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Research Article

A Study on the Application of Four-Dimensional Ultrasound Time-Space Correlation Imaging Technology in the Diagnosis of Congenital Heart Disease of Fetus in Mid-Pregnancy

You Luo[1] and Da-wei Liao[2]*

[1]Department of Ultrasound, Chongqing Rongchang District Maternal and Child Health Hospital, Rongchang, China

[2]Department of Radiology, the Affiliated Hospital of Southwest Medical University, Luzhou, China

***Corresponding Author:** Da-wei Liao, Department of Radiology, the Affiliated Hospital of Southwest Medical University, Luzhou, China.

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Abstract

Objective: Exploring the application value of four-dimensional ultrasound spatiotemporal image correlation (STIC) technology in prenatal diagnosis of congenital heart disease (CHD) in mid-pregnancy fetuses.

Method: 11456 pregnant women who underwent fetal heart malformation screening from January 2021 to December 2022 at our hospital were selected as the study subjects. All pregnant women underwent two-dimensional ultrasound and four-dimensional ultrasound STIC technology examination. Follow-up was conducted to confirm the fetal heart condition through live birth or pathological results of induced abortion. The follow-up results were used as the 'gold standard' to compare and analyze the application time of two-dimensional ultrasound and four-dimensional ultrasound STIC technology in CHD examination, as well as the image acquisition time, display of standard cardiac sections, and accuracy, sensitivity, and specificity.

Results: In this study, 200 cases of CHD were confirmed through live birth or pathological results of induced abortion. In the diagnostic examination of these 200 cases of CHD, four-dimensional ultrasound STIC technology had shorter examination and image acquisition time than two-dimensional ultrasound. It also demonstrated higher accuracy, sensitivity, and specificity compared to two-dimensional ultrasound, with lower rates of missed diagnosis and misdiagnosis. Four-dimensional ultrasound STIC technology showed higher overall satisfaction rates than two-dimensional ultrasound in displaying the right ventricular outflow tract, five-chamber heart plane, left ventricular outflow tract, aortic arch plane, three-vessel trachea plane, caval vein long-axis plane, ductal arch plane, and four-chamber heart plane.

Conclusion: In the diagnostic examination of CHD, the use of four-dimensional ultrasound STIC technology can reduce the examination time for pregnant women. It provides a more comprehensive display of various standard cardiac the fetal heart, which can improve the accuracy, sensitivity, and specificity of the diagnosis. Additionally, it can reduce the rates of missed diagnosis and misdiagnosis.

Keywords: STIC; Two-Dimensional Ultrasound; Congenital Heart Disease in Fetuses

Introduction

Congenital heart disease in fetuses (CHD) is a malformation caused by abnormal development of the heart and major blood vessels during embryonic period, with an incidence rate of 8%-12% and 60% of affected infants dying before the age of one [1,2]. Prenatal diagnosis is of great significance in reducing birth defects, lowering mortality rate, improving birth quality, and enhancing pregnancy outcomes. Currently, two-dimensional ultrasound is the primary method for prenatal screening of CHD. However, due to the limitations of intrauterine conditions and the rapid fetal heart rate, as well as the complex pathological anatomy of CHD, two-dimensional ultrasound has limitations in screening for CHD. With the continuous advancement of medical technology, real-time dynamic four-dimensional spatiotemporal image correlation (STIC) technology is increasingly prominent in prenatal diagnosis, especially in the analysis and reconstruction of fetal cardiac volume information, which allows for multi-dimensional and multi-angle observation of fetal cardiac structure and provides a new window for prenatal screening of CHD. This article discusses the value of four-dimensional ultrasound STIC technology for CHD examination.

Materials and Methods

General information

A total of 11,456 pregnant women who underwent fetal heart malformation screening at our hospital from January 2021 to December 2022 were selected as the study subjects. The age of the participants ranged from 19 to 39 years, with an average age of (28.10 ± 4.26) years. The gestational weeks ranged from 14 to 28 weeks, with an average of (25.50 ± 4.12) weeks. All pregnant women and their families understood the study content and signed an informed consent form. This study has been approved by the hospital ethics committee.

