ORIGINAL ARTICLE

CARDIOPULMONARY BYPASS IN PREGNANCY. A SINGLE-CENTER EXPERIENCE

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ABSTRACT

The aim: Presentation of a single-center experience of cardiac surgery with cardiopulmonary bypass (CPB) in pregnant women with critical cardiac pathology. The possibility of minimally invasive technique in this group of patients were presented.

Materials and methods: The present study included 19 cases of multidisciplinary care with CPB surgery in pregnant women in single center from December 2013 to December 2020. 8 patients underwent J-form median mini-sternotomy. Maternal and neonatal outcomes depending on the type of surgery (urgent or elective) were reviewed.

Results: There were no negative maternal consequences; there were 4 perinatal losses (21%): three after urgent and one after elective interventions. All other pregnancies (n=15) finished successfully with the birth of healthy newborns. We compared some values in two groups (urgent and elective) of patients who underwent CPB surgery during pregnancy. Despite the variability in some parameters the difference between the groups was not significant. Follow-up was from 5 to 72 months (39.7±16.9) without negative consequences.

Conclusions: Multidisciplinary team management is an effective strategy for pregnant women with cardiac pathology. Elective cardiac surgery in expert centers during pregnancy is a safe and effective option. Urgent CPB cardiac surgery during pregnancy increases the risk for the fetus. J-form median mini-sternotomy is a good option during pregnancy in high-experienced centers.

KEY WORDS: pregnancy, cardiopulmonary bypass, J-form median mini-sternotomy, pregnancy heart team

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INTRODUCTION

Nowadays cardiac surgical interventions during pregnancy represent an exceedingly popular topic of discussion in the expert community. Cardiac surgery during pregnancy was first introduced at the dawn of cardiac surgery, i.e., in the early 1950s. At that time, the leading cause of critical major cardiac events during pregnancy was rheumatic heart disease (85–93%) [1]. Today, due to the improvement of methods of prevention and treatment of rheumatic diseases, as well as the advance of diagnostic methods, congenital heart defects (CHD) dominate in the structure of cardiovascular pathology in Western countries and account for 75–82%, while organic rheumatic heart valve lesions are quite rare [2]. The first successful cardiac surgery in a pregnant woman was performed by Russell Brock [3] in 1952. As early as in 1958, Robert Leyse performed the first-ever open-heart surgery for combined severe subaortic and valvular aortic stenoses in a 4-month pregnant woman. The operation with cardio-pulmonary bypass (CPB) and 20-minute cardiac arrest passed without complications, the pregnancy ended in time with normal delivery but with numerous abnormalities in newborn [4].

Despite more than 60-year history of cardiac surgery, the results of cardiac interventions during pregnancy remain suboptimal. This is especially pressing challenge for CPB surgeries in which the risk of fetal loss according to the literature reaches 20–33% [5–7]. For this reason, there is no consensus among experts on clear indications for interventions during pregnancy, especially with the fetus *in utero*. The clinical guidelines of the European Society of Cardiology state that "cardiac surgery is recommended only when medical treatment or interventional procedures fail, and the mother's life is threatened" [7]. Moreover, before the CPB, the option of C-section may be considered if the gestational age is > 26 weeks, considering the gestational age of the fetus, sex, approximate weight, prior use of corticosteroids and statistical results of neonatal care for deep premature newborns [7].

Our multidisciplinary team (pregnancy heart team) involving the leading specialists of two tertiary care centers was formed according to the guidelines [6–8] in 2013 to provide both non-surgical and surgical cardiac care for pregnant and parturient women. Our team consists of the following specialists: obstetrician, cardiologist, cardiac surgeon, neonatologist, anesthesiologist, perfusionist.

THE AIM

Presentation of a single-center experience of cardiac surgery with cardiopulmonary bypass (CPB) in pregnant

Table I. Characteristics of the patients who underwent CPB surgery during pregnancy.

