Original Paper

Fetal Diagnosis and Therapy

Fetal Diagn Ther 2015;38:35–40
DOI: 10.1159/000369384

Received: October 7, 2014
Accepted after revision: October 25, 2014
Published online: January 22, 2015

Microwave Ablation for Twin-Reversed Arterial Perfusion Sequence: A Novel Application of Technology

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Key Words
Twin-reversed arterial perfusion sequence · Microwave ablation · Radiofrequency ablation · Monochorionic pregnancy · Selective termination · Acardiac mass

Abstract
Introduction: Twin-reversed arterial perfusion sequence is a rare complication of monochorionic pregnancies that is characterized by the presence of an acardiac mass perfused by an apparently normal pump twin. The risk of death to the pump twin has led to a range of therapeutic interventions aimed at separating their vascular connection. We report a novel application of microwave ablation for vessel coagulation in the treatment of twin-reversed arterial perfusion sequence. ***Material and Methods:*** Microwave ablation has been adopted by surgical subspecialties as a superior energy source for vessel and tissue ablation as it creates heat without a circuit and has less thermal spread. We describe the use of a 2.45-GHz microwave system using a 1.8-mm antenna to coagulate the intra-abdominal portion of umbilical vessels of the acardiac mass. ***Results:*** We report 6 cases of twin-reversed arterial perfusion sequence treated by microwave ablation. All patients were treated with microwave ablation with successful coagulation of intra-abdominal umbilical cord vessels of the acardiac mass with cessation of flow. ***Discussion:*** Microwave ablation is an excellent energy source for vessel coagulation due to its thermal properties and can be used effectively in the treatment of twin-reversed arterial perfusion sequence.

Introduction

Twin-reversed arterial perfusion (TRAP) sequence is a rare complication of monochorionic pregnancies that is characterized by the presence of an acardiac mass perfused by an apparently normal pump twin. The mass is perfused in a retrograde manner via arterioarterial anastomosis through a common cord insertion site [1, 2]. TRAP sequence affects approximately 1% of monochorionic twin pregnancies and 1 in 35,000 deliveries [3]. Untreated, this may lead to cardiac failure, hydrops or death of the pump twin, as well as increased risk of preterm birth and related complications. The perinatal mortality rate in untreated pump twins has ranged from 55 to 100% in various case series [2, 4]. There are multiple proposed indicators of poor prognosis in TRAP sequence, including cardiomegaly, hydrops, polyhydramnios, abnormal Doppler studies, increased ratio of the weight of the acardiac mass to the weight of the pump twin, and increased volume of the acardiac mass to the weight of the pump twin [1, 4]. An acardiac size greater than 70% of the pump

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twin correlates with findings associated with an increased risk of pump twin compromise [4, 5]. Intervention is generally performed with worsening of these indices. A recent study suggested that the early treatment of TRAP sequence may reduce adverse outcomes in comparison to expectant management with intervention once compromise becomes apparent [2]. Halting the blood flow to the acardiac twin is the goal of intrauterine therapy and has been most commonly accomplished by bipolar cord coagulation or ligation, laser cord coagulation or radiofrequency ablation. Outcome data following in utero intervention for TRAP has generally reported the survival of 80–85% of pump twins [2, 6, 7]. Radiofrequency ablation has important benefits over fetoscopy due to its less invasive, small-caliber instrumentation and ease of use. Radiofrequency ablation uses high-frequency alternating electrical current through an insulated needle shaft to active electrode tips which dissipate heat into the surrounding tissue. The majority of tissue heating is due to the transformation of electrical energy, which is troublesome when attempting to ablate vessels with high flow. Heat and energy losses can occur through stray currents and electrical sinks, which may affect the efficacy of the thermocoagulation [8, 9]. The presence of a heat sink near the vessels has been demonstrated, limiting maximal tissue temperatures [8, 9]. Radiofrequency ablation of vascular structures is less effective due to the affinity of electricity to seek the path of least resistance. Microwave ablation offers many of the same benefits as radiofrequency ablation while overcoming some of its limitations, particularly blood vessel-mediated cooling or heat sink effect [10]. Microwave ablation uses energy which causes dipole molecules (water) within the near field to create heat, leading to thermocoagulation of the surrounding tissue. A heat sink effect has not been observed using this modality [8, 9, 11, 12]. Consequently, a focused burn with more energy can be applied to the target tissue, thus allowing for higher tissue temperatures and faster ablation times [8, 9, 13]. Larger tissue ablation volumes and improved radiation and conduction profiles have also been cited as advantages of microwave ablation compared to radiofrequency ablation [8, 9, 13, 14]. Due to the inherent vascular connections in monochorionic placentas, when vascular ablation is performed it must be quick and complete to avoid hemodynamic shifts and co-twin hypotension [15, 16]. Radiofrequency ablation tines are difficult to control. Multiple placements may be necessary to achieve full coagulation. Studies in perfused bovine liver models revealed an inverse relationship between vessel flow and effective tissue ablation with radiofrequency ablation [17]. In contrast, when using microwave ablation, a predictable microwave near field is created through nonionizing radiation. Heat is confined to this region and there is little thermal effect beyond this zone. The purpose of our manuscript is to describe a novel application of microwave ablation for vessel coagulation in the treatment of TRAP sequence.