Inclusion and exclusion criteria

Inclusion criteria

(1) The study subjects had established medical records in our hospital's obstetrics clinic and received regular prenatal checkups. (2) All study subjects underwent STIC technology examination using both two-dimensional and four-dimensional ultrasound. (3) All study subjects gave birth or terminated their pregnancy in our hospital, and the follow-up results of the fetus were clear. (4) All study subjects had singleton pregnancies.

Exclusion criteria

(1) Subjects with non-standard prenatal checkups. (2) Subjects with unclear follow-up results of the fetus. (3) Pregnant women with severe cardiovascular and cerebrovascular diseases. (4) Patients with serious complications during pregnancy.

Inspection method

Examination equipment

The present study employed the Shenzhen Mindray Resona8Exp Color Doppler Ultrasound Diagnostic System for diagnosis, with the probe frequency set at 4-8 MHz and the basic conditions set to fetal heart mode. Two-dimensional imaging mode and STIC imaging mode were separately applied for fetal heart examination, and volumetric data were analyzed offline using the 4D online imaging software provided by Shenzhen Mindray Company.

Two-dimensional ultrasonic examination

All subjects were first subjected to a two-dimensional ultrasonic examination, during which pregnant women were instructed to relax and hold their breath to keep the fetus calm. The four-chamber heart plane was used as the initial scanning plane for volumetric data acquisition, with an angle ranging from 25° to 30° and a scanning time of 10-12 seconds.

STIC data acquisition

All subjects underwent a four-dimensional ultrasound STIC examination again, during which pregnant women were asked to hold their breath and minimize external movements to reduce interference with image quality. The fetal heart was scanned using advanced ultrasound tomography iPage+ to observe the right ventricular outflow tract, five-chamber heart plane, left ventricular outflow tract, aortic arch plane, three-vessel tracheal plane, inferior vena cava long-axis plane, arterial duct section, and four-chamber heart plane, and to collect volumetric data. The scanning time and angle were determined based on the gestational age of the pregnant woman, with the angle typically ranging from 10° to 20° and the acquisition time set at 8-10 seconds.

Image analysis

Blinded review of the images was performed by two experienced senior sonographers in a double-blind manner. In cases of diagnostic disagreement, a third senior physician was consulted and the final diagnosis was determined by majority consensus.

Based on the ultrasound results, the decision to continue the pregnancy or to terminate it was made according to the pregnant woman's wishes.

Observational parameters

(1) The application time and image acquisition time of two-dimensional ultrasound and four-dimensional ultrasound STIC technology in the diagnosis of CHD were statistically analyzed. (2) The display of standard cardiac sections in the diagnosis of CHD was compared between two-dimensional ultrasound and four-dimensional ultrasound STIC technology. (3) The accuracy (number of cases with diagnostic agreement/number of prenatal diagnoses × 100%), sensitivity (true positive/(true positive + false positive) × 100%), and specificity (true negative/(true negative + false positive) × 100%) of two-dimensional ultrasound and four-dimensional ultrasound STIC technology in diagnosing fetal cardiac malformations were studied using live birth confirmation or termination pathology results as the gold standard.

Statistical methodology

The data processing and analysis of all records were performed using SPSS 27.0 software. Metric data were expressed as mean ± standard deviation $(\bar{x} \pm s)$, and independent sample t-tests were used for intergroup comparisons. Count data were presented as percentages (%), and tests were used. $P < 0.05$ indicated significant differences with statistical significance.

Results

General characteristics

During the study period, there were 11,456 pregnant women who participated in the fetal heart malformation screening. Among them, 225 pregnant women were of having CHD. Among the suspected cases, 18 were lost to follow-up, and 7 pregnant women who terminated their pregnancies refused pathological autopsy. Therefore, there were 200 valid subjects. Among the 200 pregnant women with CHD, 49uses were confirmed with CHD through induced abortion or stillbirth pathology, and 151 live births were confirmed with CHD through neonatal ultrasound.

