Review

Maternal-Fetal Medicine®

OPEN

Twin Reversed Arterial Perfusion Sequence: Prenatal Diagnosis and Treatment

Xiaoqing Ye[1], Jiayan Wang[2,3,4,5,6], Jing Lu[7], Nan Li[2,3,4,5,6], Wenping Ding[8], Yuxia Fu[9], Min Chen[2,3,4,5,6,*]

Abstract

Twin reversed arterial perfusion sequence, a severe and unique complication of monochorionic multiple pregnancy, is characterized by vascular anastomosis and abnormal or absent cardiac development in the twins. This article reviewed its pathogenesis, prenatal ultrasound diagnosis, and management. The pump twin's chances for survival can be maximized by proper management. The optimal timing of the interventions remains a debate, although the latest studies encourage early intervention, i.e., in the first trimester. The most preferred approach is to interrupt the vascular supply to the acardius, such as through ultrasound-guided laser coagulation and radiofrequency ablation of the intrafetal vessels.

Keywords: Prenatal diagnosis; TRAP sequence; Acardiac twin; Pump twin; Fetal therapy

Introduction

Twin reversed arterial perfusion (TRAP) sequence is a rare phenomenon characterized by the presence of an acardiac twin perfused by a structurally normal fetus (pump twin), occurring in 1% of monochorionic pregnancies and one in 35,000 in all pregnancies.[1–3] However, because of improved ultrasound diagnosis and the widespread use of assisted reproductive technologies in recent years, the incidence of TRAP has grown to 2.6% of monozygotic twins and one in every 9500 to 11,000 pregnancies.[4,5]

The fetal blood flow in the umbilical artery comes from the pump twin to the acardiac twin through artery-artery anastomosis on the placental surface, and this anatomical feature puts the pump fetus at risk of hyperdynamic circulation and high-output cardiac failure. If no intervention is taken, in the TRAP sequence, mortality is 100% in the acardiac twin, and the demise of the pump fetus will be up to 50%.[5] Thus, it is necessary to closely monitor whether there is any cardiovascular compromise in the pump twin or significant growth of the TRAP mass through ultrasound and Doppler velocimetry. The intervention, ultrasound-guided laser coagulation, should be adopted to interrupt the vascular supply to the acardiac twin while the condition deteriorates.[6] Hydropic changes, cardiomegaly, and continued growth of the acardiac twin are significant predictors of the adverse outcome of the pump twin.[7] Currently, the application of ultrasound and Doppler velocimetry cannot accurately predict the risk or prevent sudden death. Of 30 TRAP sequence cases diagnosed at 11 to 14 weeks in a meta-analysis of Chaveeva *et al.*,[8] 11 cases suffered death or brain damage of the pump twin without any scheduled intervention. Recently published studies have shown that the survival of the pump twin might increase to 80% provided that intrafetal laser[9] or radiofrequency ablation (RFA)[10] is performed at 12 to 14 weeks of gestation.

This review aimed to evaluate the pathogenesis, diagnosis, and therapeutic management of the TRAP sequence.

Pathogenesis of TRAP sequence

Two pathways have been proposed to explain the pathogenesis of the TRAP sequence,[11] including the aberrant placental vascular pattern during the early stages of monochorionic placentation and primary defect in cardiac embryogenesis because of chromosomal abnormality or environmental factors, when the unique perfusion of the acardiac fetus is received through anastomoses between the umbilical vessels.[3] Thus, when the acardiac twin receives deoxygenated blood from the pump twin.[12]

The perinatal mortality rate of the pump twin is as high as 50% to 55%.[7,13] Therefore, it is necessary to effectively predict the occurrence of the TRAP sequence or screen for potential risk factors to improve prognosis. The following have been proposed to predict the adverse outcome in the second trimester of the pump twin[6,14,15]:

(1) the acardiac/pump twin weight ratio of higher than 50%, which is defined as big acardius (the weight of the

Xiaoqing Ye and Jiayan Wang have contributed equally to this work.
[1] Department of Ultrasound, Guangzhou Women and Children's Medical Center, Guangzhou Medical University, Guangzhou 510623, China; [2] Department of Fetal Medicine and Prenatal Diagnosis, The Third Affiliated Hospital of Guangzhou Medical University, Guangzhou 510150, China; [3] Obstetrics and Gynecology Institute of Guangzhou, Guangzhou 510150, China; [4] The Medical Centre for Critical Pregnant Women in Guangzhou, Guangzhou 510150 China; [5] Key Laboratory for Major Obstetric Diseases of Guangdong Province, Guangzhou 510150, China; [6] Key Laboratory for Reproduction and Genetics of Guangdong Higher Education Institutes, Guangzhou 510150, China; [7] Department of Obstetrics and Gynecology, The First Affiliated Hospital of Xiamen University, Xiamen 361000,China; [8] Department of Diagnostic Ultrasound, Wuhan Women and Children Medical Care Center, Wuhan 430030, China; [9] Reproductive Medicine Center, The First People's Hospital of Kashgar Prefecture, Kashgar 844000, China.

