MedNEXT
Journal of Medical an Health Sciences

REVIEW ARTICLE

DOI: 10.54448/mdnt25304

Impact of maternal diabetes on fetal cardiac function: overview of clinical studies

Mahajabin Mahata[1*]

[1] College of Basic Medical Science, China Three Gorges University, China.

*Corresponding author: Mahajabin Mahata.
College of Basic Medical Science,
China Three Gorges University.
E-mail: mahajabinmahata@ctgu.edu.cn
DOI: https://doi.org/10.54448/mdnt25304
Received: 05-21-2025; Revised: 07-02-2025; Accepted: 07-07-2025; Published: 08-04-2025; MedNEXT-id: e25304

Editor: Dr. Hae Shin Chung, MD, Ph.D.

Abstract

This research is a review study on the clinical research looking at how maternal diabetes affects fetal heart function. It investigates the effects of various forms of maternal diabetes on fetal cardiac function and development, explores the underlying mechanisms of these effects, and talks about the therapeutic consequences of these results. In this study has discusses possible future paths for this type of study, as well as intervention and preventative techniques.

Keywords: Pregnancy. Maternal diabetes. Gestational diabetes. Cardiac function.

Introduction

Worldwide, the prevalence of diabetes mellitus is rising, both in the general population and in pregnant women [1]. Gestational diabetes mellitus (GDM) is increasing in prevalence in tandem with the dramatic increase in the prevalence of overweight and obesity in women of childbearing age [2]. In the field of prenatal medicine, maternal diabetes and how it affects fetal heart function have become major research topics. An extensive analysis of clinical investigations that have been done on this junction is what this study seeks to do. Maternal diabetes mellitus is associated with increased teratogenesis, which can occur in pregestational type 1 and type 2 diabetes. [3].

Given that both Type 1 and Type 2 diabetes can have an impact on fetal cardiac outcomes, the complex link between maternal diabetes and the development of the fetal heart is a subject of intense attention. The intricacy of these relationships can be better understood by examining the many forms of maternal diabetes and their individual effects on fetal heart function. During pregnancy, complex alterations are experienced by fetal cardiac function, a crucial indicator of overall fetal health. Multiple mechanisms, including altered hemodynamics, metabolic abnormalities, and oxidative stress, have a role in the impact of maternal diabetes on fetal cardiac function. The many ways that maternal diabetes affects embryonic cardiac development can be shown by comprehending these pathways [2,3].

These effects have clinical ramifications that go beyond infancy since fetuses exposed to maternal diabetes may suffer long-term cardiovascular effects. Identification of possible hazards enables early management and intervention, reducing the likelihood of negative consequences. Modern intervention and preventive tactics include anything from improved maternal glucose management to sophisticated fetal monitoring methods [1-4].

Given this, this review study on the clinical research looking at how maternal diabetes affects fetal heart function. It investigates the effects of various forms of maternal diabetes on fetal cardiac function and development, explores the underlying mechanisms of these effects, and talks about the therapeutic consequences of these results.

Types of Maternal Diabetes

Gestational diabetes and pre-existing diabetes are the two primary forms of maternal diabetes. During pregnancy, these diseases may have a big impact on both the mother and the unborn child. Gestational diabetes is a kind of diabetes that only manifests itself while a woman is pregnant, usually between the 24th and 28th week. It is characterized by high blood sugar levels, which put both the mother and the unborn child at danger. When the body is unable to create enough insulin to satisfy the increasing demands of pregnancy, this kind of diabetes develops. The hormone insulin controls blood sugar levels by enabling cells to absorb glucose for energy. Insulin resistance is a disorder that develops when the placenta generates hormones that might hinder the action of insulin. This implies that insulin production by the mother's body may not be as efficient in lowering blood sugar levels [1-4].