Time of surgery	Pt, age	Pathology	WG	Surgery	Perinatal results
Urgent surgery (n=6)	A, 28	Mechanical prosthetic MV thrombosis	22	Redo MV replacement	Perinatal loss in 3 weeks after surgery
	B, 21	BAV stenosis. Status post CPR	27/PG	AVR	Perinatal loss in 3 days after surgery
	C, 37	BAV stenosis. AAA	20	AVR + Robicsek procedure	CS at 39 WG
	D, 31	Symptomatic severe subaortic stenosis	18/PG	Subaortic membranectomy	Vaginal delivery at 39 WG
	E, 38	VTE. Acute severe PE	25	Thrombectomy + TVR	Vaginal delivery at 39 WG
	S, 33	VTE. DVT. Acute severe PE	10	Thrombectomy + TVR	Fetal death 7 days after surgery
Elective surgery (n=13)	F, 22	AAA. MFS	19/PG	Bentall procedure	CS at 38 WG
	G, 24	BAV stenosis. AAA	21/PG	mini-AVR + AA wrapping	CS at 38 WG
	H, 32	Significant MV insufficiency, status post MV repair	21/PG	Redo MV repair	CS at 39 WG
	I, 30	MV acute infective endocarditis	11/PG	MV and TV repair	CS at 39 WG
	J, 32	BAV stenosis	18	AVR	CS at 38 WG
	K, 28	Single ventricle. Post PA banding and CoAo repair	8/PG	Bi-Di-Glenn + Blalock-Hanlon	CS at 36 WG
	L, 25	BAV stenosis	18/PG	Mini-AVR	CS at 38 WG
	M, 31	BAV stenosis	22/PG	Mini-AVR	CS at 38 WG
	N, 28	BAV stenosis	20/PG	Mini-AVR	CS at 38 WG
	O, 30	BAV stenosis	20/PG	Mini-AVR	CS at 38 WG
	P, 25	BAV stenosis. AAA	20/PG	Mini-AVR + AA wrapping	CS at 38 WG
	Q, 23	BAV stenosis	16/PG	Mini-AVR	CS 38 WG
	R, 22	BAV stenosis, iatrogenic AV block	20/PG	Mini-AVR + PM implantation	Perinatal loss in 8 weeks after surgery

MV = mitral valve, AV = aortic valve, BAV = bicuspid aortic valve, LVOT = left ventricular outflow tract, VTE = venous thromboembolism, PE = pulmonary embolism, DVT = deep venous thrombosis, TV = tricuspid valve, TVR = tricuspid valve repair, PM = pacemaker, AAA = ascending aorta aneurysm, MS = Marfan syndrome, AVR = aortic valve replacement, mini-AVR = aortic valve replacement with J-mode mini-sternotomy, PA = pulmonary artery, CPR = cardiopulmonary resuscitation, WG = weeks of gestation, CS = Cesarean section, CoAo = Coarctation of the aorta, PG = primigravida

Table II. Comparison of intra- and postoperative data between urgent and elective CPB surgery groups

Time of surgery		CPBt, min	CCt, min	t°, C	Blood loss, ml	Blood transfusion, ml			Length of POHS, days
						RBC	FFP	PT	
Urgent	Mean	142,3	81,7	32,3	266,7	425,0	265,8	75,0	13,5
	±	68,1	35,6	2,6	75,3	228,7	195,7	125,5	4,2
Elective	Mean	130,5	96,6	33,5	292,3	353,8	341,5	15,4	14,9
	±	24,9	32,9	0,9	103,8	291,3	510,8	55,5	7,9

CPBt = cardio-pulmonary bypass time, CCt = cross-clamping time, RBC = red blood cells, FFP = fresh frozen plasma, PT = platelets, POHS = post-operative hospital stay.

women with critical cardiac pathology. The possibility of minimally invasive technique in this group of patients were presented.

