twin–twin communicating vessels meet at the point of deep anastomoses (artery-to-vein anastomosis). In conditions of artery-to-artery or vein-to-vein anastomosis, and because of the nature of continuing vessels, these points cannot be used as landmarks to separate the placenta into two territories. The placentas were cut along the line that divided the placenta into two territories between both cord insertions. Each placental portion was weighed separately, thus yielding an estimated individual placental mass (EIPM). The placental share was calculated as EIPM/ total placental mass $\times$ 100%. The discordance of birthweight was calculated as [(birthweight of larger twin–birthweight of smaller twin)/birthweight of larger twin $\times$ 100%]. The discordances of umbilical venous volume flow and placental share were calculated in a similar fashion.

Statistical analysis was conducted with SPSS software (version 11.0 for Window; SPSS Inc, Chicago, IL). Qualitative data were compared by means of χ^2 test or Fisher exact test, as appropriate. For parametric data, the Wilcoxon Signed Ranks Test was used to compare values between twin pairs. Continuous variables were tested for

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TABLE 1

Characteristics of Monochorionic Twins with Selective Intrauterine Growth Restriction (group I) and Monochorionic Twins Without Intrauterine Growth Restriction (Group II)

	Group 1 (n = 21)	Group 2 (n = 30)	p value
Median gestational age at delivery (weeks) (95% CI)	33.1 (31.8~34.4)	34.4(33.3~35.6)	.021#
Maternal age at delivery (year) ± *SD*	28.3 ± 4.7	30.0 ± 3.1	.17*
Median birthweight of IUGR (smaller) twin (gm) (95% CI)	1300 (1092~1452)	2054 (1885~2222)	< .001#
Median birthweight of AGA (larger) twin (gm) (95% CI)	1870 (1658~2083)	2227 (2050~2404)	.006#
Median gestational age at detection of the UVVF (weeks) (95% CI)	24.9 (22.9~26.6)	24.6 (23,5~28.1)	.368#
Median discordance of UVVF (95% CI)	68.4 (63.2~71.8) %	15.3 (15.4~26.7) %	< .001#
Median discordance of placental share(95% CI)	66.6 (52.5~67.3) %	18.5 (12.7~21.6) %	< .001#
Median discordance of birthweight (95% CI)	28.6 (26.9~37.2)	6.4 (5.0~10.3) %	< .001#

Note: #: Mann-Whitney U test; *: student *T* test; AGA: appropriate for gestational age; SD: standard deviation; CI: confidence of interval, UVVF: umbilical venous volume flow

normality; then a *t* test or Mann-Whitney U test was used when appropriate. The correlations between UVVF discordance and birthweight discordance and between UVVF discordance and placental share discordance were tested with Pearson correlation coefficient. A p value of less than.05 was considered statistically significant.

Results

From November 2006 to May 2009, among the four cases of MC with sIUGR where the UVVF had initially been thought to progress to TTTS, three of the four cases later received laser therapy because the gestational age of the fetus upon detection of TTTS was less than 26 weeks, and one received serial amnioreduction due to advanced gestational age of the fetus upon detection of TTTS (30 weeks). Three reported cases of MC with sIUGR and four cases of MC without IUGR were not delivered at our hospital. After excluding these 11 cases, 51 cases of MCs were included in this study, totaling 21 MCs with sIUGR (group 1) and 30 MCs without IUGR (group 2). Since our hospital is a tertiary referring center and performs fetal surgery for TTTS, there were cases of MC with selective IUGR that transferred to our hospital. As a result, the ratio of the MCs with sIUGR compared to the ratio of MCs without IUGR was high in our hospital.

The basic characteristic of the two groups of MCs are listed in Table 1. This table shows that between the two groups of MCs, the maternal age at delivery was similar and the mean gestational age of delivery of group 1 MC pregnancies was less than that of group 2 MCs. The birthweight discordance, UVVF discordance and placental share discordance were all larger in group 1 than in group 2 MCs. The mean gestational age at estimation of the UVVF was 25.3 weeks; the mean interval between estimation of the UVVF and delivery was 60.1 days The median gestational age of estimation of the UVVF was 24.6 weeks in group 1 MC and 24.9 weeks in group 2 MC, showing that there was no significant difference (p = .31, Mann-Whitney U test).