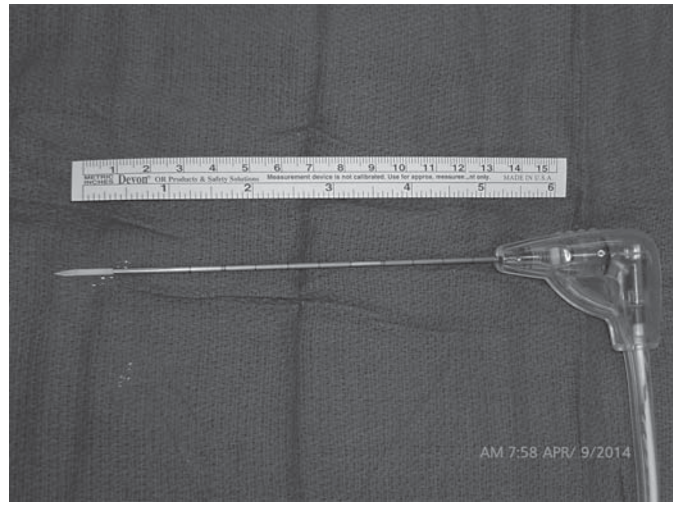

Fig. 1. 1.8-mm (15-gauge) transcutaneous antenna with a 1.5-cm active tip.

Material and Methods

The procedures were performed in the operating room, initially with general anesthesia and, most recently, with combined spinal-epidural anesthesia. General anesthesia was chosen for the initial cases to control the surgical environment. This approach was abandoned with increased experience. The surgical team included maternal fetal medicine and hepatobiliary surgical specialists. All patients were treated with a 2.45-GHz microwave ablation system using a 1.8-mm antenna (fig. 1). A small 2-mm skin incision was created and the 15-gauge antenna was passed percutaneously into the intrauterine space with ultrasound guidance, avoiding the placenta. The target was the intra-abdominal portion of the umbilical vessels of the liver of the acardiac twin (fig. 2a). Based on the size of the zone needed for coagulative necrosis, the microwave energy was estimated. Generally, 100–140 W was administered for 3–4 min to create an area of coagulation between 3–5 cm, depending on the size and nature of the vessels of the acardiac twin. Once the proper antenna placement was confirmed, microwave energy was applied, as shown in online supplementary video 1 (for all online suppl. material, see www.karger.com/doi/10.1159/000369384) and figure 2a and b. Color Doppler was used to observe the extent of the microwave near field during the ablation. Conveniently, the effects of the microwave near field are delineated by color Doppler for intraoperative monitoring (fig. 3) [18]. This coagulation zone has been confirmed by pathological examination, demonstrating a well-de-

Color version available online

Fig. 2. Ultrasound imaging of the microwave ablation procedure. **a** Note the target vessel within the fetal liver. **b** Microwave energy deployed. Observe increasing echogenicity with applied energy. **c** Postmicrowave ablation echo-bright coagulation effects.

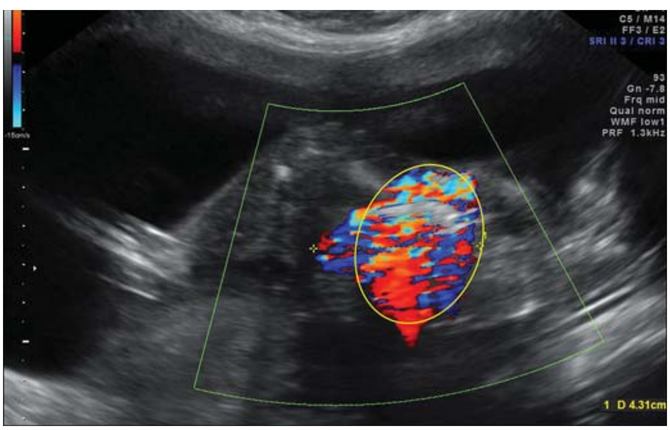

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Fig. 3. Ultrasound imaging of the Doppler effects during microwave ablation.