* Corresponding author: Min Chen, Department of Fetal Medicine and Prenatal Diagnosis, The Third Affiliated Hospital of Guangzhou Medical University, Guangzhou 510150, China. E-mail: edchen99@gmail.com

Maternal-Fetal Medicine (2022) 4:4

Received: 6 March 2022 / Accepted: 16 August 2022

First online publication: 26 September 2022

http://dx.doi.org/10.1097/FM9.0000000000000172

acardiac twin can be calculated with the following formula prenatally: weight (in grams) = length × width × height × 0.52 in centimeters, or using 3D ultrasound where 1 mL will be 1 gram;
(2) inconsistent ratio of pump/acardiac umbilical venous diameter (UVD);
(3) an acardiac twin that has a developed body and upper limbs;
(4) the ratio of the abdominal circumference between acardiac and pump twin of higher than 50%;
(5) monoamnionicity;
(6) the manifestation with signs and symptoms of high-output cardiac failure, including umbilical vein pulsations, tricuspid regurgitation, the absent or reversed in ductus venosus A-wave, hydrops fetalis, and polyhydramnios;
(7) the continuous growth of the acardiac twin;
(8) an increase in peak middle cerebral artery velocity;
(9) a ratio of umbilical artery pulsatility index acardiac/pump twin of less than 1.

Because acardiac twin is a rare event, no large series are available on the predictive accuracy of these variables.

Ultrasound diagnosis

An acardiac twin should be considered when an ultrasound examination identifies one of the fetuses with evident abnormalities in monochorionic twins.[16] The typical ultrasound feature is the pathognomonic reversed blood flow into the acardiac twin through its umbilical artery on color Doppler ultrasound. Furthermore, the key finding is a fetus with multiple profound malformations, subcutaneous edema, massive fluid collections, and no heart (Fig. 1).[12] The pathognomonic finding mentioned above might be evident even during the first trimester. The arterial blood is pumped from the pump twin to the acardiac twin in a retrograde fashion, which can alter the hemodynamic status and fetal cardiac function. It will cause congestive heart failure/chronic high-output failure if left untreated. The color Doppler is the most common and direct method to evaluate fetal safety in utero. The most commonly used fetal Doppler parameters include umbilical artery and middle cerebral artery pulsatility indexes, middle cerebral artery peak systolic velocity, and cerebroplacental ratio.[17]

With the suspected demise of one of the monochorionic twins, the absence of blood flow should be revealed during the Doppler examination. The TRAP sequence should be suspected when the persistent intrafetal blood flow is identified. Other differential diagnoses include intra-amniotic or placental tumors, such as chorioangioma, a placental cyst or teratoma, and an early single demise in an MC twin pregnancy.[18]

An acardiac fetus is clinically divided into pseudocardiac (the presence of rudimentary cardiac structures) and halocardia (the absence of cardiac structures). It is widely classified into four different subgroups morphologically[19,20]: acardius acephalus (lacking cranial structures), acardius anceps (with rudimentary cranial structures), acardius acormus (only facial structures are present), and acardius amorphus (no recognizable form is present). This classification can make an accurate morphological description but has no predictive role in management and prognosis. It has been suggested that the size of the acardiac twin is correlated with perinatal mortality. In addition to the weight of the acardiac fetus,[1] some researchers have proposed the use of the abdominal circumference (AC) ratio as a prognostic factor to estimate the effect between acardius fetus and pump twins.[7] A classification based on prenatal ultrasound findings of acardius size and signs of cardiac function impairment in the pump twin has been developed by them, which might help identify the most severe cases or those requiring prenatal interventions. Acardiac anomalies are divided into type I, small or medium-sized acardiac twin (the AC ratio of the acardiac fetus to the pump twins is less than 50%) and type II, giant acardiac twins (the AC ratio of the acardiac fetus to the pump twins is greater than 50%).