The absolute value of UVVF (ml/min) and UVVF is normalized by the estimated fetal weight (mL/kg/min) in the IUGR (smaller) and AGA (appropriate for gestational age) (larger) twin in both groups of MCs and is presented in Table 2. The UVVF was significantly smaller in the IUGR (smaller) twin than in the AGA (larger) twin. In the group I MCs, the UVVF of the IUGR twin was almost one-third of the AGA twin. After normalization of the UVVF by estimated fetal weight (mL/kg/min), the UVVF per weight was still heavier in the AGA (larger) twin than in the IUGR (smaller) twin.

The median discordances of birthweight, placental share and UVVF between the two twins of the two groups of MCs are listed in Figure 1, where we found that in both groups of MCs, the discordance of UVVF was closer to the placental share discordance than the birthweight discordance. The differences between the discordance of UVVF and placental share were not significant in both groups 1 and 2 MCs (Wilcoxon signed ranks test, p = .394 and 0.165 in groups 1 and 2 MCs, respectively), while the difference between the median discordance of UVVF and birthweight were significant in both groups 1 and 2 MCs (Wilcoxon signed ranks test, p < .001, both in groups 1

TABLE 2

The Values of Umbilical Venous Volume Flow (UVVF) and UVVF When Normalized by Fetal Weight Estimates Between the Larger (AGA) and Smaller (IUGR) Fetuses

	Larger or AGA twin	Smaller or IUGR twin	p value
UVVF (ml/min)			
Group I MCs (n = 21)	160 ± 136	61 ± 73	< .001*
Group II MCs (n = 30)	118 ± 84	94 ± 76	< .001*
UVVF/EFW ((ml/min)/kg)			
Group I MCs (n = 21)	177 ± 99	83 ± 67	< .001*
Group II MCs (n = 30)	146 ± 73	118 ±56	< .001*

Note: AGA: appropriate for gestational age; Group 1 MCs: monochorionic twins with selective intrauterine growth restriction; Group 2 MCs: monochorionic twins without intrauterine growth restriction; UV: umbilical vein; UVVF: umbilical venous volume flow; EFW: estimated fetal weight; *: Paired sample *t* test.

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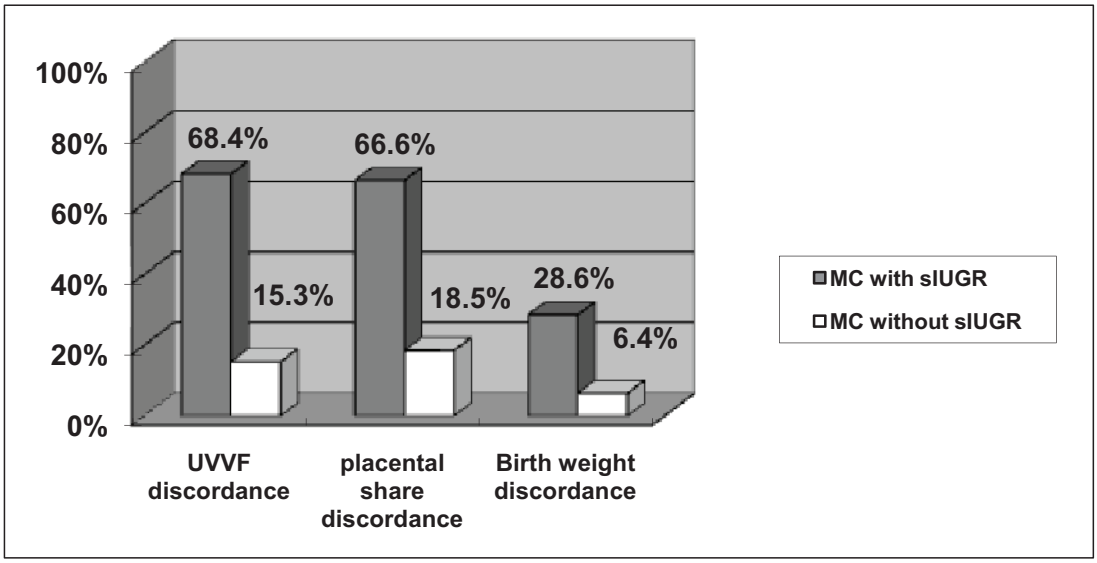