MATERIALS AND METHODS

For 7 years (from December 2013 to December 2020), 158 pregnant and parturient women with high cardiovascular risk class were admitted to the cardiac surgery facility for multidisciplinary care management. The type of management for patients was personalized but based on modern recommendations of the European Society of Cardiology [2]. It was set on after the multidisciplinary team counseling. Multidisciplinary pregnancy heart team (MPHT) was composed of obstetrician, cardiologist, cardiac surgeon, neonatologist, anesthesiologist, perfusionist and interventional cardiologist. Due to the specific features of our

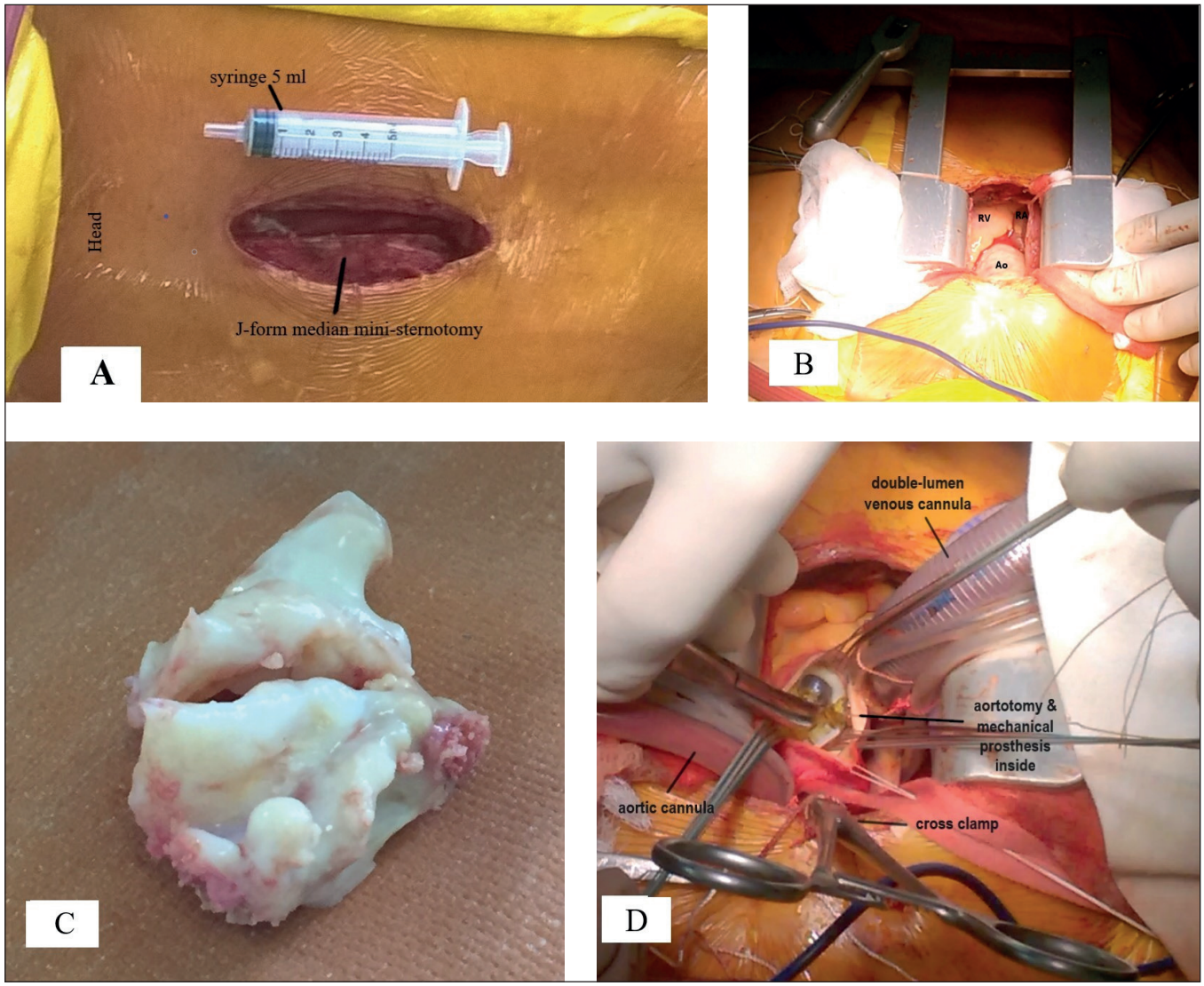

Fig. 1. Stages of AVR with partial J-form median mini-sternotomy in a pregnant woman with severe aortic stenosis, BAV, AA dilation. A: Skin incision and J-form median mini-sternotomy. From surgeon's point. The sternum is dissected longitudinally and crosses to the right III-IV intercostal space. B: Visualization of the heart and great vessels. All lines are in one approach. From anesthesiologist's point. C: Dissected bicuspid aortic valve. D: Mechanical aortic valve implantation. From anesthesiologist's point

hospital structure specialists from different departments (congenital, acquired, aortic pathology, infective endocarditis, rhythm disturbances, myocardial pathology, chronic coronary disease, radiology department) were involved into the teamwork depending on the clinical situation and comorbidity of the patient.

