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Maternal Focal Atrial Tachycardia During Pregnancy: A Systematic Review

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Abstract

Introduction: The presentation and optimal management of maternal focal atrial tachycardia (AT) during pregnancy is unknown. The objective of this study was to conduct a comprehensive summary of the existing evidence.

Methods and Results: A systematic review of all reported cases of maternal focal AT during pregnancy was performed. The primary search queried PubMed using the MeSH terms “supraventricular tachycardia” and “pregnancy.” A stepwise ancillary search included article bibliographies, citations listed by the Google internet search engine, and PubMed using the MeSH terms “atrial tachycardia” and “pregnancy.” In total, 28 citations that described 32 patients were retrieved. A case from our institution was added. Detailed information was available for 30 patients. Clinical characteristics at presentation included a mean $\pm$ standard deviation of 28.3 ± 5.7 years for maternal age and 24.6 ± 7.7 weeks for gestation age. Suspected tachycardia-induced cardiomyopathy was present in 20 of 30 (67%) patients and left ventricular ejection fraction improved in 15 of 15 (100%) patients with follow-up measurements. Medication failure was common. Focal AT resolved spontaneously after delivery in 8 of 9 (89%) patients treated with only medications. Automaticity was suggested by discrete electrograms at sites of origin and lack of reported inducibility and termination with programmed stimulation in all patients who underwent electrophysiology studies. There were 9 cases of successful catheter ablation with zero fluoroscopy since 2010.

Conclusions: Automaticity is the dominant mechanism for patients with maternal focal AT during pregnancy. Catheter ablation with zero fluoroscopy is an emerging therapy for medically refractory cases.

Keywords

atrial tachycardia; catheter ablation; fluoroscopy; pregnancy; supraventricular tachycardia; systematic review; focal atrial tachycardia; medications

1 INTRODUCTION

Maternal paroxysmal supraventricular tachycardia (SVT) has long been noted to be exacerbated by pregnancy.¹ In the United States of America, maternal SVT has an estimated frequency of 22 per 100,000 pregnancy-related hospitalizations.² In the absence of structural heart disease, it was historically felt to have little adverse maternal or fetal consequences.¹ More recently, an observational study from Taiwan of over 2.3 million women without congenital heart disease demonstrated a positive association between the presence of maternal SVT during pregnancy and the individual outcomes of severe maternal morbidity, Cesarean delivery, low birth weight, preterm labor, fetal stress, and obvious fetal abnormalities.³ Therefore, developing optimal management strategies for maternal SVT during pregnancy is of high interest.

The 3 paroxysmal SVTs are classically atrioventricular nodal reentrant tachycardia (AVNRT), atrioventricular reentrant tachycardia (AVRT), and focal atrial tachycardia (AT). The most common SVTs in women of child-bearing age, from most to least frequent, are AVNRT, AVRT, and focal AT.⁴ Less is known about the distribution during pregnancy. The birth of invasive cardiac electrophysiology in 1967 led to the ability to distinguish SVT mechanisms and to tailor therapeutic strategies.⁵ Despite these advances, management of maternal SVT in pregnant patients does not distinguish between these 3 types in the current guideline from the American College of Cardiology (ACC), the American Heart Association (AHA), and the Heart Rhythm Society (HRS).⁶ Differentiation may have importance due to underlying mechanisms as AVNRT and AVRT are due to reentry while focal AT may be due to triggered activity, enhanced automaticity, or microreentry.⁷ In non-pregnant patients, mechanistic differences of focal ATs translate into differences in patient characteristics and may alter management recommendations.^{6,8,9}

Reviews that address management of general maternal arrhythmias during pregnancy have been published.^{10,11} The purpose of this manuscript was to conduct and report the first systematic review of maternal focal AT during pregnancy. A case report from our institution is included.

2 CASE REPORT

A 28-year-old woman of white race in the 22nd week of pregnancy presented to the University of Pittsburgh Medical Center (UPMC) emergency department with shortness of breath and palpitations for approximately 1 week. She had a history of hypothyroidism, depression, and anxiety. Levothyroxine was recently increased from 120 mcg to 150 mcg daily, and her thyroid stimulating hormone was within the normal range. She had a height of 170 cm, a weight of 86 kg, and a body mass index of 29.8 kg/m². The electrocardiogram

(ECG) on presentation was interpreted as sinus tachycardia at 120 bpm. She was given 2 liters of intravenous (IV) fluids and discharged home.

One week later, she returned to the emergency department with similar symptoms. The ECG demonstrated a heart rate of 116 bpm with 1:1 atrioventricular conduction (Figure 1). The PR interval was 160 ms. P-waves were upright in I and aVL; negative in V1; and isoelectric in II, III, and aVF. Telemetry demonstrated SVT with heart rates between 110 and 180 bpm with “warm-up” and “cool-down” phenomena. Administration of adenosine 6 mg and 12 mg IV led to transient termination (Figure 2) before spontaneous return. Diltiazem 10 mg IV and 2 doses of metoprolol 5 mg IV led to slowing of the heart rate. She was started on metoprolol tartrate 50 mg twice daily by mouth. A chest computed tomography with angiography was negative for acute pulmonary embolism. A transthoracic echocardiogram was normal with a left ventricular ejection fraction (LVEF) of 55–60%. Fetal status was reassuring as assessed by ultrasound at the time of admission, with normal fetal heart rate and normal amniotic fluid index.

