International Journal of General Medicine

Dovepress
Taylor & Francis Group

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ORIGINAL RESEARCH

Application and Evaluation of Spiral CT in the Diagnosis of Congenital Heart Disease in Children

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Objective: This study aims to explore the application of spiral CT in the diagnosis of congenital heart disease in children and evaluate its clinical value.

Methods: The study included children diagnosed and treated at our hospital from January 2021 to October 2023 as research subjects. After excluding children who did not meet the complete inclusion criteria, a total of 60 cases were finally included. General data of all children were collected and summarized. Spiral CT and echocardiography were performed on all children, and the diagnostic results of both were compared with surgical findings to analyze and evaluate their application effectiveness.

Results: Spiral CT detected 39 cases of intracardiac anomalies, 30 cases of abnormal connections of the great vessels, and 66 cases of extracardiac vascular anomalies, while echocardiography detected 33 cases of intracardiac anomalies, 29 cases of abnormal connections of the great vessels, and 43 cases of extracardiac vascular anomalies. Compared with surgical results, the detection rate of extracardiac vascular anomalies (98.59%) and the overall cardiovascular anomaly detection rate (98.54%) by spiral CT were significantly higher than those by echocardiography, with $P<0.05$.

Conclusion: Spiral CT is a high-resolution, rapid, and safe imaging technique. Compared with traditional echocardiography, it is not only superior in diagnostic accuracy but also faster in imaging speed. It can clearly display the anatomical structure and spatial relationships of lesions, making it of great value in the diagnosis of congenital heart disease in children. It is suitable for clinical promotion and use.

Keywords: spiral CT, 128-slice CT, congenital heart disease, diagnosis, application evaluation

Introduction

Congenital heart disease (CHD) is a common structural abnormality of the heart in children, involving developmental defects in the heart's interior or major blood vessels. It is one of the common lethal congenital diseases in infants. The underlying cause is abnormal development of heart blood vessels during fetal development or failure of channels that should close automatically after birth, leading to congenital malformations. The clinical manifestations and severity vary depending on the type and extent of the lesion, with some cases requiring early diagnosis and intervention to improve prognosis. Currently, the main treatment method in clinical practice is repair through surgery.[1,2] Before treatment, accurate and effective imaging examinations are crucial for definitive diagnosis, planning surgical procedures, and are key factors for surgical success, especially for complex CHD, which may involve multiple extracardiac vascular anomalies, highlighting the importance of preoperative examinations. Traditional diagnostic methods include echocardiography, cardiac catheterization, etc. However, these methods have certain limitations. For instance, echocardiography can be operator-dependent and may struggle with visualizing complex heart structures or cases with poor acoustic windows. Cardiac catheterization, while highly informative, is invasive and carries risks such as bleeding or infection, making it less suitable for certain patients. MRI, though non-invasive and providing detailed images, can be limited by long scan times, high costs, and difficulties in pediatric patients who have trouble holding their breath. These limitations highlight the need for alternative, non-invasive methods that offer high resolution and comprehensive anatomical imaging.[3,4] With the development of medical imaging technology, in recent years, multidetector spiral CT (MSCT)

Received: 13 November 2024
Accepted: 10 February 2025
Published: 23 April 2025

has attracted attention due to its advantages of high spatial and density resolution, showing great potential as a high-resolution, rapid, and safe imaging technique in the diagnosis of congenital heart disease in children.[5,6] Spiral CT offers several advantages over traditional imaging methods, including its ability to provide high-quality, three-dimensional reconstructions of the heart and vessels, which can be invaluable in cases of complex congenital heart disease. Additionally, its rapid scan times reduce motion artifacts, which is particularly important in pediatric patients. Furthermore, while it does involve radiation, advancements in low-dose CT protocols have significantly minimized exposure, making it a safer option for children compared to older CT technologies.