Examination time and image acquisition time of two-dimensional ultrasound and four-dimensional ultrasound STIC technology for diagnosing CHD

The examination time of single fetal heart by two-dimensional ultrasound was (9.9 ± 2.5 min), and the image acquisition time was (1.2 ± 0.8 min). The examination time of single fetal heart by four-dimensional ultrasound STIC technology was (7.5 ± 2.0 min), and the image acquisition time was (0.8 ± 0.4 min) ($P < 0.05$). Four-dimensional ultrasound STIC technology was found to be less time-consuming than two-dimensional ultrasound in the examination and image acquisition of single fetal heart.

Satisfaction rates of standard cardiac section display in the diagnosis of CHD using two-dimensional ultrasound and four-dimensional ultrasound STIC technology

Overall satisfaction rate of the right ventricular outflow tract, five-chamber heart plane, left ventricular outflow tract, aortic arch plane, three-vessel tracheal plane, long-axis view of the inferior vena cava, ductus arteriosus view and four-chamber heart plane by four-dimensional ultrasound STIC technology was higher than that of two-dimensional ultrasound (Table 1).

Section	Two-dimensional ultrasound (n = 200)			STIC (n = 200)				P
	Satisfaction	Dissatisfaction	Satisfaction rate (%)	Satisfaction	Dissatisfaction	Satisfaction rate (%)		
Right ventricular outflow tract	190	10	95	195	5	97.5	1.108	0.292
five-chamber heart	196	4	98	197	3	98.5	1.339	1
Left ventricular outflow tract	195	5	97.5	195	5	97.5	0	1
Aortic arch	189	11	94.5	192	8	96	0.221	0.638
three-vessel tracheal	187	13	93.5	190	10	95	0.184	0.667
inferior vena cava long-axis	178	22	89	183	17	91.5	0.454	0.500
arterial duct	180	20	90	185	15	92.5	0.500	0.479
Four-chambered heart	196	4	98	198	2	99.0	2.016	0.685

Table 1: Satisfaction of Standard Fetal Cardiac Sections Displayed by Two-dimensional Ultrasound and Four-dimensional Ultrasound STIC Technology.

Comparison of the diagnostic value of two-dimensional ultrasound and four-dimensional ultrasound IC technology in the diagnosis of CHD

Among 200 pregnant women with CHD, 49 fetuses were confirmed as CHD by induction or stillbirth pathology, and 151 live-born infants were confirmed as CHD by neonatal ultrasound. Of the 200 CHD cases, 170 were true positives by two-dimensional ultrasound examination and 193 were true positives by four-dimensional ultrasound STIC technology (Table 2, Table 3). The accuracy of detecting fetal heart defects by two-dimensional ultrasound and four-dimensional ultrasound STIC technology was 85% and 96.5%, respectively, with a sensitivity of 97.1% and 98.9%, a specificity of 60% and 100%, a missed diagnosis rate of 2.5% and 1%, and a misdiagnosis rate of 5% and 0% (Table 4).

Two-dimensional echocardiography	Gold standard		Total
	Positive	Negative	
Positive	170	10	180
Negative	5	15	20
Total	175	25	200

Table 2: Diagnostic evaluation of two-dimensional echocardiography (example).

STIC	Gold standard		Total
	Positive	Negative	
Positive	193	0	193
Negative	2	5	7
Total	195	5	200

Table 3: Diagnostic Performance of Four-Dimensional Ultrasound STIC Technique (Example).

Detection method	Accuracy	Sensitivity	Specificity	False negative rate	False positive rate
Two-dimensional ultrasound	85 (170/200)	97.1 (170/175)	60 (15/25)	2.5 (5/200)	5 (10/200)
STIC	96.5 (193/200)	98.9 (193/195)	100 (5/5)	1 (2/200)	0 (0/200)

Table 4: Compares the diagnostic value of two-dimensional ultrasound and four-dimensional ultrasound STIC technology (%).