Electrophysiology study with a goal of zero fluoroscopy was recommended, with agreement from the maternal-fetal medicine service, due to the incessant, highly symptomatic nature of the arrhythmia and medication failure. Given that she had already received radiation in the evaluation for pulmonary embolism, it was desirable to minimize additional radiation. In the electrophysiology laboratory, she was placed in the left lateral tilt position. Three venous access sites in the right femoral vein were obtained using the modified Seldinger technique. The CARTO® 3 mapping system and a 4 mm tip NAVISTAR® non-irrigated radiofrequency ablation catheter (Biosense Webster, Diamond Bar, CA) were used to create a 3-dimensional map of the right atrium and coronary sinus in a point-by-point fashion. Location points for the His bundle and tricuspid valve annulus were tagged on the mapping system. Diagnostic electrophysiology catheters, visualized by the mapping system, were placed near the His bundle and in the coronary sinus.

The baseline measurements, after sedation with propofol IV was administered, demonstrated an ectopic atrial rhythm with a cycle length of 695 ms, an AH interval of 142 ms, and an HV interval of 48 ms. The Wenckebach cycle length was 450 ms. The effective refractory period of the atrioventricular (AV) node was 350 ms at a drive train of 600 ms. There was no AH “jump” during right atrial pacing suggestive of dual AV nodal physiology. The retrograde conduction was concentric and decremental. Isoproterenol was initiated and titrated to 2 mcg/min which led to an increase in the heart rate. Ventricular overdrive pacing yielded a V-A-A-V response that was followed by spontaneous transition into a slower heart rate with upright P-waves in the inferior leads consistent with normal sinus rhythm (Figure 3). Activation mapping of the SVT demonstrated centrifugal activation radiating from a discrete source, the putative site of origin, near the superoanterior tricuspid valve annulus (Figure 4). The totality of the findings supported a diagnosis of focal AT due to enhanced automaticity.

Delivery of radiofrequency energy in a temperature-controlled mode with a target temperature of 55°C at a power of 30–50 W resulted in only transient heart rate decrease. The decision was made to switch to a 3.5 mm tip THERMOCOOL SMARTTOUCH® (Biosense Webster) irrigated radiofrequency ablation catheter. Lesions up to 40 watts were

delivered, leading to eventual arrhythmia termination. The procedure was ended after 20 minutes of isoproterenol infusion at 2 mcg/min without return of the focal AT. The entire procedure was performed with zero fluoroscopy. Fetal heart rates were assessed before and after the procedure by obstetric ultrasound. Her post-procedural ECG revealed normal sinus rhythm (Figure 5A).

She was discharged with close interdisciplinary follow-up involving cardio-obstetrics, maternal-fetal medicine, and anesthesia services. She continued to have less frequent palpitations of a different character and was maintained on metoprolol. ECGs in clinic demonstrated sinus rhythm (Figure 5B) and a 30-day event monitor revealed short episodes of sinus tachycardia with rates between 120 and 150 bpm. The episodes did not have bursts, or abrupt “warm-up” and “cool-down”, to suggest enhanced automaticity. At a gestation of 37 weeks and 0 days, she had a spontaneous vaginal delivery of a healthy female infant who weighed 3,330 grams. The Apgar scores were 4 at 1 minute, 7 at 5 minutes, and 9 at 10 minutes. Her palpitations eventually resolved in the postpartum period and metoprolol was stopped.

This case lends supporting evidence that catheter ablation with zero fluoroscopy may be an effective therapy to manage medically-refractory focal AT during pregnancy. This is also, to the best of our knowledge, the first report of catheter ablation of focal AT arising near the tricuspid annulus in a pregnant patient. Cellular differences may predispose to focal AT arising near the tricuspid annulus.⁸ Consent for the publication of this case report was obtained from the patient.

3 METHODS

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.¹²

3.1 Data Sources, Search Strategy, and Study Selection

A systematic literature search for all relevant articles listed on PubMed was conducted without limitation for year of publication. MeSH terms included “supraventricular tachycardia” and “pregnancy.” Restrictions included English language and human subjects. Publications were identified and included if they described clinical situations in which pregnant women had maternal arrhythmias described as and consistent with focal ATs with or without electrophysiology study confirmation. Abstracts were independently identified by two investigators (C.S. and T.J.M.) and underwent full-text review to determine eligibility for inclusion in the systematic review. Discrepancies were adjudicated by a third reviewer (N.C.W). Exclusion criteria included abstracts, patients with complex congenital heart disease, arrhythmias only during active labor, and arrhythmias only in the postpartum period. A stepwise ancillary search was performed in the following order: 1) manual review of bibliographies from retrieved articles, 2) review of citations of the retrieved articles by the Google search engine, and 3) PubMed search using the MeSH terms “atrial tachycardia” and “pregnancy.”

3.2 Data Extraction, Synthesis, and Analysis

Data collected were divided into 4 main categories: 1) clinical characteristics, 2) acute and chronic treatments, 3) electrophysiology study and catheter ablation data, and 4) delivery outcomes. If more than one pregnancy for a woman was reported, information from the pregnancy that was the focus of the report was used. It was anticipated that the articles retrieved would be limited to case reports and case series with small numbers, given discussions from prior reviews on maternal arrhythmias during pregnancy.^{10,11} Data for patients with detailed information were listed in table form.