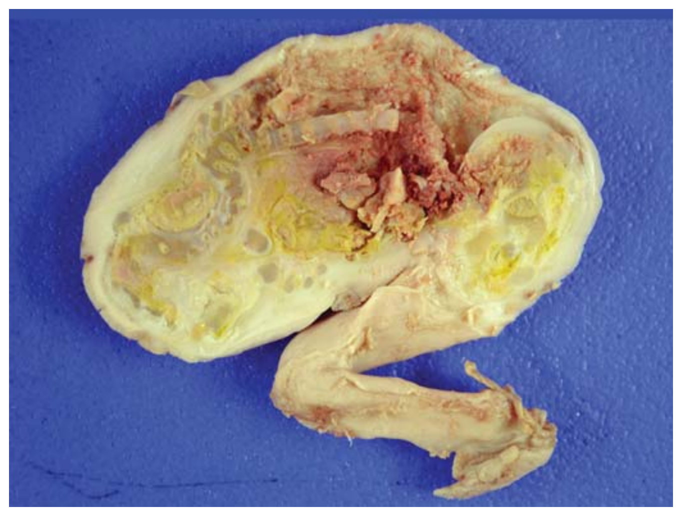

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Fig. 4. The delivered acardiac specimen demonstrates a 2.5-cm area of homogeneous coagulative necrosis within the abdominal cavity with little thermal spread.

marcated region of coagulative necrosis while the adjacent tissue remained unaffected (fig. 3, 4) [18]. Postablation ultrasound was used to confirm the absence of blood flow through the acardiac mass and the presence of blood flow to the intact fetus (fig. 2c).

Results

We report 6 cases of TRAP sequence treated by microwave ablation (table 1). This report is an extension of the first 2 previously reported cases [19]. Patient consent and approval from the Carolinas Health Care System IRB (file 08-10-09E) were obtained to compile the data used in this report. The patients were extensively counseled regarding the novel application of microwave to treat TRAP sequence and were offered bipolar coagulation or radiofrequency ablation as well. The first patient, with a history of preterm delivery, presented with TRAP sequence as a referral from an outside facility at 20 weeks of gestation. At 23 0/7 weeks of gestation, she showed signs of increasing polyhydramnios and worsening cardiac function. The acardiac mass to pump twin ratio was greater than 0.70. Intervention was offered and microwave ablation was performed. Follow-up ul-

Table 1. Characteristics of patients treated with microwave ablation using a 2.45-GHz antenna

Patient	Chorionicity	Amnionicity	Number of fetuses	GA at presentation, weeks	GA at surgery, weeks	GA at delivery, weeks	Present age, months	Power	Time	Postoperative day 1 result	Complication
1	monochorionic	diamniotic	2	20 0/7	23 0/7	25 3/7	32	120 W, 100 W	3 min, 4 min	no flow	none
2	monochorionic	diamniotic	3	11 3/7	16 0/7	18 5/7	n.a.	100 W	3 min	no flow	none
3	monochorionic	diamniotic	2	13 3/7	21 3/7	36 2/7	4	100 W, 120 W	1.5 min, 2 min	no flow	none
4	monochorionic	diamniotic	2	21 2/7	21 3/7	38 0/7	3	120 W, 120 W	3 min, 3 min	no flow	none
5	monochorionic	monoamniotic	2	15 3/7	18 5/7	28 4/7	n.a.	120 W	3 min	no flow	none
6	monochorionic	diamniotic	2	20 3/7	20 4/7	still pregnant	n.a.	140 W, 140 W	4 min, 3 min	no flow	none

Patient 2 declined further intervention to address the cord entanglement between the normal fetuses – both fetuses demised. Patient 5 required additional procedure due to entanglement; the patient underwent fetoscopic transection of the TRAP cord 2 weeks after the microwave ablation; intrauterine fetal demise at 28 4/7 weeks due to amniotic band adhesion around the cord. GA = Gestational age; n.a. = not applicable.