FIGURE 1

The median discordance of umbilical venous volume flow (UVVF), placental share and birthweight in monochorionic twins (MC) with and without selective intrauterine growth restriction (sIUGR).

TABLE 3

The Correlation Between Birthweight Discordance and Placental Share Discordance and That Between Umbilical Venous Volume Flow and Placental Share Discordance in Group I and II MCs

	Group I MCs (n = 21)	Group II MCs (n = 30)
UVVF discordance/birthweight discordance	0.161 (0.485)	0.030 (0.877)
UVVF discordance/placental share discordance	0.533 (0.013)	0.483 (0.007)

Note: Data are expressed as Pearson correlation (p value); MCs: monochorionic twins; Group 1 MCs: monochorionic twins with selective intrauterine growth restriction; Group 2 MCs: monochorionic twins without intrauterine growth restriction; UVVF: umbilical venous volume flow.

and 2 MCs). This means that the discordance of UVVF was close to the discordance of placental share, but the discordance of UVVF was different and larger than the birthweight discordance, both in groups 1 and 2 MCs. The correlations between the discordance of UVVF and placental share were significant and the correlations between the discordance of UVVF and birthweight were not significant in both groups 1 and 2 MCs (Table 3).

Discussion

The discordance of the UVVF between the two fetuses is close to the discordance of placental share but not to the birthweight discordance in MCs with or without sIUGR. Even after normalization of the estimated fetal weight, the UVVF/kg still is higher in the AGA (larger) twin than in the sIUGR (smaller twin; Table 2). As a result, the individual UVVF in MCs is reflected in the individual placental mass but not the fetal weight. It is a fact that the birthweight discordance is significantly smaller than the discordance of placental share in MCs, and it is especially obvious in MCs with sIUGR (Figure 1).

There are two theories to explain this phenomenon: (1) 'rescue transfusion,' which means that the bigger placenta helps the smaller one by intertwin anastomoses (Denbow et al., 2000), or (2) 'a placental reserve,' where a small portion of MC placenta perfused the fetus more efficiently than the larger portion of the placenta (Chang et al., 2008). UVVF is the circuit between placenta and fetus and by either of these two hypotheses; the sIUGR (smaller) twin's placental territory would perfuse more UVVF than the ratio of the placental share. In other words, the discordance of UVVF could be close to the discordance of fetal weight but not to the placental share. In this study, we found that even after normalization of estimated fetal weight, the normalized UVVF was still higher in the AGA twin than in the sIUGR twin (Table 2). So, 'fetus reserve' would seem a more likely etiology that better coincided with our present study findings: the ratio of placental supply of blood flow to the two MC fetuses ran parallel with the ratio of the placental share; the smaller (sIUGR) fetus became smaller but only as small as the placental share ratio (or the UVVF ratio). And this postulation lends further credence to the notion that in the growth-restricted fetus, the decrease of UVVF does not happen later in pregnancy — the decrease of UVVF actually happens before the growth restriction is found. And, it would be compatible with previous studies reporting that reduction in UV blood could be detected weeks before IUGR was detectable by conventional fetal biometry (Gill et al., 1984) and that in singletons the reduction of the UV velocity in the IUGR fetus was observed in early pregnancy (Rigano et al., 2001), suggesting that the reduced

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placental blood flow represented an early event in the pathogenesis of IUGR (Acharya et al., 2005). In our cases, the mean gestational age of estimation of the UVVF in group 1 MCs was 24.6 weeks and the significant discordance of UVVF was already detected. UVVF in normally developing and growth restricted fetuses were evaluated and were reported as significantly reduced in the restricted fetuses (Boito et al., 2002).