MPHT management of pregnant and parturient women included different types of cardiac surgery (n=73), conservative treatment (n=34), childbirth in cardiac surgery facility (n=37), and combined care - cardiac surgery and childbirth (n=14). Delivery under the supervision of MPHT and combined management took place in patients with life-threatening cardiac conditions in the conditions of the prepared operating room. In cases of viable fetus the first stage was C-section, then cardiac surgery. Medical treatment and supervision by MPHT were provided for pregnant women with compensated cardiac pathology without indications for urgent cardiac intervention (some of them underwent surgery in follow-up period).

The study presents 19 cases of CPB during pregnancy. The mean age was 28,6±6,1 year. Baseline characteristics are shown in Table I. Data was collected from the hospital digital patient files and internal institutional database.

CPB during pregnancy was performed under general anesthesia, with normothermic/mild hypothermic perfusion, myocardial protection was provided with cold crystalloid cardioplegic solution, with retrograde/antegrade or combined inflation; uterine tone and fetal heart rate were monitored. In most cases fetal heart rate was controlled by echocardiography using the technique established by local protocol. We also used cardiotocography in two cases.

RESULTS

We performed 13 elective and 6 urgent interventions with CPB in pregnant women. All these surgeries were performed with *fetus in utero* condition.

Urgent interventions were performed in cases of an emergency or acute circulatory failure and critical heart pathology in 10 - 27 weeks of gestation. Urgent CPB interventions included surgeries for severe bicuspid aortic valve (BAV) stenosis (n=1), severe BAV stenosis combined with ascending aorta aneurysm (n=1), symptomatic congenital subaortic stenosis (n=1), mechanical prosthetic mitral valve (MV) thrombosis (n=1), and acute pulmonary embolism (n=2).

Thirteen elective CPB interventions performed at 8-21 weeks of gestation included ascending aorta surgery in a patient with Marfan syndrome (MFS) and severe aortopathy (n=1), aortic valve replacement (AVR) (n=7) alone and in combination with the wrapping of the ascending aorta (n=2), MV redo repair (n=1), MV and tricuspid valve (TV) repair for acute infective endocarditis (n=1), bidirectional Glenn and Blalock-Hanlon procedure in a patient with complex CHD (single ventricle after previous pulmonary artery banding with pacemaker implantation) (n=1). Due to the high risk of aortic dissection or even rupture (AA diameter 45 mm and aortic sinuses 62 mm), the patient F provided consent for preventive surgery and underwent Bentall procedure at 19 weeks of gestation. At 38 weeks, she gave birth to a healthy baby by elective C-section. Cases of such interventions in patients with MFS during pregnancy is a rather rare observation [7, 9, 10].

All elective cardiac surgeries in pregnant women were performed with perfusion parameters relatively "friendly" for the fetus (temperature 32–34 °C, perfusion flow rate 2.5–2.8 L/min/m^2, perfusion pressure 65–70 mmHg, hematocrit ratio 25–28). Despite the variability in CPB time, CCt, blood loss, postoperative transfusion of blood components and time to discharge after operation, the difference between urgent and elective CPB surgery groups is not significant (table II).

The mean values in both groups were as follows: CPB 134.3±41.6 min, cross-clamping time (CCt) 91.9±33.8 min, CPB t° 33.1±1.6°C, blood loss 284.2±94.4 ml, red blood cell transfusion 376.3±268.8 ml, fresh frozen plasma transfusion 317.6±431.2 ml, platelets transfusion 34.2±85.1 ml. Mean length of postoperative hospital stay was 14.4±6.8 days.