Prior SVT was defined as a history of SVT in the non-pregnant state. Tachycardia-induced cardiomyopathy was assigned when the LVEF was <50% or noted as reduced. Acute and chronic treatments were listed for those administered for treatment of SVT during pregnancy. Successful medications were listed for patients who did not proceed to electrophysiology study. The electrogram at the ablation site, or site of origin, supported triggered activity or enhanced automaticity if it was discrete, defined as <20% of the tachycardia cycle length.⁷ The electrogram supported microreentry if it was fractionated and 35% of the tachycardia cycle length.⁷

4 RESULTS

4.1 Study results

A literature flow diagram outlining the systematic review is depicted in Figure 6. In total, 28 articles that included 30 patients were retrieved.^{13–40} The primary search via PubMed yielded 564 articles and identified 9 articles for review.^{16,22,24–29,33} The ancillary search identified an additional 19 articles. With the addition of our case report, there were a total of 33 patients included in our review. One article from Poland contained 3 cases did not have detailed information, other than all women had successful catheter ablation procedures performed with zero fluoroscopy and had uncomplicated healthy, full-term births.³⁷ Therefore, 30 patients were included in our presentation of detailed information.

4.2 Clinical characteristics

Clinical characteristics of the 30 patients are listed on Table 1. The case report presented in this manuscript is listed as case 30 under UPMC. The mean $\pm$ standard deviation was 28.3 ± 5.7 years for maternal age and 24.6 ± 7.7 weeks for gestation age, both recorded at the time of presentation. The mean $\pm$ standard deviation maximum heart rate was 193 ± 36 beats per minute.

The most common symptoms were palpitations and shortness of breath which were reported in 21 (70%) and 19 (63%) patients, respectively. Only 6 (20%) patients had a prior history of paroxysmal SVT. Suspected tachycardia-induced cardiomyopathy was present in 20 (67%) of patients and LVEF improved in all 15 patients that had follow-up measurements.

4.3 Acute and chronic treatments

Acute and chronic treatments received are listed on Table 2. Vagal maneuvers were successful in 0 of 5 patients. Adenosine terminated focal AT in 3 of 11 patients. Atrial

overdrive pacing was performed in 3 patients and failed on all occasions. In one patient, atrial overdrive pacing was described as being performed through an esophageal lead that was initially placed for diagnostic purposes.³⁹ Direct current cardioversion was successful in 1 of 14 patients. Medication failure was commonly reported. In 12 patients who were medically managed without attempted catheter ablation, 8 of 9 (89%) patients had spontaneous resolution of their arrhythmias after successful delivery.^{13,15–18,20–22,35}

Two patients had severe hemodynamic responses to verapamil.^{20,28} The first patient was a 30-year-old woman in her 24th week of gestation who presented with dyspnea on exertion, ankle swelling, and focal AT with a rate of 200 bpm.²⁰ Verapamil 5 mg IV was given followed by another 5 mg IV after 5 minutes. This resulted in a decrease in blood pressure to “unrecordable levels.” She was successfully treated with IV fluids and calcium gluconate. An echocardiogram later demonstrated a reduced fractional shortening of 8%. Ultimately, her arrhythmia was managed successfully with sotalol and she had a normal delivery in her 43rd week of pregnancy.

The second patient with a severe adverse reaction to verapamil was a 24-year-old woman who was in her 36th week of pregnancy when she had an elective Cesarean section due to incessant focal AT.²⁸ She had a known LVEF of 30% as assessed 12 weeks prior. After successful delivery, she was given verapamil 120 mg by mouth for tachycardia greater than 180 bpm and developed cardiogenic shock within 24 hours. An echocardiogram demonstrated a LVEF of 10% while on inotropic support. She was placed on extracorporeal membrane oxygenation and underwent successful catheter ablation of a focus near the left inferior pulmonary vein. She ultimately had a favorable outcome with improvement of her LVEF to 60%.

4.4 Electrophysiology study and catheter ablation data

Information from 18 electrophysiology studies and catheter ablation data are listed on Table 3. Of these, 2 patients had their procedures soon after delivery.^{19,40} The first report of catheter ablation for focal AT in a pregnant patient was in 2004 from India.²³ In Table 3, only irrigated was listed if both non-irrigated and irrigated radiofrequency ablation catheters were used, as was the situation in 2 cases reported by Mizumaki et al.³⁴ and UPMC.

All electrograms at the sites of origin were discrete and none of the electroanatomic maps supported microentry. All subjects save one who underwent electrophysiology studies had spontaneous arrhythmias. The one who did not was induced with isoproterenol. None of the arrhythmias were induced or terminated with programmed electrical stimulation.

In the reported literature, catheter ablation was successful in 18 of the 19 (95%) patients who underwent the procedure during pregnancy, when the 3 patients without detailed information were added.³⁷ There have been 9 patients with successful ablation for focal AT with zero fluoroscopy, including the case report presented in this manuscript.^{26,27,32,37–39} The one failed ablation attempt occurred in a patient where the focus was ultimately determined to be a diverticulum within the right atrial appendage.³⁴ Cure was achieved after surgical excision. The reported cases of focal AT during pregnancy over the last decade have almost exclusively been patients who underwent catheter ablation.

4.5 Delivery outcomes

Delivery outcomes are listed on Table 4. There were 2 fetal deaths.^{29,31} The first patient was a 28-year-old woman at 26 weeks gestation who had focal AT with a heart rate of 229 bpm.²⁹ This was refractory to adenosine, direct current cardioversion, and amiodarone. An echocardiogram demonstrated global hypokinesia. She developed cardiogenic shock and fetal distress with absent heart beats. After veno-arterial extracorporeal membrane oxygenation initiation, she underwent successful catheter ablation of a right atrial focus. Unfortunately, fetal demise occurred during the process of transitioning to extracorporeal membrane oxygenation. Delivery by Cesarean section followed maternal stabilization.