Management

Management of TRAP aims to preserve the pump twin and reach the term for delivery. Karyotyping for the pump twin should be offered. In Europe, most centers offer a prophylactic intervention to arrest the reversed perfusion if it is still present in the early second trimester.[20] In the United States, most centers only offer treatment if the acardiac to pump weight ratio exceeds 50%, the cardiac mass grows rapidly, or the pump twin shows signs of heart failure or anemia. This more cautious approach aims to avoid unnecessary intervention. In the absence of poor prognostic features, they follow TRAP cases with a weekly follow-up scan until the blood flow to the acardiac twin stops, or the relative weight

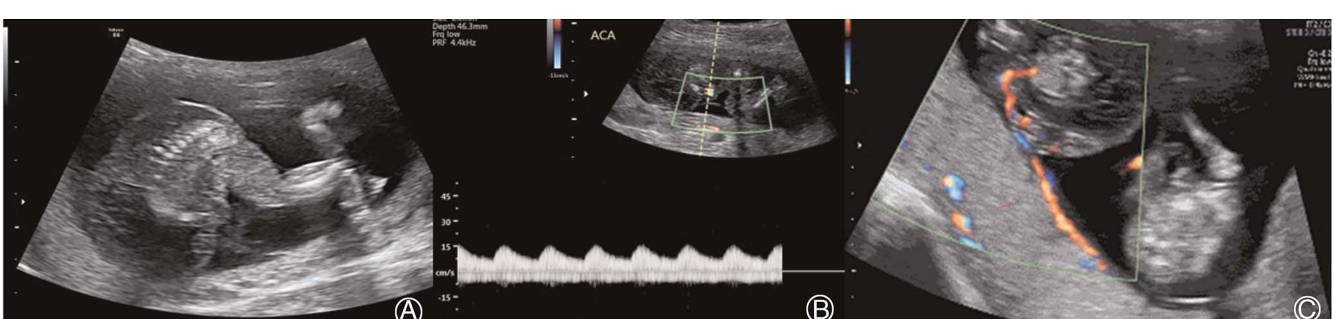

Figure 1. The typical ultrasound features of twin reversed arterial perfusion sequence. A Ultrasound image of an acardius acephalus twin at 16 weeks. B Color and pulsed Doppler image of the acardiac twin showing blood flow. C Color Doppler image showing reverse perfusion through the umbilical cord via the arterioarterial anastomosis.

of the acardiac twin declines or remains constant for two consecutive scans.

Timing for fetal therapy

The optimal timing for treatment remains controversial. The spontaneous death of the pump twin in TRAP pregnancies is between 35% and 50%.[21,22] With advances in ultrasound techniques, the diagnosis of TRAP pregnancies may be made in the early first trimester, which provides a potential for early therapeutic intervention for this condition. There are studies reporting that the intervention usually is undertaken at 16 to 18 weeks.[23]

Scheier *et al.*[24] have reported seven cases of TRAP pregnancies diagnosed before 16 weeks of gestation. Six of seven received interstitial laser (IL) before 18 weeks with 100% survival, and the pump twins were delivered healthy at a median of 38 (minimum 34^{+3} weeks; maximum 40^{+6} weeks) gestational weeks. One fetus treated with IL died after the procedure at 20^{+3} weeks.[24]

Roethlisberger *et al.*[25] have revealed improved survival when the pump twin was larger relative to the acardiac twin and regarded the ratio between the pump twin's crown-rump length and the acardiac twin's upper pole-rump length as predictive factors for pregnancy outcome. The other study by Berg *et al.*[26] have also reported 11 cases of TRAP treated with IL before 20 weeks of gestation. Three ILs were performed before 14 weeks, another five were performed between 14 and 16 weeks, and the remaining three were performed between 16 and 20 weeks. The intrauterine demises of the pump twin occurred in three cases within a few days after the procedure (27.3%, two cases treated at ≤16 weeks, and one treated at ≥20 weeks).[26]

A recent study by Tavares de Sousa *et al.*[27] has reported outcomes for 12 cases of TRAP at a median gestational age of 39^{+6} weeks who underwent IL before 14^{+3} weeks. They have reported a single intrauterine fetal demise within two weeks of the procedure, 91.7% overall survival, and only one case of preterm birth. Differences in inclusion criteria and operative techniques concerning the interventions could explain the variations in outcomes.[27]

A multicenter study about the intervention of TRAP in recent years (https://clinicaltrials.gov/ct2/show/NCT02621645) is on going. The study aims to define the optimal time for treatment by comparing the treatment of outcome of early (12.0–14.0 weeks) and late interventions (16.0–19.0 weeks).