Among the elective CPB cardiac surgery interventions, a total of 8 AVRs were performed with and without ascending aorta wrapping (2 and 6 cases, respectively) with J-form median mini-sternotomy: upper J-form median mini-sternotomy from the incisura jugularis to the IV right intercostal space (Figure 1) according to the modified technique described by Lars Svensson and Richard D'Agostino [11]. In the position of the patient on the back, a skin incision (6-8 cm) is made longitudinally from the jugular notch to the third, in some cases, to the fourth intercostal space. The sternum is dissected longitudinally to the same level and crosses to the right in the intercostal space. The pericardium opens longitudinally, with a T-shaped incision in the lower edge of the surgical wound. Drainage systems and epicardial electrodes are placed after sternotomy and before heparin administration.

To ensure CPB after heparin administration, the ascending aorta or the arch was cannulated depending on the extent of the aortic dilatation. A double-lumen venous cannula was inserted into the right atrial appendage. Drainage of the left ventricle was performed through the orifice of the right superior pulmonary vein. The operations were performed under conditions of mild or moderate hypothermia (32-34 °C). In all cases, it was possible to install a cardioplegic cannula in the coronary sinus to ensure delivery of the cardioplegic solution using a combined technique. After clamping the aorta and cardiac arrest (combined retro-antegrade cardioplegia, Custodiol®, 20 ml/kg), the main stage of correction of the pathology of the aortic valve and, if necessary, ascending aorta was performed. After aortotomy, revision of the affected aortic valve was performed, after removal of which it was replaced with an artificial mechanical or bioprosthesis. With the concomitant aneurysm, the ascending aorta was cut off and a pre-sutured conduit was implanted. After suturing the aorta and preventing air embolism, the clamp was removed from the aorta and cardiac activity was restored. The patient was gradually warmed up to natural values. After the weaning from the CPB, decannulation of the heart cavities was performed. After controlling hemostasis, the pericardial cavity was sutured with separate sutures, the sternum was fixed with four separate sutures. This mini-invasive approach is less traumatic than conventional sternotomy, implies lower risk of post-surgery complications, and facilitates shorter rehabilitation period.

We used fetal monitoring in each case of CPB during pregnancy according to the local protocol technique applying echocardiography in most cases and cardiotocography in two cases. Fetal heart rate measuring points were at the initial stage of perfusion, every 30 minutes during the CPB period, after normalization of the temperature and after weaning from CPB. Uterine tone was also monitored according to the original technique [12]. Fetal bradycardia (fetal heart rate reduction to less than 90 bpm) was corrected by the increase in perfusion flow rate and the temperature of perfusate. We avoided hypocapnia which could lead to vasoconstriction of uterus and placenta, and fetal hypoxia; we also tried to reduce CPB time. Pulsatile flow was not applied.

Among pregnant women who underwent CPB surgery, neither immediate nor long-term maternal losses were observed. Three perinatal losses in the group of urgent interventions and one in the elective surgery group were observed. The reasons of fetal losses are quite clear. One pregnant woman (26 weeks of gestation) with severe aortic valve stenosis (peak AV pressure gradient 120 mmHg) developed ventricular fibrillation, underwent resuscitation and emergency AVR. Obviously, in this case, hypothermic perfusion (28–31 °C) was used to protect the mother's body after resuscitation. As a result, we detected antenatal fetal death on the third day after surgery. The patient herself was discharged in satisfactory condition and one year later gave birth to a healthy child. The second case of antenatal fetal death was also associated with hypothermia during the CPB in a pregnant patient (22 weeks of gestation) with prosthetic MV thrombosis who underwent urgent intervention — mitral valve prosthesis replacement. Antenatal fetal death was observed at the third week after surgery.

Fetal death after urgent thrombectomy in patient with acute severe pulmonary embolism in 10th week of gestation was also observed in 7 days after surgery. The fourth fetal loss was in a woman who underwent elective surgery for severe symptomatic aortic stenosis at 20 weeks of gestation. We observed antenatal fetal death in this woman 8 weeks after surgery. Unfortunately, autopsy revealed multiple chromosomal abnormalities of the fetus.