The second patient with a fetal death was a 32-year-old woman at 21 weeks gestation who had focal AT refractory to amiodarone and beta-blockers.³¹ Her LVEF was 18%. She underwent electrophysiology study which diagnosed focal AT from the free wall of the right atrium. Catheter ablation was successfully performed, but she developed hypoxia, tachypnea, and hypotension at the end of the procedure. Although not confirmed, it was felt that she sustained an acute pulmonary embolism due to a high alveolar-arterial oxygen gradient and a high plasma D-dimer level. She was given heparin IV and placed on mechanical ventilation. Fetal demise was subsequently diagnosed. These 2 cases emphasize the potentially serious consequences of poorly treated focal AT and the need to develop optimal peri-procedural protocols if pregnant patients are to be taken to the electrophysiology laboratory.

There was one case of co-existent maternal and fetal SVT. The mother, a 34-year-old woman, had a history of inappropriate sinus tachycardia and AT with two prior catheter ablation procedures.³⁶ She also had suspected tachycardia-induced cardiomyopathy with a LVEF of 35%. After failure of flecainide and digoxin, she and her fetus were successfully managed with metoprolol 100 mg twice daily and amiodarone 600 mg daily from 16 to 38 weeks gestation, at which time labor was induced. The mother had converted to sinus rhythm at 19 weeks gestation. The infant, despite an uncomplicated delivery, continued to have incessant AT at 250 bpm with reduced biventricular function.

5 DISCUSSION

The systematic review that we present here is the first comprehensive summary on the worldwide experience on maternal focal AT during pregnancy. The selected reports, spanning numerous countries over nearly 5 decades, revealed several important findings. First, the literature is predominantly composed of case reports and case series with small numbers. Second, the compiled characteristics supported abnormal automaticity as the dominant mechanism in this patient population. Third, many reported cases consisted of patients with high maximum heart rates, failed initial therapies, and tachycardia-induced cardiomyopathy. Finally, most publications in recent years involved catheter ablation, including several performed with zero fluoroscopy. We believe that these observations have important considerations when assessing management recommendations in the current SVT guideline from ACC, AHA, and HRS.⁶

Case reports have many well-acknowledged limitations that include their anecdotal nature and their penchant for bias.⁴¹ Journals also tend to favor novel reports that generate high interest.⁴² Indeed, it is difficult to imagine the first report in our systematic review, a 1971 manuscript of a woman who had repeated cardioversions leading to “a normal labor and delivery”, gaining interest from most journals today.¹³ Milder cases of focal AT, with manageable symptoms treated effectively with medications, may not be considered worthy for submission. Nevertheless, medical therapy for clinically impactful focal AT has been recognized to have limited success even in non-pregnant patients, leading to a recent transition to catheter ablation as first-line therapy in select patients.⁹

The signal at the site of successful ablation was discrete in all the case reports in our review. Therefore, micro-reentry seems to be an uncommon mechanism in this patient population.⁷ This is consistent with prior observations that suggested microreentry is typically found in older patients.⁸ Reproducible inducibility and termination with programmed electrical stimulation, which would support triggered activity, was not reported in any cases.⁷ All but one of the patients in our review were in spontaneous, incessant arrhythmia at the time of electrophysiology study. Moreover, it has been estimated that 80% of those with tachycardia-induced cardiomyopathy secondary to incessant focal AT, present in most of the patients in our review, are due to increased automaticity.⁸ The evidence therefore supports enhanced automaticity as the most likely mechanism for maternal focal AT during pregnancy.

The biological basis for the manifestation of focal AT due to automaticity during pregnancy, with remission after delivery, is unclear. Histologic or cellular abnormalities have been associated with sites of focal AT due to automaticity.⁸ Plasma volume markedly increases during normal pregnancy. Autonomic adaptations to hemodynamic changes during pregnancy may incite cells that are already vulnerable to arrhythmogenesis. Normal pregnancy is associated with increased β -2 adrenergic sensitivity and β adrenergic agonists are known to increase automaticity.^{43,44}

In a study of female Sprague-Dawley rats, right atrial dimensions increased in full-term pregnant rats when compared to virgin rats to accommodate for the increase in plasma volume.⁴⁵ Electrical changes that predispose to arrhythmogenesis may be mediated through stretch-activated channels.⁴⁶ In a study of female CD1 mice, upregulation of I_f by way of higher protein expression of HCN2 channels was found to be the dominant mechanism for normal heart rate increase in pregnancy.⁴⁷ The pathophysiologic basis of a subset of focal AT, referred to as ivabradine-sensitive AT, is felt to be due to abnormal activity of I_f .⁴⁸ Ivabradine is currently contraindicated during pregnancy.⁴⁹ However, there is a report of successful treatment of inappropriate sinus tachycardia with ivabradine initiated at the 19th week of pregnancy.⁵⁰ Ultimately, it is conceivable that several cellular mechanisms are responsible for focal ATs due to automaticity.