Techniques for fetal therapy

Obliteration of the umbilical blood flow in the acardiac twin can be achieved either at the umbilical cord level (extrafetal) or at its vessels beneath its insertion into the abdomen (intrafetal). Bipolar cord coagulation (BCC) is the most popular extrafetal method. Among intrafetal techniques, RFA and IL therapy (ILT) are the most commonly used.[28] Laser coagulation with fetoscope has become less popular, whereas microwave ablation (MWA) is a new technique that needs more investigation.

All the previously mentioned procedures are invasive and should be performed under local anesthesia, and an aseptic technique, and antibiotic cover are recommended. One common and major technical difficulty to all these invasive methods is whether there is a window for the insertion of an instrument to approach the target. An anteriorly located placenta may limit access, and sometimes, the target twin is below the placenta or the pump twin, making the procedure more challenging. Therefore, a noninvasive approach using high-intensity focused ultrasound to the intrafetal umbilical vessels has also been tried.[28,29]

BCC

Since its introduction by Deprest *et al.*[30] in 2000 in treating complicated MC twin pregnancies, BCC has been used to occlude the umbilical cord.

Under either ultrasound or fetoscopic guidance, the acardiac's cord is coagulated using bipolar energy. It can be performed using 2.4- to 3-mm bipolar forceps, which are inserted into the acardiac twin's amniotic sac, with caution not to puncture the intertwin membrane. The forceps are advanced to the umbilical cord in the target twin, close to its abdominal insertion site or its placental insertion site, or any site at which the loop of the cord is stable. The forceps blades are then opened to grasp the cord's entire width. After confirming the correct position of the forceps, coagulation is performed with a power setting of 30 W for 30 seconds. The power can be increased up to 50 W until tissue coagulation is achieved. The real-time thermal effect can be observed under ultrasound guidance during the procedure. A stream of bubbles from the forceps blades indicates local heat generation and eventual solidification of the tissue. Higher initial energy should be avoided to prevent tissue carbonization from causing the forceps' blades to stick to the cord. It is significant to get the device away from the placenta, the fetus, and the intertwin membranes to avoid inadvertent thermal damage during the procedure. Color Doppler ultrasound is used to confirm the absence of umbilical blood flow after the forceps are freed from the cord. Sometimes, the absence of blood flow on color Doppler may be caused by temporary vasospasm rather than real vascular obliteration; hence, it is recommended to repeat two to three separate applications in adjacent sites to ensure complete occlusion. The treatment of TRAP sequence by BCC is limited to selected cases with a thick hydropic cord after 18 weeks, where intrafetal coagulation is not an option, and laser coagulation is likely to fail, for example, in cases of a monoamniotic TRAP diagnosed at 20 weeks. The overall success rate for cord coagulation is around 80%,[31] which is lower than intrafetal or fetoscopic laser coagulation.[14] Because the entry is through a 3.3-mm port, the risks of iatrogenic rupture of the membranes are higher, with a lower gestational age at birth (35–36 weeks). BCC can be technically demanding if the cord is short or directly originating from the pump twin's cord.

RFA

RFA has been initially introduced to clinical use for the local treatment of various neoplasms. The application of RFA in the TRAP sequence was first reported in 2002 by Tsao *et al.*,[32] who used a 14G (3-mm) RFA probe to induce tissue coagulation. As the RFA probe has now been reduced to only 17G, and because of the ease of use, it has become a very prevalent modality for the selective reduction in MC twin complications.[33–35]

Several types of RFA needles are available.[36] The size of the needle and its coagulation depth are chosen depending on the size of the target twin, but the smallest size is 17G. There are various types of electrodes for RFA. In most reports regarding RFA for TRAP sequence, an expandable needle electrode with tines or an internally cooled electrode without tines is used with similar success rates.

The RFA probe is inserted under continuous ultrasound guidance into the target twin's abdomen, aiming at the base of its umbilical cord insertion. After confirming the correct position, the tines of the RFA device are deployed. The degree of deployment should be estimated according to the size of the target zone of the fetus, which varies with its gestation. Precaution measures in ensuring that all deployed tines are within the fetal body must be performed. The initial power of 30 watts (W) is then applied and increased by 10-W increments every two minutes to a maximum of 100 W. Some authors advocate a high starting power instead to achieve a rapid completion of coagulation to minimize the potential hemodynamic instability of the cotwin.[34] The procedure may need to be repeated for one or two additional cycles until umbilical cord blood flow cessation is confirmed with power color and pulsed Doppler ultrasound. It is significant to get the electrode away from the uterine wall and membranes to prevent the spread of thermal injury. The tines must be retracted before the removal of the electrode.[36,37]