No other fetal losses were reported. Deliveries were conducted in our two tertiary care centers. The mode and the place of deliveries depended on cardiac conditions and obstetric situation. Healthy babies were born in 15 cases, weighted from 2800 to 3940 g and had high Apgar scores. Long-term infant mortality and morbidity results were observed in 12 of 15 cases, maternal results in all 19 cases. Follow-up was from 5 to 72 months (39.7±16.9) without negative consequences.

DISCUSSION

Delayed diagnosis or a woman's strong desire to become a mother, despite the risks to health and life, from time to time calls the pregnancy heart team for complex decision-making to perform cardiac surgery during pregnancy to save both lives.

Deciding on the management of pregnant women with cardiovascular diseases and high cardiovascular risk is one of the most complex and important personalized clinical decisions which is solved by a joint counselling of the multidisciplinary team members. Cardiac surgery during pregnancy carries a minimal risk for the mother, but quite significant risk for the fetus, while delayed surgery intervention can lead to the mother's death or disability.

The tactics of some teams [5, 13, 14] and the recommendations of the European Society of Cardiology [7] suggest conducting an optional preoperative delivery in pregnant women who have reached >26 weeks of pregnancy and require CPB surgery. After reaching gestational age of ≥28 weeks, preterm delivery is recommended. However, as noted in the recommendations [7], this decision should be made according to the potential benefits for the baby at this gestational age and depends on the gender, approximate weight, prior use of corticosteroids before the delivery and neonatal outcomes statistics. Compared to other babies, deep premature babies with very low body weight (1000–1499 g) or extremely low body weight (500–999 g) have significantly higher mortality and morbidity rates. Consequently, the strategy should be personalized and determined after the joint multidisciplinary team counselling with the obligatory participation of an obstetrician-gynecologist, cardiologist, cardiac surgeon, neonatologist, and anesthesiologist. Considering the unsatisfactory results of care for deep premature babies and based on extensive experience in the field of cardiac surgery, as well as observing of pregnant women with cardiovascular diseases of high cardiovascular risk, our team chose the tactics of elective cardiac surgery intervention at 18–22 weeks with subsequent continuous follow-up by the multidisciplinary team. Certainly, if there are clear absolute indications for an open-heart surgery and significant risks associated with its delay.

Another controversial issue is the choice of the type of intervention. Thus, in high-income countries, a compromise option in pregnant women with severe aortic stenosis is the use of percutaneous techniques, such as transcatheter replacement or repair of heart valves. These reports are presented in limited literary sources [15, 16], in recommendations of the European Society of Cardiology [7] and the American College of Cardiology [17]. Classes of recommendations and levels of evidence have not been yet optimal (IIa/C-IIa/B) [18]. The use of transcatheter aortic valve implantation (TAVI) in a pregnant patient was first reported in 2015 [15]. However, for low-income or medium-income countries, this option is still less realistic today. Therefore, CPB surgery in pregnant women with clear indications with certain perfusion parameters and fetal monitoring should be considered as an alternative to costly and sometimes less effective endovascular procedure. We have demonstrated the effectiveness and relative safety of such interventions in our series of patients.

Special attention should be paid to pregnant women with life-threatening conditions who obligatory must undergo urgent cardiac surgery interventions. Undoubtedly, this group of pregnant patients is the most complex: it is not always possible to comply with "safe" parameters of CPB procedure and optimal gestational age. The main priority in such cases is life and health of the mother.

Minimally invasive cardiac surgery during pregnancy is a quite safe and effective technique which could decrease "stigma" of surgery and surgical trauma.

CONCLUSIONS

Pregnancy management by a multidisciplinary team is an effective strategy of tertiary care for pregnant women with critical heart lesions.

Performing elective cardiac surgery during pregnancy with *fetus in utero* in expert centers is a highly effective and safe option for pregnant women with high cardiovascular risk (mWHO class III-IV) and critical pathology of the heart and great vessels. Urgent CPB during pregnancy increases the risk for the fetus due to uncomfortable temperature parameters.

Cardiac surgery with partial J-form median mini-sternotomy conducted by a multidisciplinary team in pregnant women in tertiary care centers is a good option to reduce surgical trauma and rehabilitation period for these women.

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The Authors declare no conflict of interest.

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