Because UVVF can be significantly different among different fetuses — even at the same gestational age (Acharya et al., 2005) — it can be difficult to compare the UVVF between IUGR and AGA fetuses in singletons. The major advantage of the twin model for UVVF research is that it optimizes the effect of maternal confounding variables such as nutrition, hypertension, diabetes or smoking. Furthermore, in MC with sIUGR, the two twins are genetically identical, with the same gestational age with one classified as AGA and the other classified as IUGR, thus making them an extremely good model to evaluate the UVVF in IUGR fetuses caused by small placental mass. Our study showed that the UVVF of the IUGR twin was significantly smaller than the AGA twin (Table 2), which provides stronger evidence than other studies using singleton to study the UVVF in the IUGR fetus. We use estimated fetal weight to normalize the UVVF as in Table 2, but the accuracy of the ultrasonographic estimated fetal weight had been reported as to be lower for twin gestations than for singleton gestations (Danon et al., 2008), so potentially the normalization of UVVF by estimated fetal weight may have significant estimation bias.

There were 35 cases in which the gestational age at the time of detection of UVVF was during the mid-trimester and 16 cases in which they were detected during the third trimester. The correlations of discordance of UVVF and discordance of placental share are 0.853 ($p < .001$, Pearson correlation test) and 0.768 ($p = .001$, Pearson correlation test) in cases in which the UVVF was detected during the second and third trimesters, respectively. The interval of UVVF detection to delivery is 74.3 days and 29.0 days in cases where UVVF was detected during the second and third trimesters, respectively. This finding indirectly points out that the discordance of UVVF of MC is relatively constant from the second to third trimesters during pregnancy, but this hypothesis needs to be proved by another prospective longitudinal study.

The weakest part of the study is the method we used to define the EIPM because the placenta is arbitrarily separated to get the EIPM. Different cut lines would get different placental shares. There were different methods to define the placental share in MCs (Fick et al., 2006; Lewi et al., 2007). In the study by Lewi et al., after injection, the limits of the veins were outlined and the surface was calculated. Discordance was calculated as a ratio between twins for each parameter (Lewi et al., 2007). In the method created by Fisk et al., the vascular equator was defined by a colored dye injection and the placental share was estimated visually as the percentage of placenta on either side of the vascular equator (Fick et al., 2006). In both methods, the placental share was estimated by a two-dimensional method; so the thickness of the placenta was not considered in the measurement of placental share. The thickness of the placenta could be different between the two territories in MC; the same two-dimensional areas with different thicknesses would have different placental weights. The method we use to define the placental share is using the EIPM (Chang et al., 2008; Quintero et al., 2005). In this method, the placenta was cut freshly without fixation to change the placenta weight; this method is especially useful when the thicknesses of the MC placentas are not equal. But, since we cut the placenta freshly so the injection study is not performed, the vascular equator drawn by our method may be less precise than those drawn using the dye injection method (Fick et al., 2006; Lewi et al., 2007).

There are other limitations to this study. Firstly, although MC twins with identical genetic make-up provide a distinct advantage when studying the UVVF between IUGR and AGA fetuses, the influence of the effect of inter-twin transfusion on the UVVF (even though we excluded cases of TTTS) cannot be totally ruled out. Secondly, because we cut the placenta immediately after birth, the injection study of the placenta was not performed and thus the effect of the pattern of the intertwin anatomoses couldn't be evaluated in this study.

In summary, in MC; without TTTS; with and without sIUGR: the discordance of the UVVF flow detected before birth correlates better with the discordance of placental share rather than with the birthweight discordance.