Potential complications are thermal injury to the cotwin and thigh burns on the mother from the ground pads.[38]

ILT

For intrafetal neodymium-doped yttrium-aluminium-garnet (Nd: YAG), an 18G to 20G needle is used. A 400- to 600-μm laser fiber is then passed through the needle and advanced a few millimeters beyond the tip of the needle.[38] Because the needle is smaller than the ones typically used for RFA (17G) and MWA (15G), intrafetal laser coagulation is an attractive technique for treatment in the early second trimester. Potential risks are that the needle may break off when the fiber is not fully advanced, and coagulation may occur inside the needle.

After the needle cannula is placed into the target fetal abdomen just beneath its cord insertion site under ultrasound guidance, the laser fiber is then passed through the cannula, and its tip is advanced forward by a few millimeters beyond the tip of the cannula into the target lesion. Power of 40 W is applied in short bursts until the tissues close to the fiber become echogenic and the umbilical arterial flow stops. Each time the laser is fired, an area of hyperechogenicity is spread circumferentially from the fiber tip. The procedure is considered successful once the complete cessation of blood flow is achieved.[9,40]

Although intrafetal laser is very suitable in earlier gestation because of the smaller caliber of the target vessels and the smaller size of the instrument, it may not be ideal after 16 weeks because of the bigger size of the vessels and the possibly incomplete coagulation.

MWA

MWA is a relatively new intrafetal method with only two case series reported in the literature. Unlike RFA, MWA creates heat without an electric circuit and has less thermal spread or heat sink effect, especially in high-flow blood vessels.[41–43] Therefore, a more focused burn with higher energy can be applied to the target tissue, thus allowing for higher tissue temperatures and faster ablation time, which is more advantageous over RFA in vessel coagulation.

A microwave generator emits an electromagnetic wave through the exposed, noninsulated portion of an antenna.[43] The 15G (1.8 mm) antenna has an internal cooling system, with either room-temperature fluid or carbon dioxide. The emitted microwaves agitate water molecules, producing frictional heat, thus, inducing thermocoagulation and necrosis. The heating zone is usually ellipsoidal or teardrop-shaped around the end of the antenna.[42,43]

Similar to other intrafetal approaches, the antenna is passed percutaneously, aiming at the intra-abdominal portion of the umbilical vessels of the target fetus. Once the proper antenna placement is confirmed, microwave energy is applied. The amount of microwave energy is estimated based on the size of the target zone. Generally, 100 to 140 W are administered for three to four minutes to create an area of coagulation of diameter between three and five cm.[42,43] A lower power of 50 W is recommended for fetuses at smaller gestation.[42,43] Color Doppler ultrasound is used to observe the effect of MWA. As the heating zones are usually ellipsoidal or teardrop-shaped around the end of the antenna, it is recommended to enter the fetal abdomen from its side.[42,43]

High-intensity focused ultrasound

Noninvasive methods, such as high-intensity focused ultrasound, are still in an experimental phase, with very limited data available.[44–46]

In recent years, RFA and ILT have been more frequently used in the treatment of TRAP sequence because of their reliability and safety. Although the neonatal survival rate is almost similar between RFA and ILT (85% *vs*. 82%, $P = 0.63$), the incidence of preterm premature rupture of the membranes at less than 32 weeks is significantly higher with RFA (22% *vs*. 7%, $P = 0.045$).[9] In a multicenter study, Scheier *et al.*[24] have reported that intrauterine mortality was higher in pump twins who received RFA between 15 and 19 weeks compared with RFA after 19 weeks (33.3% *vs*. 10.7%). Chaveeva *et al.*[8] have indicated that if the therapeutic intervention was performed between 12 and 14 weeks, the risk of death to the pump twin using intrafetal laser was lower than at the third trimester of pregnancy. A real comparison between RFA and ILT has been almost impossible to perform.[8] In a recently published cohort study, risk factors for cotwin fetal demise after selective fetal reduction in monochorionic multiple pregnancies using RFA performed at less than 16 weeks have been discussed, with a loss rate of 30.8% (4/13) following RFA.[47]

Limitations, future research questions, and technique development

TRAP is a rare complication. There are no good studies to guide us on when to intervene and which technique to use. Additionally, the high heterogeneity of the literatures makes the comparisons between each study prone to bias. Better data that document the best timing of the intervention and the impact of TRAP and its treatment on the long-term neurodevelopment of the pump twin are needed.