Type 1 or type 2 diabetes that a woman had before to being pregnant is referred to as pre-existing diabetes. The immune system targets and kills the insulin-producing cells in the pancreas in type 1 diabetes, an autoimmune disease. Insulin injections are necessary for people with type 1 diabetes to control their blood sugar levels. For a type 1 diabetic woman to maintain maximum control and avoid problems, constant blood sugar monitoring and insulin modifications are essential. Contrarily, type 2 diabetes is characterized by insulin resistance, which is identical to what happens in gestational diabetes. In type 2 diabetes, however, the body's cells eventually develop a resistance to the actions of insulin. Due to the hormonal changes and increasing demands on the body during pregnancy, insulin resistance might get worse. For women with type 2 diabetes, maintaining stable blood sugar levels throughout pregnancy may require changing their medication schedule or switching to insulin injections [4-7].

Maintaining control of blood sugar levels is essential to lowering the hazards to the mother and the unborn child in both gestational and pre-existing diabetes. This entails routinely checking blood sugar levels, altering food, exercising often, and, if required, using insulin or other drugs as directed by a healthcare professional. A healthcare team that includes obstetricians, endocrinologists, and nutritionists will often work closely with pregnant women with diabetes to guarantee the best results for both the mother and the unborn child. Finally, gestational diabetes and pre-existing diabetes are both included in the term "maternal diabetes," because each condition has unique difficulties and effects on pregnancy [8,9].

Normal Fetal cardiac Development and Function

The human heart is one of the first organs to form and function during embryogenesis [4,5]. Fetal cardiac function describes the complex mechanisms by which a fetus's developing heart circulates oxygen and nutrients throughout the body while also pumping blood. The fetal heart experiences amazing changes throughout pregnancy as it adjusts to the special requirements of the womb and its particular environment.

These modifications affect many different facets of cardiac function, such as contractility, heart rate, and blood flow control. By the end of gestational week 3, passive oxygen diffusion becomes insufficient to support metabolism of the developing embryo [3-5], and thus the fetal heart becomes vital for oxygen and nutrient distribution [6]. The heart starts out as a basic tube-like structure in the early stages of fetal development before eventually dividing into four chambers: the left and right atria, as well as the left and right ventricles. The right alignment and connectivity of blood arteries, valves, and chambers are ensured by a complex interplay of genetic, molecular, and mechanical variables that play a role in the formation of the heart. The efficient operation of the heart at birth depends on this orchestration.

Pumping oxygenated blood via the umbilical vein from the placenta to the growing body is one of the fetal heart's main jobs. A temporary fetal channel called the ductus venosus aids in this process by diverting some oxygen-rich blood away from the liver and into the inferior vena cava. This guarantees that the unborn brain and other important organs receive an appropriate quantity of oxygen. Additionally, blood can skip the lungs, which are dormant in pregnancy, thanks to a hole between the atria called the foramen ovale, which improves oxygen delivery even more. The heart rate of a fetus normally ranges from 110 to 160 beats per minute, which is significantly greater than that of a newborn or adult [7].

The mother heart rate, gestational age, and regulatory signals from the autonomic nerve system all have an impact on this high rate. Heart rate variability, which is essential for responding to shifting demands and stresses, is maintained by the autonomic nervous system. The autonomic balance changes as the fetus develops, resulting in less variable heart rate and more stable heart rate in preparation for delivery.

A key factor in determining cardiac output, which refers to the amount of blood the heart pumps in a given amount of time, is fetal cardiac contractility, or the force of the heart's contractions. Fetal heart rate, preload, the amount of blood filling the heart, and afterload, the resistance the heart must overcome to pump blood, all have an impact on cardiac contractility. Adrenal hormones, such as adrenaline, can momentarily boost fetal cardiac contractility to accommodate the body's shifting demands [7,8].

The distribution of blood flow in the fetal circulation differs from that in postnatal life. Vital organs get oxygenated blood from the placenta, with the lungs receiving a lower amount. By joining the pulmonary artery to the aorta, the ductus arteriosus, another transient fetal channel, diverts some blood away from the lungs. Because the lungs are full with fluid when a person is pregnant and don't begin to function normally until after birth, this redirection is crucial. Complex systems, including regional vasodilators and constrictors, as well as the autonomic nervous system, are involved in controlling fetal blood flow [8-10].