According to relevant epidemiological surveys, CHD is one of the common structural abnormalities of the heart in children, and its incidence varies with region, race, and genetic factors. A family history of CHD patients may increase the risk of children developing the disease. Chromosomal abnormalities and gene mutations may also lead to CHD.[7,8] In addition, maternal exposure to harmful substances during pregnancy, malnutrition, maternal infection, etc., may affect fetal cardiac development and increase the risk of CHD. Therefore, more accurate and comprehensive preoperative diagnosis of CHD in children is extremely important. This study aims to explore the application and evaluation of spiral CT in the diagnosis of congenital heart disease in children, provide more information about this technology to clinical doctors, and provide theoretical basis and guidance for its promotion and application in clinical practice.

Subjects and Methods

Study Subjects

This retrospective study included children diagnosed with congenital heart disease (CHD) and undergoing intervention treatment at our hospital from January 2021 to October 2023. General data of all children were collected and summarized. After excluding children who did not meet the complete inclusion criteria, a total of 60 cases were selected. These cases were grouped according to routine clinical practices. Spiral CT and echocardiography were performed on all children, and the diagnostic results of both were compared with surgical findings to analyze and evaluate their diagnostic effectiveness. This study was approved by the Ethics Committee of the Children's Hospital of Soochow University, and all parents or legal guardians provided informed consent for their children's participation in the study.

Inclusion Criteria

Patients meeting the following conditions were included: age below 12 years, exhibiting typical symptoms and signs, ie, having one or more pathological physiological changes or several cardiovascular malformations simultaneously, and already diagnosed by echocardiography (UCG). These patients had complete clinical data, were not limited by gender, and excluded those with neurological diseases or poor compliance. The inclusion criteria were applied in a non-randomized manner, based on clinical characteristics such as the presence of multiple heart malformations or suspected extracardiac vascular anomalies that were deemed to require further imaging for accurate diagnosis. A CT scan was indicated when echocardiographic results were inconclusive, or when there was a need for clearer anatomical detail, especially for complex cases requiring surgical intervention.

Diagnostic Methods

We used the high-end 128-slice CT equipment Optima CT660 (128T) spiral CT from GE Healthcare for scanning. Before the examination, patients were required to fast for 4–6 hours. During the scan, patients were instructed to hold their breath after inhaling once, followed by completing the scan. The scan range extended from the thoracic inlet to the diaphragmatic level. We used the non-ionic contrast agent iodixanol injection (Yangtze River Pharmaceutical Group) (100mg:30g) at a dose of 1.5–2mL/kg body weight, not exceeding a total of 80mL, and injected the contrast agent at a flow rate of 0.6–2.0mL/s (based on the patient's age and weight) using a single-barrel high-pressure injector. During the examination, patients were instructed to maintain a stable position, cooperate with calm breathing and breath-holding, and avoid swallowing saliva or blinking. For patients who could not cooperate with the examination, rectal hydration or anesthesia was used to complete the scan while they were asleep.

Diagnostic Criteria

A three-segment analysis method was used for image analysis and diagnosis, which evaluates based on visceral-atrial position, atrial-ventricular connection, and ventricular-great artery connection. CT images were independently analyzed by two experienced cardiothoracic imaging diagnostic physicians, and in case of disagreement, a consensus was reached through joint discussion to obtain a consistent conclusion.

Data Analysis

Data were organized and analyzed using SPSS 26.0. Quantitative data were expressed as mean ($\bar{x}\pm$ standard deviation), and intergroup comparisons were performed using the *t*-test; qualitative data were expressed as [n (%)], and intergroup comparisons were performed using the chi-square test. A significance level of $P<0.05$ was used to indicate statistical significance.

Results

General Information

This study included a total of 60 children, with 33 males and 27 females, aged 0–12 years, with a mean age of (4.96±2.27) years, and a weight range of 2.5–37kg, with a mean weight of (9.94±4.22) kg. See Table 1.

Diagnostic Accuracy

Intracardiac Anomalies

Spiral CT detected 39 cases of intracardiac anomalies, while echocardiography detected 33 cases. The difference between the two groups was not significant, with $P>0.05$. See Table 2.

Abnormal Connections of the Great Vessels

Spiral CT detected 30 cases of abnormal connections of the great vessels, while echocardiography detected 29 cases. The difference between the two groups was not significant, with $P>0.05$. See Table 3.