Adenosine, atrial overdrive pacing, and direct current cardioversion were not reported to have much success. Whether these observations are true effects or reporting bias are unclear, but they are consistent with observations in non-pregnant patients with focal AT secondary to enhanced automaticity.⁹ Adenosine has a class I recommendation should vagal maneuvers

fail.⁶ This seems reasonable for focal AT, despite the low rate of success in our review, as it has a short half-life and transient adverse effects. From an investigational standpoint, it may add evidence to suggest the underlying mechanism.⁷ From a practical standpoint, termination with re-initiation may make the P-wave morphology more evident. This may be helpful to predict the site of origin and procedural planning should catheter ablation be considered.⁵¹ The P-wave morphology on ECG, however, has limitations in that the site of origin may be in a different part of the atrium than the endocardial breakout site, connected by a pathway of preferential conduction.⁵² The success rate for termination with adenosine would be expected to be lower for focal AT than AVNRT and AVRT. In a prior study, success rates for arrhythmia termination with adenosine were 100% (82 of 82 subjects) for AVNRT, 100% (47 of 47 subjects) for AVRT, 58% (14 of 24 subjects) for automatic AT, and 30% (6 of 20 subjects) for triggered or reentrant AT.⁵³

Atrial overdrive pacing is unlikely to be successful in pregnant patients with focal AT and it is not recommended in the SVT guideline.⁶ This therapy has been studied in patients with implanted permanent pacemakers and success rates are low for focal AT arising from triggered or automatic mechanisms.⁵⁴ Women in the child-bearing ages are unlikely to have permanent pacemakers. Therefore, atrial overdrive pacing would generally involve placement of an esophageal electrode.³⁹ Recommending an invasive procedure that is unlikely to be successful should be discouraged. Patients with structural heart disease and/or prior atrial ablation have higher probability for microreentry and may be exceptions.⁷

Synchronized, direct current cardioversion has a class I recommendation for SVT in pregnant women who are hemodynamically unstable.⁶ Those with major symptoms, extremely rapid heart rate, or tachycardia-induced cardiomyopathy may also benefit. Nevertheless, the failure rate seen in our review was striking and supports enhanced automaticity as the dominant mechanism.⁹ Therefore, physicians should anticipate recurrence and preemptively consider additional therapeutic options, even if cardioversion is successful. Antiarrhythmic drug loading prior to cardioversion may be considered.

Medication therapy for focal AT has limited effectiveness, even in non-pregnant patients.⁹ The findings from our systematic review would not suggest immediate changes to current guideline recommendations or Food and Drug Administration risk categories.^{6,10} The main role of medications should be viewed as a “bridge to delivery.” Patients who have successful delivery without curative ablation for focal AT should have careful follow-up. Postpartum arrhythmia resolution was common in our review, but not universal.¹⁶ Persistent rapid focal AT leading to tachycardia-induced cardiomyopathy after delivery has been reported in a patient with a failed catheter ablation attempt during pregnancy.³⁴

The most notable caution with medications that we would recommend is the use of IV or oral non-dihydropyridine calcium channel blockers, particularly verapamil, in the setting of heart failure signs and/or symptoms when the LVEF is unknown or known to be reduced. Two cases where verapamil resulted in cardiovascular collapse both involved patients with reduced LVEF.^{20,28} Currently, verapamil has a class IIa recommendation for any symptomatic SVT during pregnancy.⁶ Other agents should be attempted first. In addition, outpatient use of non-dihydropyridine calcium channel blockers should be coupled with

monitoring for arrhythmia burden and heart rate profile as progression to tachycardia-induced cardiomyopathy may increase the risk of continued use.

The ability to perform catheter ablation with zero fluoroscopy is the greatest recent development in the treatment armamentarium for maternal SVT during pregnancy. Peri-procedural considerations have been extensively discussed in prior reviews.^{10,11} Radiation exposure to the developing fetus has long been a concern. Advances in electroanatomic mapping with or without intracardiac echocardiography has made zero fluoroscopy the goal of many, if not most, catheter ablation procedures. Approximately 75% of focal ATs are localized to the right atrium.⁵¹ In fact, the crista terminalis is so active that it has been dubbed a “ring of fire.”⁵⁵ Most cases in our review where electrophysiology studies confirmed the sites of origin were also localized to the right atrium. This allows for a “straight shot” from femoral access via the inferior vena cava. For left atrial sites of origin, transseptal puncture is now also routinely performed with zero fluoroscopy using guidance from intracardiac echocardiography.

High density mapping with multielectrode catheters may decrease procedure time and increase ablation success.⁵⁶ Although none of the patients in our review had microentry, high density mapping has recently been reported to be useful in defining circuits and best ablation sites.^{57,58}

The risks of catheter ablation must be carefully considered. One concerning report of suspected acute pulmonary embolism that occurred immediately at the end of a successful catheter ablation was associated with fetal demise.³¹ Minimal use of catheters is recommended. Anticoagulation during and immediately after the procedure, even those that involve only the venous system, requires additional study and consideration.

Catheter ablation has a class IIb recommendation for focal AT, and all paroxysmal SVTs, mainly due to the radiation related increase in the fetal risk of congenital malformations when performed early in pregnancy and the downstream risk of childhood malignancy.⁶ However, we believe that a higher class of recommendation may be considered in select circumstances that increase the risk of adverse maternal and/or fetal outcomes. High-risk features include medication failure, incessantly elevated heart rates, severe symptoms, hemodynamic compromise, and suspected tachycardia-induced cardiomyopathy. The threshold to consider catheter ablation may also be lower at high volume centers with experience in zero fluoroscopy procedures. An additional series, that reported 6 cases of focal AT, was published after completion of our literature review.⁵⁹ A multidisciplinary team approach is recommended.⁶⁰ Finally, continuation of focal AT in the postpartum period may be an opportunity to target an arrhythmic source if the patient wishes to become pregnant again as some may only have activity around pregnancy.²¹

6 LIMITATIONS

Systematic reviews of uncommon arrhythmias or uncommon co-existent situations, such as maternal focal AT during pregnancy, have inherent limitations. The high likelihood of reporting bias with case reports and small case series may lead to inaccurate assumptions

regarding clinical presentations, effective therapies, and best practices. Results presented here should be considered preliminary. We recognize that there are overlapping characteristics for focal AT mechanisms and there is no gold standard to differentiate automaticity, triggered activity, and microreentry.⁸ Our findings are not generalizable to pregnant patients with complex congenital heart disease.