As robotic technology rapidly improves with newer platforms, smaller instruments, enhanced simulation, and telesurgery capabilities, robotic fetal surgery will be propelled into the next era.

Conclusions

Management of TRAP sequence faces unsolved challenges, as the choice of proper technique and the optimal timing for intervention remain to be elucidated. Furthermore, the optimal timing of treatment remains controversial if intervention therapy is required, although the latest literature encourages performing an intervention in early pregnancy. For the interruption of the vascular communication between acardiac twins, laser coagulation, or RFA of the intrafetal vessels is usually preferred.

Funding

None.

Author Contributions

MC and XY designed the study. XY and JW searched the literature. XY, JW, and MC drafted the manuscript. MC and JL revised the manuscript. All authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Editor Note

Min Chen is an Editorial Board member of *Maternal-Fetal Medicine*. The article was subject to the journal's standard procedures, with peer review handled independently of this editor and his research groups.

References

[1] Moore TR, Gale S, Benirschke K. Perinatal outcome of forty-nine pregnancies complicated by acardiac twinning. Am J Obstet Gynecol 1990;163(3):907–912. doi:10.1016/0002-9378(90)91094-s.
[2] van Gemert MJ, Pistorius LR, Benirschke K, et al. Hypothesis acardiac twin pregnancies: pathophysiology-based hypotheses suggest risk prediction by pump/acardiac umbilical venous diameter ratios. Birth Defects Res A Clin Mol Teratol 2016;106(2):114–121. doi:10.1002/bdra.23467.
[3] Wataganara T, Phithakwatchara N, Pooliam J, et al. Morphology, intrafetal vascular pattern, and umbilical artery Doppler indices of acardiac twins. Prenat Diagn 2020;40(8):958–965. doi:10.1002/pd.5710.
[4] Yapıcıoğlu-Yıldızdaş H, Ece Ü, Sucu M, et al. Twin reversed arterial perfusion syndrome in a monochorionic monoamniotic twin pregnancy. Turk J Pediatr 2017;59(6):724–727. doi:10.24953/turkjped.2017.06.020.
[5] Aldiansyah D, Lubis MP, Handayani D, et al. Twin reversed arterial perfusion sequence managed by bipolar cord coagulation and amniopatch: case report. Int J Surg Case Rep 2022;93:106893. doi:10.1016/j.ijscr.2022.106893.
[6] Tan TY, Sepulveda W. Acardiac twin: a systematic review of minimally invasive treatment modalities. Ultrasound Obstet Gynecol 2003;22(4):409–419. doi:10.1002/uog.224.
[7] Wong AE, Sepulveda W. Acardiac anomaly: current issues in prenatal assessment and treatment. Prenat Diagn 2005;25(9):796–806. doi:10.1002/pd.1269.
[8] Chaveeva P, Poon LC, Sotiriadis A, et al. Optimal method and timing of intrauterine intervention in twin reversed arterial perfusion sequence: case study and meta-analysis. Fetal Diagn Ther 2014;35(4):267–279. doi:10.1159/000358593.
[9] Pagani G, D'Antonio F, Khalil A, et al. Intrafetal laser treatment for twin reversed arterial perfusion sequence: cohort study and meta-analysis. Ultrasound Obstet Gynecol 2013;42(1):6–14. doi:10.1002/uog.12495.
[10] Cabassa P, Fichera A, Prefumo F, et al. The use of radiofrequency in the treatment of twin reversed arterial perfusion sequence: a case series and review of the literature. Eur J Obstet Gynecol Reprod Biol 2013;166(2):127–132. doi:10.1016/j.ejogrb.2012.10.009.
[11] Søgaard K, Skibsted L, Brocks V. Acardiac twins: pathophysiology, diagnosis, outcome and treatment. Six cases and review of the literature. Fetal Diagn Ther 1999;14(1):53–59. doi:10.1159/000020889.
[12] Brock CO, Johnson A. Twin reverse arterial perfusion: timing of intervention. Best Pract Res Clin Obstet Gynaecol 2022;S1521-6934(22):00045–1. doi:10.1016/j.bpobgyn.2022.03.006.
[13] Chandramouly M, Namitha. Case series: TRAP sequence. Indian J Radiol Imaging 2009;19(1):81–83. doi:10.4103/0971-3026.45352.
[14] Dashe JS, Fernandez CO, Twickler DM. Utility of Doppler velocimetry in predicting outcome in twin reversed-arterial perfusion sequence. Am J Obstet Gynecol 2001;185(1):135–139. doi:10.1067/mob.2001.113906.
[15] Jelin E, Hirose S, Rand L, et al. Perinatal outcome of conservative management versus fetal intervention for twin reversed arterial perfusion sequence with a small acardiac twin. Fetal Diagn Ther 2010;27(3):138–141. doi:10.1159/000295176.