Discussion

CHD is one of the more common congenital malformations, which is caused by obstacles and developmental abnormalities in the formation of the heart and major blood vessels during fetal development, resulting in anatomical structural abnormalities [3]. Some CHDs are characterized by failure of the relevant channels to close automatically at the time of birth, and CHD is the leading cause of neonatal death [4]. Improving the detection rate of CHD is of great significance: (1) It allows pregnant women to determine whether to terminate pregnancy based on chromosome karyotype and genetic counseling; (2) For pregnant women with a high risk of CHD or a family history of CHD, increasing the detection rate can enable early and safer induction of labor; (3) For pregnant women who choose to continue the pregnancy, early postnatal counseling can be provided for infants with congenital heart disease.

Two-dimensional ultrasound is a commonly used non-invasive screening method for CHD due to its high safety, ability to be repeatedly checked, and clear display of fetal heart size, morphology, and function [5]. However, the complex structure and rapid pulsation of the fetal heart, combined with differences in operator experience, as well as factors such as a history of abdominal surgery and a relatively thick abdominal wall fat layer in pregnant women, have increased the difficulty of early and accurate screening for CHD by two-dimensional ultrasound to varying degrees.

The STIC technique, which has recently emerged and rapidly developed as a real-time three-dimensional ultrasound imaging technology for fetal cardiac prenatal screening, adds a time factor to the image acquisition process to obtain cubic dynamic images, improving the temporal and spatial referencing of the images and compensating for the shortcomings of traditional two-dimensional ultrasound [6]. STIC technology has the following advantages [7]: (1) It can be combined with automatic software to automatically display various standard sections of the fetal heart, with less dependence on ultrasound doctors, a simple image acquisition process, and reduced scanning time; (2) All data storage is digital, enabling offline analysis and remote transmission, making case teaching and remote consultation more convenient and efficient; (3) Volume data can be adjusted in any section, and multiple imaging modes can analyze various features of the heart structure; (4) It can be combined with color Doppler or B-flow blood imaging mode to obtain blood information of the fetal heart.

In this study, four-dimensional ultrasound STIC technology had a shorter examination and image acquisition time than two-dimensional ultrasound; the accuracy, sensitivity, and specificity of four-dimensional ultrasound STIC technology in detecting fetal cardiac malformations were higher than those of two-dimensional ultrasound, while the missed diagnosis rate and misdiagnosis rate were lower than those of two-dimensional ultrasound; four-dimensional ultrasound STIC technology had a higher overall satisfaction rate than two-dimensional ultrasound in displaying the right ventricular outflow tract, five-chamber heart section, left ventricular outflow tract, aortic arch section, three-vessel tracheal section, caval vein long axis section, ductus arteriosus section, and four-chamber heart section. The results of this study indicate that four-dimensional ultrasound STIC technology can shorten the examination time for pregnant women and more comprehensively display various standard sections of the fetal heart, thereby improving the diagnostic accuracy of CHD, reducing missed diagnosis and misdiagnosis rates.

Four-dimensional ultrasound STIC technology has significant advantages in mid-pregnancy CHD screening, but still has certain limitations [8]: (1) The image acquisition process is easily affected by factors such as maternal respiratory motion, fetal movement, fetal position, and abnormal amniotic fluid, which can cause image distortion and displacement, resulting in distorted and blurred post-processing images, leading to misdiagnosis and missed diagnosis [9]; (2) It can display three mutually perpendicular cardiac sections simultaneously, but the resolution is relatively low; (3) In the process of three-dimensional reconstruction, information loss is inevitable [10]; (4) It requires high operation skills from ultrasound doctors, who need professional training, and the high cost of four-dimensional ultrasound STIC technology limits its popularity in primary hospitals.

Conclusion

In summary, the application of four-dimensional ultrasound STIC technology in mid-pregnancy CHD screening can reduce the examination time for pregnant women, more comprehensively display various standard sections of the fetal heart, improve the diagnostic accuracy, sensitivity, and specificity, and reduce the missed diagnosis and misdiagnosis rates.

Author's Contribution

You Luo wrote the paper, including the first draft. Da-wei Liao revised the paper. All authors have agreed to publish.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

Ethical Approval and Consent to Participate

This study was conducted in accordance with the ethical standards of our hospital.

Consent to Publication

All participants' families provided informed consent for the publication of this article.

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