7 CONCLUSIONS

The primary mechanism for maternal focal AT during pregnancy is automaticity. Medication failure and tachycardia-induced cardiomyopathy were commonly reported. Verapamil should be avoided altogether or used with caution in patients with known or suspected reduced LVEF. Recent technological advances have led to the ability to perform catheter ablation with zero fluoroscopy with high safety and effectiveness. This may lower the threshold to consider catheter ablation in high-risk scenarios. A multicenter prospective study involving collaboration between obstetrics and cardiology services would facilitate understanding of maternal focal AT, and indeed all SVTs, during pregnancy.

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Figure 1.
The presenting 12-lead electrocardiogram demonstrated a long R-P interval supraventricular tachycardia at 116 bpm.

Figure 2.

Intravenous administration of adenosine 12 mg terminated the supraventricular tachycardia and a sinus rhythm P-wave emerged (arrow).

Figure 3.

Supraventricular tachycardia, with interspersed multifocal atrial complexes, resumed after ventricular overdrive pacing maneuver performed at a cycle length of 240 ms. The V-A-A-V response suggested atrial tachycardia. Subsequently, spontaneous termination with a change in P-wave morphology indicated a transition to sinus rhythm (arrow).

Figure 4.

A, The putative site of origin near the tricuspid valve annulus had a discrete electrogram (black arrow) and was where radiofrequency ablation commenced (red arrow). B, Activation map in the right anterior oblique projection with dots to demonstrate His bundle signals (yellow), earliest endocardial signal (green), and ablation lesions (red). C, Activation map in the left anterior oblique projection.

Figure 5.

A, The post-ablation 12-lead electrocardiogram demonstrated sinus rhythm at 80 bpm. B, The 12-lead electrocardiogram during outpatient follow-up demonstrated sinus rhythm at 97 bpm.

Figure 6.
Literature flow diagram. SVT, supraventricular tachycardia.

TABLE 1.

Clinical characteristics of individual patients with detailed information.

Case	First author, year	Country	Maternal age (years)	Gestation (weeks)*	Maximum heart rate	P-wave	Prior SVT	Initial LVEF	Follow-up LVEF
1	Schroeder ¹³ , 1971	USA	26	30	250	NR	Yes	NR	NR
2	Sheriff ¹⁴ , 1982	Pakistan	25	20	214	NR	No	NR	NR
3	Hubbard ¹⁵ , 1983	UK	20	15	180	V1-, left inferior axis	No	Normal	NR
4	Doig ¹⁶ , 1992	UK	24	21	210	V1+, left inferior axis	No	Normal	NR
5	Murphy ¹⁷ , 1992	UK	34	38	215	V1+, left inferior axis	No	Reduced	Improved
6	Treagle ¹⁸ , 1992	USA	33	25	215	NR	No	NR	NR
7	Forgione ¹⁹ , 1994	Italy	29	40	220	V1-, inferior axis	No	Reduced	Normal
8	Lawrenson ²⁰ , 1995	South Africa	30	24	200	V1-, left inferior axis	No	Reduced	47
9	Ahmed ²¹ , 1996	USA	31	26	159	V1+, left axis	No	50→35	55
10	Ou ²² , 2004	Taiwan	29	22	160	NR	Yes	Normal	NR
11	Pagad ²³ , 2004	India	24	24	240	V1-, left inferior axis	Yes	22	50
12	Berrueto ²⁴ , 2007	Spain	30	30	165	V1-, left inferior axis	Yes	30	Improved
13	Roscani ²⁵ , 2010	Brazil	23	30	180	V1-, left inferior axis	No	NR	NR
14	Szumowski ²⁶ , 2010	Poland, France, Australia	31	24	240	V1-, left axis	No	45	NR
15	Szumowski ²⁶ , 2010	Poland, France, Australia	29	37	250	V1-, left axis	No	41	NR
16	Ferguson ²⁷ , 2011	USA	20	27	180	V1+, right superior axis	No	40	Normal
17	Scherret ²⁸ , 2012	France	24	24	200	V1+, right inferior axis	No	30→10	60
18	Sim ²⁹ , 2012	Taiwan	28	26	229	V1-, left inferior axis	No	Reduced	NR
19	Wu ³⁰ , 2012	Australia	32	14	220	V1-, left inferior axis	No	40	NR
20	Yang ³¹ , 2014	Republic of Korea	30	17	214	V1-, left inferior axis	No	38	68
21	Yang ³¹ , 2014	Republic of Korea	32	21	160	V1+, left inferior axis	No	18	40
22	Zuberi ³² , 2014	UK	48	28	178	V1-, left superior axis	No	30	53
23	Raman ³³ , 2015	USA	18	33	155	V1, II, III, aVF biphasic	No	37.5	NR
24	Mizukami ³⁴ , 2016	Japan	26	19	180	V1-, left inferior axis	No	50→22	67
25	Paulpandian ³⁵ , 2016	India	22	NR	150	V1+, inferior axis	No	56	NR