Understanding fetal heart activity is essential for both monitoring the health of the developing fetus throughout pregnancy and for spotting any anomalies or dysfunctions. The anatomy and operation of the embryonic heart may be precisely seen thanks to contemporary medical imaging procedures like fetal echocardiography. This new technique has completely changed how congenital heart problems are diagnosed and treated, enabling doctors to act sooner and achieve better results [9,10].

The distinct structure and function of the fetal heart are tuned to meet the particular needs of prenatal life, guaranteeing adequate oxygen and nutrition delivery to sustain the growing fetus. The extraordinary alterations that the embryonic heart experiences during gestation serve as a reminder of how intricately human growth is and how precisely nature's design is made [10].

Maternal Diabetes and Fetal Cardiac Development

Fetal heart development may be profoundly impacted by maternal diabetes. High blood sugar levels, or hyperglycemia, during pregnancy in diabetic women can result in a number of issues that could harm the fetus's growing heart. Here are some important details about the connection between maternal diabetes and fetal heart growth,

- ✓ **Congenital Heart problems (CHDs):** Congenital heart defects (CHDs) are the most common structural birth defect, occurring in 1-5% of live births [8-10]. The maternal DM including PGDM and GDM are significantly associated with risk of CHDs and its most phenotypes. The PGDM seems to be more likely to cause CHDs in offspring than GDM. Further studies are needed to clarify the underlying mechanisms [11]. Children whose moms with uncontrolled diabetes are more likely to experience congenital heart problems. If the mother's blood sugar levels are not effectively controlled throughout the crucial stage of organ development, particularly during the first trimester, this risk is heightened.
- ✓ **Cardiomyopathy**: Fetal hypertrophic cardiomyopathy with impaired cardiac function complicates maternal diabetes independently of the degree of glycemic contro [12,13]. The fetal heart's structure and function can alter as a result of maternal diabetes. The abnormalities in the heart's muscular tissue that define diabetic cardiomyopathy might cause the newborn to have lifelong heart issues as well as reduced cardiac function.
- ✓ **Growth anomalies:** Pregnancies affected by diabetes frequently experience macrosomia, or fetal overgrowth. This can result in larger-than-average newborns, and the risk of cardiac problems rises because the heart may not expand proportionately to handle this extra development.
- ✓ **Cardiac hypertrophy:** Cardiac hypertrophy is the most common heart abnormality found with matDM reportedly affecting 50% of infants of mothers with type 1 DM and 25% of type 2 DM in one study [14]. The underlying mechanism for cardiac hypertrophy is not related to a disruption of cardiac developmental pathways but is proposed to be related to fetal hyperinsulinemia and increased expression of insulin receptors which leads to proliferation and hypertrophy of cardiomyocytes [15-17].
- ✓ **Arrhythmias:** Arrhythmias can develop as a result of maternal diabetes, which can interfere with the electrical signals that regulate the fetus's heartbeat. The capacity of the heart to pump blood and its overall functionality may be impacted by these irregular cardiac beats.
- ✓ **Structural abnormalities:** Hyperglycemia may affect how the heart's valves and blood arteries grow. The heart's capacity to properly circulate blood may be hampered as a result of certain disorders.
- ✓ **Oxygen Delivery:** If maternal diabetes is not well managed, there may be a reduction in the amount of oxygen delivered to the fetus, potentially endangering heart development. In order to make up for this, the heart might have to work harder, putting the organ under long-term strain.
- ✓ **Epigenetic Alterations:** According to recent study, maternal diabetes may cause epigenetic alterations in the fetal DNA. These changes may affect gene expression and have an effect on many elements of heart growth and function.
- ✓ **Mechanism of impact:** These mechanisms work together to affect fetal cardiac function as a result of maternal diabetes, which may have long-term effects on the child's cardiovascular health.
- ✓ **Hyperglycemia-induced Oxidative stress:** Since the fetal heart depends on glucose

metabolism, hyperglycemia may cause the fetus's metabolism to accelerate, and induced hypoxia and increased oxidative stress would initially harm the RV, which may account for decreased cardiac performance [18].