[16] Sepúlveda WH, Quiroz VH, Giuliano A, et al. Prenatal ultrasonographic diagnosis of acardiac twin. J Perinat Med 1993;21(3):241–246. doi:10.1515/jpme.1993.21.3.241.
[17] Zhang L, Liu H, Huang S, et al. Alterations in fetal doppler parameters before and twenty-four hours after radiofrequency ablation for twin reversed arterial perfusion sequence. Front Med (Lausanne) 2022;9:802666. doi:10.3389/fmed.2022.802666.
[18] Vitucci A, Fichera A, Fratelli N, et al. Twin reversed arterial perfusion sequence: current treatment options. Int J Womens Health 2020;12:435–443. doi:10.2147/IJWH.S214254.
[19] Pepe F, Teodoro MC, Luca C, et al. Conservative management in a case of uncomplicated trap sequence: a case report and brief literature review. J Prenat Med 2015;9(3–4):29–34. doi:10.11138/jpm/2015.9.3.029.
[20] Buyukkaya A, Tekbas G, Buyukkaya R. Twin reversed arterial perfusion (TRAP) sequence; characteristic gray-scale and Doppler ultrasonography findings. Iran J Radiol 2015;12(3):e14979. doi:10.5812/iranjradiol.12(3)2015.14979.
[21] Gembruch U, Viski S, Bagamery K, et al. Twin reversed arterial perfusion sequence in twin-to-twin transfusion syndrome after the death of the donor co-twin in the second trimester. Ultrasound Obstet Gynecol 2001;17(2):153–156. doi:10.1046/j.1469-0705.2001.00334.x.
[22] Athwal S, Millard K, Lakhoo K. Twin reversed arterial perfusion (TRAP) sequence in association with VACTERL association: a case report. J Med Case Rep 2010;4:411. doi:10.1186/1752-1947-4-411.
[23] Lewi L, Valencia C, Gonzalez E, et al. The outcome of twin reversed arterial perfusion sequence diagnosed in the first trimester. Am J Obstet Gynecol 2010;203(3):213.e1–e4. doi:10.1016/j.ajog.2010.04.018.
[24] Scheier M, Molina FS. Outcome of twin reversed arterial perfusion sequence following treatment with interstitial laser: a retrospective study. Fetal Diagn Ther 2012;31(1):35–41. doi:10.1159/000334156.
[25] Roethlisberger M, Strizek B, Gottschalk I, et al. First-trimester intervention in twin reversed arterial perfusion sequence: does size matter?. Ultrasound Obstet Gynecol 2017;50(1):40–44. doi:10.1002/uog.16013.
[26] Berg C, Holst D, Mallmann MR, et al. Early vs late intervention in twin reversed arterial perfusion sequence. Ultrasound Obstet Gynecol 2014;43(1):60–64. doi:10.1002/uog.12578.
[27] Tavares de Sousa M, Glosemeyer P, Diemert A, et al. First-trimester intervention in twin reversed arterial perfusion sequence. Ultrasound Obstet Gynecol 2020;55(1):47–49. doi:10.1002/uog.20860.
[28] Huang G, Liao H, Hu Q, et al. Intrafetal laser therapy in a monochorionic diamniotic triplet pregnancy with two acardiac fetuses: a case report and literature review. BMC Pregnancy Childbirth 2021;21(1):245. doi:10.1186/s12884-021-03716-6.
[29] Shaw CJ, Rivens I, Civale J, et al. Maternal and fetal cardiometabolic recovery following ultrasound-guided high-intensity focused ultrasound placental vascular occlusion. J R Soc Interface 2019;16(154):20190013. doi:10.1098/rsif.2019.0013.
[30] Deprest JA, Audibert F, Van Schoubroeck D, et al. Bipolar coagulation of the umbilical cord in complicated monochorionic twin pregnancy. Am J Obstet Gynecol 2000;182(2):340–345. doi:10.1016/s0002-9378(00)70221-3.
[31] Lanna MM, Rustico MA, Dell'Avanzo M, et al. Bipolar cord coagulation for selective feticide in complicated monochorionic twin pregnancies: 118 consecutive cases at a single center. Ultrasound Obstet Gynecol 2012;39(4):407–413. doi:10.1002/uog.11073.
[32] Tsao K, Feldstein VA, Albanese CT, et al. Selective reduction of acardiac twin by radiofrequency ablation. Am J Obstet Gynecol 2002;187(3):635–640. doi:10.1067/mob.2002.125242.
[33] Paramasivam G, Wimalasundera R, Wiechec M, et al. Radiofrequency ablation for selective reduction in complex monochorionic pregnancies. BJOG 2010;117(10):1294–1298. doi:10.1111/j.1471-0528.2010.02624.x.
[34] Bebbington MW, Danzer E, Moldenhauer J, et al. Radiofrequency ablation vs bipolar umbilical cord coagulation in the management of complicated monochorionic pregnancies. Ultrasound Obstet Gynecol 2012;40(3):319–324. doi:10.1002/uog.11122.
[35] Roman A, Papanna R, Johnson A, et al. Selective reduction in complicated monochorionic pregnancies: radiofrequency ablation vs. bipolar cord