Case	First author, year	Country	Maternal age (years)	Gestation (weeks)*	Maximum heart rate	P-wave	Prior SVT	Initial LVEF	Follow-up LVEF
26	Gabarin ³⁶ , 2017	Canada	34	16	123	V1–, left superior axis	Yes	35	48
27	Barros ³⁸ , 2018	Brazil	32	12	250	V1+, inferior axis	Yes	Normal	NR
28	Liu ³⁹ , 2019	China	29	11	150	V1+, right inferior axis	No	48	52
29	Sonsöz ⁴⁰ , 2019	Turkey	28	37	134	V1+, right inferior axis	No	45	Normal
30	UPMC	USA	28	22	180	V1–, left axis	No	57.5	NR

Abbreviations: LVEF, left ventricular ejection fraction; NR, not reported; SVT, supraventricular tachycardia; UK, United Kingdom

UPMC, University of Pittsburgh Medical Center; USA, United States of America.

* Gestation age at the time of initial presentation with focal atrial tachycardia.

TABLE 2.

Acute and chronic treatments for individual patients with detailed information.

Case	First author, year	Vagal	Adenosine	AOP	DCCV	Failed medications	Successful medications (patients without EPS)	EPS
1	Schroeder ¹³ , 1971	Failed	No	No	Success	digoxin	propranolol, quinidine	No
2	Sheriff ¹⁴ , 1982	No	No	Failed	Failed	digoxin, verapamil	propranolol, quinidine	No
3	Hubbard ¹⁵ , 1983	No	No	No	Failed	None attempted	None attempted	No
4	Doig ¹⁶ , 1992	Failed	No	No	Failed	digoxin, verapamil, metoprolol, flecainide	amiodarone	No
5	Murphy ¹⁷ , 1992	No	No	No	Failed	verapamil, disopyramide, flecainide	None	No
6	Treacle ¹⁸ , 1992	Failed	No effect	No	Failed	digoxin, verapamil, procainimide, metoprolol, flecainide	propranolol	No
7	Forgione ¹⁹ , 1994	No	AV block	No	Failed	digoxin, propafenone, amiodarone		Yes [*]
8	Lawrenson ²⁰ , 1995	No	AV block	Failed	No	verapamil, esmolol, metoprolol, digoxin, propafenone	sotalol	No
9	Ahmed ²¹ , 1996	Failed	Success	No	Failed	verapamil, diltiazem, quinidine, digoxin, procainimide	metoprolol, flecainide	No
10	Ou ²² , 2004	No	No	No	No	None	nifedipine	No
11	Pagad ²³ , 2004	No	No effect	No	Failed	metoprolol, diltiazem, verapamil, amiodarone, propafenone		Yes
12	Berrueto ²⁴ , 2007	No	No	No	No	"antiarrhythmic drugs"		Yes
13	Roscini ²⁵ , 2010	No	No effect	No	No	metoprolol	None [†]	No
14	Szumowski ²⁶ , 2010	No	No	No	No	"beta-blockers", verapamil		Yes
15	Szumowski ²⁶ , 2010	No	No	No	No	"beta-blockers"		Yes
16	Ferguson ²⁷ , 2011	No	No	No	Failed	"beta-blockers", "calcium antagonists", amiodarone		Yes
17	Scherer ²⁸ , 2012	No	No effect	No	Failed	verapamil, amiodarone		Yes
18	Sim ²⁹ , 2012	No	No effect	No	Failed	amiodarone		Yes
19	Wu ³⁰ , 2012	No	No	No	No	digoxin, labetalol, metoprolol, flecainide		Yes
20	Yang ³¹ , 2014	No	No	No	No	none attempted		Yes
21	Yang ³¹ , 2014	No	No	No	No	"beta-blockers", amiodarone		Yes
22	Zubert ³² , 2014	No	Success	No	No	digoxin, labetalol		Yes
23	Raman ³³ , 2015	No	No	No	No	metoprolol, diltiazem, digoxin, sotalol		Yes
24	Mizukami ³⁴ , 2016	No	No	No	Failed	"beta-blockers", verapamil		Yes
25	Paulpandian ³⁵ , 2016	Failed	AV block	No	No	digoxin, carvedilol	verapamil	No
26	Gabarin ³⁶ , 2017	No	No	No	No	flecainide, digoxin	metoprolol, amiodarone	No
27	Barros ³⁸ , 2018	No	No	No	No	propafenone, sotalol		Yes

Case	First author, year	Vagal	Adenosine	AOP	DCCV	Failed medications	Successful medications (patients without EPS)	EPS
28	Liu ³⁹ , 2019	No	No	Failed	No	metoprolol, propafenone		Yes
29	Sonsöz ⁴⁰ , 2019	No	No	No	Failed	“medical therapy”		Yes [*]
30	UPMC	No	Success	No	No	metoprolol		Yes

Abbreviations: AOP, atrial overdrive pacing; AV, atrioventricular; DCCV, direct current cardioversion; EPS, electrophysiology study
UPMC, University of Pittsburgh Medical Center.

^{*} Patients proceeded to electrophysiology studies in the postpartum period.

[†] Patient had premature vaginal delivery as an inpatient at a gestation of 32 weeks.

TABLE 3.

Electrophysiology study and catheter ablation data for individual patients with detailed information.