- ✓ **Altered Nutrient Exchange:** Maternal diabetes affects the mother's and fetus's placental blood flow and nutrient exchange. As a result of excessive glucose and free fatty acid transfer to the embryo as a result of insulin resistance, fetal cardiac cells may experience metabolic stress.
- ✓ **Hyperinsulinemia:** The fetus may create too much insulin in reaction to maternal hyperglycemia. Due to increased cell proliferation and changed gene expression, this might cause cardiac hypertrophy (enlargement of the heart muscle).
- ✓ **Epigenetic Modifications:** Fetal cardiac genes may experience epigenetic modifications as a result of maternal diabetes. These changes may have an impact on gene expression patterns, resulting in aberrant heart growth and operation.
- ✓ **Inflammation:** Both maternal and fetal tissues become inflamed as a result of hyperglycemia. Fetal cardiac cells can become dysfunctional as a direct result of inflammatory chemicals.
- ✓ **Advanced Glycation End Products (AGEs):** AGEs can develop as a result of high glucose levels. These substances can build up in the heart and other fetal tissues, resulting in morphological and functional problems.
- ✓ **Mitochondrial dysfunction:** Fetal cardiac cells' ability to operate as mitochondria is hampered by maternal diabetes. As a result, energy synthesis is impaired, which lowers contractile performance and raises stress susceptibility.
- ✓ **Endothelial Dysfunction:** Reduced blood supply to the fetus can result from diabetes-related endothelial dysfunction in the placenta. The healthy growth of the heart may be hampered by this decreased oxygen and nutrition delivery.
- ✓ **Impaired Cardiac Autonomic Control:** The fetal autonomic nerve system, which regulates heart rate and rhythm, might be affected by maternal diabetes. This system's disruption may result in abnormal heart activity.
- ✓ **Structural Abnormalities:** Studies have suggested that maternal diabetes may result in anatomical abnormalities in the developing fetal heart, including thickening of the heart walls or changed chamber sizes [17-20].

In addition, morphological changes, such as cardiac hypertrophy, have been observed following fetal exposure to elevated glucose levels in PDM as well as in GDM [19]. Besides structural and morphological changes, maternal diabetes can result in sonographic changes in the fetal heart that are suggestive of functional impairment [20].

Clinical Implications

The results highlight the significance of regularly monitoring diabetic pregnant women, since their condition might significantly affect embryonic heart development. Clinicians should exercise caution when evaluating the heart function of fetuses using noninvasive techniques like echocardiography, particularly when the mother's diabetes is not well managed. However, current practice does not include evaluation of fetal cardiac function during the course of pregnancy, since the prevalence, type and impact of functional changes on echocardiography are still unclear. With the growing burden of maternal diabetes, both pregestational and gestational, and evidence that the impact goes beyond structural abnormalities, more insight into the effects of maternal diabetes on fetal heart development and function is essential [21].

Aiming to reduce negative consequences, early diagnosis of any anomalies in embryonic heart function might enable prompt treatments and individualized care techniques. These clinical investigations further emphasize the necessity for thorough multidisciplinary treatment, involving endocrinologists, obstetricians, and pediatric cardiologists, to guarantee the health of both the mother and the growing fetus. Healthcare practitioners can lessen the potential long-term cardiovascular effects for kids exposed to maternal diabetes in pregnancy by improved surveillance and tailored therapies [22].

Fetal HQ can be used to identify sub-clinical cardiac morphology, size, and function changes in the fetus of diabetic mothers [22]. Given the clear risk for structural cardiac malformations, routine clinical practice includes an advanced fetal ultrasound scan in pregnancies with PDM, which encompasses detailed cardiac evaluation [23].