coagulation. Ultrasound Obstet Gynecol 2010;36(1):37–41. doi:10.1002/uog.7567.

[36] Bebbington M. Selective reduction in complex monochorionic gestations. Am J Perinatol 2014;31(suppl 1):S51–S58. doi:10.1055/s-0034-1383852.

[37] Lu J, Ting YH, Law KM, et al. Radiofrequency ablation for selective reduction in complicated monochorionic multiple pregnancies. Fetal Diagn Ther 2013;34(4):211–216. doi:10.1159/000355406.

[38] Napolitani FD, Schreiber I. The acardiac monster. A review of the world literature and presentation of 2 cases. Am J Obstet Gynecol 1960;80:582–589. doi:10.1016/s0002-9378(16)36520-6.

[39] Klaritsch P, Albert K, Van Mieghem T, et al. Instrumental requirements for minimal invasive fetal surgery. BJOG 2009;116(2):188–197. doi:10.1111/j.1471-0528.2008.02021.x.

[40] O'Donoghue K, Barigye O, Pasquini L, et al. Interstitial laser therapy for fetal reduction in monochorionic multiple pregnancy: loss rate and association with aplasia cutis congenita. Prenat Diagn 2008;28(6):535–543. doi:10.1002/pd.2025.

[41] Prefumo F, Cabassa P, Fichera A, et al. Preliminary experience with microwave ablation for selective feticide in monochorionic twin pregnancies. Ultrasound Obstet Gynecol 2013;41(4):470–471. doi:10.1002/uog.12286.

[42] Prefumo F, Cabassa P, Fichera A, et al. Microwave ablation in complicated monochorionic twin pregnancies. Fetal Diagn Ther 2015;38(2):159. doi:10.1159/000381951.

[43] Stephenson CD, Temming LA, Pollack R, et al. Microwave ablation for twin-reversed arterial perfusion sequence: a novel application of technology. Fetal Diagn Ther 2015;38(1):35–40. doi:10.1159/000369384.

[44] Ichizuka K, Matsuoka R, Aoki H, et al. Basic study of less invasive high-intensity focused ultrasound (HIFU) in fetal therapy for twin reversed arterial perfusion (TRAP) sequence. J Med Ultrason (2001) 2016;43(4):487–492. doi:10.1007/s10396-016-0725-x.

[45] Okai T, Ichizuka K, Hasegawa J, et al. First successful case of non-invasive in-utero treatment of twin reversed arterial perfusion sequence by high-intensity focused ultrasound. Ultrasound Obstet Gynecol 2013;42(1):112–114. doi:10.1002/uog.12466.

[46] Seo K, Ichizuka K, Okai T, et al. Treatment of twin-reversed arterial perfusion sequence using high-intensity focused ultrasound. Ultrasound Obstet Gynecol 2019;54(1):128–134. doi:10.1002/uog.20101.

[47] Ting YH, Poon L, Tse WT, et al. Outcome of radiofrequency ablation for selective fetal reduction before vs at or after 16gestational weeks in complicated monochorionic pregnancy. Ultrasound Obstet Gynecol 2021;58(2):214–220. doi:10.1002/uog.22160.

Edited By Yang Pan

How to cite this article: Ye X, Wang J, Lu J, Li N, Ding W, Ding W, Fu Y, Chen M. Twin Reversed Arterial Perfusion Sequence: Prenatal Diagnosis and Treatment. Maternal Fetal Med 2022;4(4):262–267. doi: 10.1097/FM9.0000000000000172.