Case	First Author, year	Ablation signal	Gestation (weeks)*	Induction	Mapping system	Ablation catheter	Fluoroscopy		Site of origin	Result
							Time (min)	Dose (mGy)		
7	Forgione ¹⁹ , 1994	Discrete	PP	Spontaneous	None	RF, non-irrigated	NR	NR	RA septum	Success
11	Pagad ²³ , 2004	Discrete	24	Spontaneous	None	RF, non-irrigated	4	NR	RA crista terminalis	Success
12	Berrueto ²⁴ , 2007	Discrete	30	Spontaneous	None	RF, non-irrigated	8	0.25	RA appendage	Success
14	Szumowski ²⁶ , 2010	NR	24	Spontaneous	Echocardiography	RF	0	0	RA crista terminalis	Success
15	Szumowski ²⁶ , 2010	NR	37	Spontaneous	CARTO	RF	1.1	NR	RA para-Hisian	Success
16	Ferguson ²⁷ , 2011	Discrete	27	Spontaneous	EnSite NavX	RF, non-irrigated	0	0	LA mitral annulus	Success
17	Scherer ²⁸ , 2012	NR	36	Spontaneous	None	RF	NR	NR	LIPV os	Success
18	Sim ²⁹ , 2012	NR	26	Spontaneous	NR	NR	NR	NR	RA "root"	Success
19	Wu ³⁰ , 2012	Discrete	14	Spontaneous	EnSite NavX	RF, irrigated	0.9	NR	RA appendage	Success
20	Yang ³¹ , 2014	Discrete	17	Spontaneous	EnSite NavX	RF	6	35.1	RA sinus venosus	Success
21	Yang ³¹ , 2014	Discrete	21	Spontaneous	EnSite NavX	RF	1	13.5	RA free wall	Success
22	Zubert ³² , 2014	Discrete	30	Spontaneous	EnSite NavX	RF, non-irrigated	0	0	RA crista terminalis	Success
23	Raman ³³ , 2015	Discrete	33	Spontaneous	CARTO	RF, irrigated	1.3	5.21	LA mitral annulus	Success
24	Mizukami ³⁴ , 2016	Discrete	26	Spontaneous	CARTO	RF, irrigated	NR	NR	RA appendage	Failed
27	Barros ³⁸ , 2018	Discrete	12	Isoproterenol	EnSite NavX	RF	0	0	aortic cusp	Success
28	Liu ³⁹ , 2019	Discrete	11	Spontaneous	CARTO	RF, irrigated	0	0	LA appendage	Success
29	Sonsöz ⁴⁰ , 2019	NR	PP	Spontaneous	Columbus	RF, irrigated	NR	NR	LA appendage	Success
30	UPMC	Discrete	23	Spontaneous	CARTO	RF, irrigated	0	0	RA tricuspid annulus	Success

Abbreviations: LA, left atrium; LIPV, left inferior pulmonary vein; mGy, milligray; min, minute; NR, not reported; PP, postpartum; RA, right atrium; RF, radiofrequency

UPMC, University of Pittsburgh Medical Center.

* Gestation age at the time of electrophysiology study.

TABLE 4.

Delivery outcomes for individual patients with detailed information.

Case	First author, year	Gestation (weeks)*	Mode of delivery	Fetal outcome, maternal complication
1	Schroeder ¹³ , 1971	35	VD	healthy child
2	Sheriff ¹⁴ , 1982	NR	NR	NR
3	Hubbard ¹⁵ , 1983	38	VD	healthy boy (3,000 g)
4	Doig ¹⁶ , 1992	31	VD	healthy twins
5	Murphy ¹⁷ , 1992	38	CS	healthy girl (3,180 g; Apgar 7/10)
6	Treacle ¹⁸ , 1992	“term”	VD	healthy girl
7	Forgione ¹⁹ , 1994	40	CS	healthy boy
8	Lawrenson ²⁰ , 1995	43	VD	healthy boy
9	Ahmed ²¹ , 1996	“term”	VD	healthy boy
10	Ou ²² , 2004	36	CS	healthy boy (2,950 g; Apgar 8/9)
11	Pagad ²³ , 2004	“term”	CS	healthy child
12	Berrueto ²⁴ , 2007	NR	VD	healthy child
13	Roscani ²⁵ , 2010	32	VD	healthy child, pre-eclampsia
14	Szumowski ²⁶ , 2010	NR	VD	healthy child
15	Szumowski ²⁶ , 2010	NR	VD	healthy child
16	Ferguson ²⁷ , 2011	“term”	NR	healthy child
17	Scherer ²⁸ , 2012	36	CS	healthy child, multiorgan failure
18	Sim ²⁹ , 2012	26	CS	fetal demise, cardiogenic shock
19	Wu ³⁰ , 2012	NR	NR	NR
20	Yang ³¹ , 2014	“term”	NR	healthy child
21	Yang ³¹ , 2014	21	NR	fetal demise, pulmonary embolism
22	Zuberi ³² , 2014	37	CS	healthy twins
23	Raman ³³ , 2015	33	CS	healthy boy
24	Mizukami ³⁴ , 2016	39	NR	healthy child
25	Paulpandian ³⁵ , 2016	“term”	VD	healthy boy
26	Gabarin ³⁶ , 2017	38	VD	girl with TIC (2,740 g; Apgar 9/9)
27	Barros ³⁸ , 2018	38	CS	healthy child (3,150 g)
28	Liu ³⁹ , 2019	“term”	CS	healthy boy
29	Sonsöz ⁴⁰ , 2019	37	VD	healthy child
30	UPMC	37	VD	healthy girl (3,330 g; Apgar 4/7/9)

Abbreviations: CS, Cesarean section; g, grams; NR, not reported

TIC, tachycardia-induced cardiomyopathy; VD, vaginal delivery

* Gestation age at the time of delivery.