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References

Acharya, G., Wilsgaard, T., Berntsen, G. K., Maltau, J. M., & Kiserud, T. (2005). Reference ranges for serial measurements of blood velocity and pulsatility index at the intra-abdominal portion, and fetal and placental ends of the umbilical artery. *Ultrasound in Obstetrics and Gynecology, 26,* 162–169.

Acosta-Rojas, R., Becker, J., Munoz-Abellana, B., Ruiz, C., Carreras, E., & Gratacos, E. (2007). Twin chorionicity and the risk of adverse perinatal outcome. *International Journal of Gynaecology and Obstetrics, 96,* 98–102.

Bejar, R., Vigliocco, G., Gramajo, H., Solana, C., Benirschke, K., Berry, C., Coen, R., & Resnik, R. (1990). Antenatal origin of neurologic damage in newborn infants. II. Multiple gestations. *American Journal of Obstetrics and Gynecology, 162,* 1230–1236.

https://doi.org/10.1375/twin.14.2.192 Published online by Cambridge University Press

Bellotti, M., Rognoni, G., de Gasperi, C., Panteghini, M., Berlanda, N., Ferrazzi, E., & Buscaglia, M. (2001). Controlled fetal blood-letting of the recipient twin as a new method for the treatment of severe twin-twin transfusion syndrome: preliminary results. *Ultrasound in Obstetrics and Gynecology, 18,* 666–668.

Boito, S., Struijk, P. C., Ursem, N. T., Stijnen, T., & Wladimiroff, J. W. (2002). Umbilical venous volume flow in the normally developing and growth-restricted human fetus. *Ultrasound in Obstetrics and Gynecology, 19,* 344–349.

Chang, Y.-L. (2007). Unique complications of monochorionic twins. *Journal of Medical Ultrasound, 15,* 1–8.

Chang, Y. L., Chang, S. D., Chao, A. S., Hsieh, P. C., Wang, C. N., & Tseng, L. H. (2008). The individual fetal weight/estimated placental weight ratios in monochorionic twins with selective intrauterine growth restriction. *Prenatal Diagnosis, 28,* 217–221.

Chang, Y. L., Chang, S. D., Chao, A. S., Hsieh, P. C., Wang, C. N., & Wang, T. H. (2009). Clinical outcome and placental territory ratio of monochorionic twin pregnancies and selective intrauterine growth restriction with different types of umbilical artery Doppler. *Prenatal Diagnosis, 29,* 253–256.

Danon, D., Melamed, N., Bardin, R., & Meizner, I. (2008). Accuracy of ultrasonographic fetal weight estimation in twin pregnancies. *Obstetrics and Gynecology, 112,* 759–764.

Denbow, M. L., Cox, P., Taylor, M., Hammal, D. M., & Fisk, N. M. (2000). Placental angioarchitecture in monochorionic twin pregnancies: Relationship to fetal growth, fetofetal transfusion syndrome, and pregnancy outcome. *American Journal of Obstetrics and Gynecology, 182,* 417–426.

Fick, A. L., Feldstein, V. A., Norton, M. E., Wassel Fyr, C., Caughey, A. B., & Machin, G. A. (2006). Unequal placental sharing and birth weight discordance in monochorionic diamniotic twins. *American Journal of Obstetrics and Gynecology, 195,* 178–183.

Gerada, M., Struijk, P. C., Stewart, P. A., Guerriero, S., Melis, G. B., & Wladimiroff, J. W. (2006). Comparison between color Doppler cineloop- and conventional spectral Doppler-derived maximum velocity and flow in the umbilical vein. *Ultrasound in Obstetrics and Gynecology, 28,* 156–161.

Gill, R. W., Kossoff, G., Warren, P. S., & Garrett, W. J. (1984). Umbilical venous flow in normal and complicated pregnancy. *Ultrasound in Medicine and Biology, 10,* 349–363.