trasound on postoperative days (POD) 1 and 7 showed normal cardiac function in the pump twin, decreased polyhydramnios and a decreased acardiac mass to pump twin ratio of 0.53. The patient was then released to follow-up at the referral facility. She presented there in preterm labor at 25 3/7 weeks of gestation and delivered. The child is now 2.5 years old and reaching appropriate milestones. The second patient presented with monochorionic-diamniotic triplet gestation with TRAP sequence at 11 3/7 weeks of gestation. By 16 0/7 weeks, the acardiac mass to pump twin ratio was greater than 0.70. She underwent microwave ablation of the acardiac mass. The patient declined selective reduction of the monoamniotic pair after extensive counseling regarding the risks of entanglement. The microwave ablation was performed at 16 1/7 weeks of gestation as described, with successful cessation of blood flow to the acardiac mass. On POD 1, the remaining monochorionic monoamniotic pair initially showed improved cardiac function and normal umbilical artery Doppler signals. Follow-up ultrasound on POD 7 at 17 weeks showed significant cord entanglement with intermittent reversed end-diastolic flow to one of the fetuses. Again, the patient declined selective fetal reduction. At 18 5/7 weeks, an intrauterine demise of the monoamniotic twins was noted. Gross examination of fetuses B and C at the time of delivery showed cord entanglement and knotting. The third patient presented at 13 3/7 weeks with TRAP sequence. She was closely followed until 21 3/7 weeks when the acardiac mass to pump twin ratio increased to greater than 0.70 and abnormal Doppler studies were noted. She underwent microwave ablation. The patient delivered at 36 2/7 weeks for fetal indications. The neonate was discharged with his mother and is now 4 months old. The fourth patient presented at 21 2/7 weeks with TRAP sequence with evidence of pump twin compromise by evidence of cardiac dysfunction, polyhydramnios and an acardiac mass to pump twin ratio of 1.15. She underwent microwave ablation, ultimately delivered at 38 weeks, and the infant is 3 months old. The fifth patient presented with monoamniotic pregnancy at 15 3/7 weeks complicated by TRAP sequence. The umbilical cords had a common placental insertion site and were entwined. Because of the short cord and large size of the acardiac twin, access to the acardiac cord was obstructed and, therefore, a staged procedure was planned. The patient first underwent microwave ablation of the acardiac mass at 18 5/7 weeks to reduce the acardiac volume and then cord transection at 20 6/7 weeks to release the mass. At 29 weeks of gestation, the patient had a sudden intrauterine demise due to an amniotic band that formed around the base of the cord. The fetus was well grown and showed no signs of compromise preceding the loss. The sixth patient presented at 20 4/7 weeks with monochorionic diamniotic TRAP sequence with an acardiac mass to pump twin ratio of 2.8. She underwent microwave ablation at 20 5/7 weeks and is currently doing well at 28 3/7 weeks. All cases were successful in ablating the intrahepatic vessels of the acardiac abdominal cord insertion site. There were no maternal complications.

Discussion

We suggest microwave ablation as an alternative treatment modality that may have advantages over other methods of intrafetal vessel ablation. Firstly, the procedure involves a single puncture of the uterus with a 1.8-mm-diameter (15-gauge) antenna. This is slightly larger than the diameter described with radiofrequency ablation (17-gauge) but still significantly smaller than the typical 3.8-mm-diameter operative sheath used in bipolar cord coagulation. In studies comparing radiofrequency ablation to bipolar cord coagulation, a narrower diameter has shown a trend toward lower rates of preterm premature rupture of membranes and preterm delivery; however, statistical significance was not reached due to small sample size [15, 16]. Secondly, microwave ablation has excellent operator control over the size of the coagulation zone. Because the radiofrequency ablation system involves deployable tines from the electrode while within the target tissue, there is little to no control of the location of these tines. This can lead to adjacent structure injury through either direct puncture or delivery of stray electrical current. Furthermore, radiofrequency ablation electrical currents are susceptible to electrical sink effect, leading to less effective tissue and blood vessel coagulation [8, 13]. Since electricity seeks a path of least resistance, heat can be lost downstream from a vessel. Microwave ablation creates its thermocoagulative effect through nonionizing radiation and not through electrical currents [13]. This microwave near field is not susceptible to the electrical sink effect and is more effective in tissue and, in particular, vessel coagulation [8, 13]. No heat is lost from vascular flow.

The microwave near field, a circumferential energy field created around the active tip of the antenna, can be monitored in real-time ultrasound throughout the ablation and has been shown to correlate with the final thermocoagulation zone [17, 18] (fig. 3). The size of the microwave near field can be directly controlled through power output and time. Finally, there is a risk of maternal injury from thermal burns created by high current through radiofrequency ablation dispersive electrodes (grounding pads) [13, 14, 20, 21]. Microwave ablation does not require grounding pads and, therefore, eliminates the risk of this injury. Percutaneous microwave ablation has the technical ease and benefits of radiofrequency ablation compared to fetoscopic procedures, is similar with regard to cost and specialized equipment required compared to radiofrequency ablation, is an excellent energy delivery method for vessel coagulation with increased precision of the thermocoagulation zone, and has a decreased risk of heat sink energy loss [9]. While our experience is limited to 6 cases, there is considerable evidence in other surgical subspecialties that microwave ablation, due to its inherent physical properties, is more efficacious in cauterizing vessels. We present these cases to illustrate that microwave ablation can be used as an effective alternative for percutaneous intrauterine ablation of acardiac vessels. Unfortunately, the risks of monoamnionicity and preterm delivery continue to be a hurdle in the treatment of fetal conditions. With our small number of cases, a definitive conclusion about the overall perinatal benefits cannot be determined and a larger multicenter comparative trial would be ideal.

In conclusion, microwave ablation is an excellent energy source for vessel coagulation and can be used effectively in the treatment of TRAP sequence.

Disclosure Statement

The authors report no conflicts of interest.

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