Invention and Prevention

An important development in prenatal care and newborn health is the introduction of clinical investigations examining the effects of maternal diabetes on fetal heart function. The realization that maternal diabetes, both gestational and pre-existing, can have significant effects on the developing fetal heart gave rise to this ground-breaking scientific field. In this context, invention refers to the creative strategies and procedures used by researchers to understand the complex connection between maternal diabetes and fetal cardiac development. Our capacity to noninvasively examine embryonic heart anatomy and function has been transformed by the development of advanced imaging techniques like fetal echocardiography, which enables physicians and researchers to identify minor anomalies at an earlier stage [24].

The incorporation of molecular and genetic analysis into clinical investigations has also uncovered underlying pathways and processes that underlie the negative effects of maternal diabetes on fetal cardiac development. These developments provide a thorough understanding of the complex interactions between maternal metabolic condition and fetal cardiac outcomes [24].

Clinical studies suggest an overall healthy lifestyle with regular exercise before and during pregnancy is important to ensure a healthy outcome of the newborns [24]. Exercise has a number of benefits including, but not limited to, improvements of metabolism, cardiovascular health, cognition, fertility, bone health, immune response, and even slowing down aging [25]. Exercise during gestation lowers the risk of gestational diabetes mellitus and improves offspring health [26].

Contrarily, prevention includes a variety of tactics designed to lessen the negative effects of maternal diabetes on fetal cardiac function. Clinical research has changed the way prenatal care is provided by illuminating a number of possible interventional pathways. Lifestyle changes, such as improving maternal glycemic control through dietary changes and exercise routines, have become essential pillars in averting the negative cardiac outcomes for diabetic fetuses. Pharmacological therapies have shown promising outcomes in reducing the effects of hyperglycemia on embryonic cardiac function when supported by data from clinical studies. Additionally, personalized medicine strategies have the ability to detect high-risk pregnancies early and adapt therapies to individual requirements. These strategies are driven by genetic insights gained from clinical trials [25,26].

Finally, the innovative advances in clinical research examining the effect of maternal diabetes on fetal cardiac function have not only revealed the complex processes behind this association but have also prepared the way for fresh preventative methods. These developments highlight how multidisciplinary cooperation between physicians, academics, and technology specialists has the power to fundamentally alter the prenatal care environment. The field is poised to revolutionize our understanding of maternal-fetal health and usher in a new era of proactive interventions that protect fetal cardiac well-being in the face of maternal diabetes by utilizing cutting-edge imaging techniques, molecular analyses, and personalized medicine approaches [26].

Conclusion

The complicated interaction between maternal health and fetal development is shown by research on the effect of maternal diabetes on fetal heart function. Fetal cardiac development and function have been demonstrated to be impacted by a number of maternal diabetes types, including gestational and preexisting diabetes. Modified metabolic, circulatory, and genetic pathways are only a few of the many mechanisms that underlie these changes. Clinicals studies highlight the significance of monitoring fetal cardiac function in diabetes-complicated pregnancies because compromised cardiac development can have long-term effects on the cardiovascular health of the fetus. The necessity for strong cooperation between obstetricians, endocrinologists, and neonatologists is highlighted by the importance of early identification and intervention techniques in addressing these risks. Future investigations into the molecular processes underlying the effects of maternal diabetes on fetal heart function are necessary. The creation of focused strategies to lessen undesirable effects may result from this. Additionally, research into how genetic predisposition and environmental variables interact may help develop more specialized methods of prevention and therapy.

CRediT

Author contributions: **Conceptualization; Data curation; Formal Analysis; Investigation; Methodology; Project administration; Writing - original draft; Writing-review & editing -** Mahajabin Mahata.

Acknowledgment

Not applicable.

Ethical Approval

Not applicable.

Informed Consent

Not applicable.

Funding

Not applicable.

Data Sharing Statement

No additional data are available.

Conflict of Interest

The authors declare no conflict of interest.

Similarity Check

It was applied by Ithenticate@.

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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