Gonsoulin, W., Moise, K. J., Jr., Kirshon, B., Cotton, D. B., Wheeler, J. M., & Carpenter, R. J., Jr. (1990). Outcome of twin-twin transfusion diagnosed before 28 weeks of gestation. *Obstetrics and Gynecology, 75,* 214–216.

Gratacos, E., Carreras, E., Becker, J., Lewi, L., Enriquez, G., Perapoch, J., Higueras, T., Cabero, L., & Deprest, J. (2004). Prevalence of neurological damage in monochorionic twins with selective intrauterine growth restriction and intermittent absent or reversed end-diastolic umbilical artery flow. *Ultrasound in Obstetrics and Gynecology, 24,* 159–163.

Gratacos, E., Van Schoubroeck, D., Carreras, E., Devlieger, R., Roma, E., Cabero, L., & Deprest, J. (2002). Impact of laser coagulation in severe twin-twin transfusion syndrome on fetal Doppler indices and venous blood flow volume. *Ultrasound in Obstetrics and Gynecology, 20,* 125–130.

Hadlock, F. P., Harrist, R. B., & Martinez-Poyer, J. (1991). In utero analysis of fetal growth: A sonographic weight standard. *Radiology, 181,* 129–133.

Ishii, K., Hayashi, S., Nakata, M., Murakoshi, T., Sago, H., & Tanaka, K. (2007). Ultrasound assessment prior to laser photocoagulation for twin-twin transfusion syndrome for predicting intrauterine fetal demise after surgery in Japanese patients. *Fetal Diagnosis and Therapy, 22,* 149–154.

Lewi, L., Cannie, M., Blickstein, I., Jani, J., Huber, A., Hecher, K., Dymarkowski, S., Gratacós, E., Lewi, P., & Deprest, J. (2007). Placental sharing, birthweight discordance, and vascular anastomoses in monochorionic diamniotic twin placentas. *American Journal of Obstetrics and Gynecology, 197,* 587 e1–8.

Link, G., Clark, K. E., & Lang, U. (2007). Umbilical blood flow during pregnancy: Evidence for decreasing placental perfusion. *American Journal of Obstetrics and Gynecology, 196,* 489 e481–487.

Quintero, R. A., Martinez, J. M., Lopez, J., Bermudez, C., Becerra, C., Morales, W., & Arroyo, J. (2005). Individual placental territories after selective laser photocoagulation of communicating vessels in twin-twin transfusion syndrome. *American Journal of Obstetrics and Gynecology, 192,* 1112–1118.

Quintero, R. A., Morales, W. J., Allen, M. H., Bornick, P. W., Johnson, P. K., & Kruger, M. (1999). Staging of twin-twin transfusion syndrome. *Journal of Perinatology, 19,* 550–555.

Rigano, S., Bozzo, M., Ferrazzi, E., Bellotti, M., Battaglia, F. C., & Galan, H. L. (2001). Early and persistent reduction in umbilical vein blood flow in the growth-restricted fetus: A longitudinal study. *American Journal of Obstetrics and Gynecology, 185,* 834–838.

Russell, Z., Quintero, R. A., & Kontopoulos, E. V. (2007). Intrauterine growth restriction in monochorionic twins. *Seminars in Fetal and Neonatal Medicine, 12,* 439–449.

Sebire, N. J., Snijders, R. J., Hughes, K., Sepulveda, W., & Nicolaides, K. H. (1997). The hidden mortality of monochorionic twin pregnancies. *British Journal of Obstetrics and Gynaecology, 104,* 1203–1207.

Taylor, M. J. (2006). The management of multiple pregnancy. *Early Human Development, 82,* 365–370.

Yamamoto, M., Nasr, B., Ortqvist, L., Bernard, J. P., Takahashi, Y., & Ville, Y. (2007). Intertwin discordance in umbilical venous volume flow: A reflection of blood volume imbalance in twin-to-twin transfusion syndrome. *Ultrasound in Obstetrics and Gynecology, 29,* 317–320.

https://doi.org/10.1375/twin.14.2.192 Published online by Cambridge University Press