Table 1 General Information of Patients

		Children with Congenital Heart Disease
Number of Cases	–	60
Gender	Male	33
–	Female	27
Age	–	0–12
–	Mean	4.96±2.27
Body weight	–	2.5–37
–	Mean	9.94±4.22

Table 2 Comparison of Intracardiac Anomaly Detection Between Two Methods in Patients

Type	Surgery	Spiral CT		UCG	
		Detection	Missed Diagnosis	Detection	Missed Diagnosis
Ventricular septal defect	22	22	0	21	1
Atrial septal defect	10	9	1	8	2
Right heart position	1	1	0	1	0
Tricuspid atresia	2	2	0	1	1
Single ventricle	1	1	0	1	0
Pulmonary valve malformation	4	4	0	1	3
Total	40	39	1	33	7

Abbreviation: UCG, echocardiography.

https://doi.org/10.2147/IJGM.S506437

Table 3 Comparison of Abnormal Connections of the Great Vessels Detection Between Two Methods in Patients

Type	Surgery	Spiral CT		UCG	
		Detection	Missed Diagnosis	Detection	Missed Diagnosis
Transposition of the great arteries	4	4	0	4	0
Double outlet right ventricle	3	3	0	2	1
Aortic overriding	17	17	0	17	0
Anomalous pulmonary venous connection	2	2	0	2	0
Persistent left superior vena cava	4	4	0	4	0
Total	30	30	0	29	1

Extracardiac Vascular Malformations

Spiral CT detected 66 cases of extracardiac vascular malformations, while echocardiography detected 43 cases. The difference between the two groups was significant, with P<0.05. See Table 4.

Detection Rate of Cardiovascular Malformations

Comparing with surgical results, the detection rate of extracardiac vascular malformations (98.59%) and the overall cardiovascular malformation detection rate (98.54%) by spiral CT were significantly higher than echocardiography, with P<0.05. See Table 5.

Although echocardiography is a commonly used diagnostic tool for heart disease, some congenital heart defects were not accurately diagnosed in this study. This may be related to the limitations of ultrasound technology, such as difficulty obtaining clear images for certain complex cardiac structures or lesions in special positions. Additionally, the interpretation of ultrasound images is highly dependent on the operator's experience and skill, whereas CT can provide more detailed anatomical information, especially in complex cases.

Table 4 Comparison of Extracardiac Vascular Malformation Detection Between Two Methods in Patients

Type	Surgery	Spiral CT		UCG	
		Detection	Missed Diagnosis	Detection	Missed Diagnosis
Pulmonary artery stenosis	18	18	0	12	6
Pulmonary artery atresia	7	7	0	6	1
Aortic stenosis	10	10	0	7	3
Aortic interruption	5	5	0	3	2
Vagus subclavian artery	2	2	0	1	1
Patent ductus arteriosus	14	13	1	12	2
Aortic branch vessels stenosis	11	11	0	2	9
Total	67	66*	1	43*	24

Notes: *indicates a significant difference in the number of detections between spiral CT and echocardiography, with P<0.05.

Table 5 Comparison of Detection Rates Between Two Methods in Patients

Type	Spiral CT	UCG	*t*	*P*
Intracardiac malformation	97.22%	88.89%	0.859	0.354
Cardiac great vessel connection abnormality	100.00%	96.67%	–	–
Extracardiac vascular malformation	98.59%	61.97%	30.073	<0.001
Total cardiovascular malformation	98.54%	76.64%	30.221	<0.001

Discussion

Congenital heart disease, commonly abbreviated as CHD, is one of the most common birth defects and a leading cause of neonatal mortality. Statistics show that the incidence of CHD is approximately 8 to 12 cases per 1000 live births. CHD encompasses a wide range of diseases, with diverse lesions and complex pathological features that can lead to hemodynamic changes.[9,10] With advances in surgical techniques and precise diagnostic imaging, the survival rate of CHD patients has steadily increased. Imaging plays a crucial role in preoperative assessment and postoperative follow-up of CHD patients. Accurate assessment of anatomical abnormalities and functional evaluation is essential for CHD diagnosis. Common cardiac imaging methods include echocardiography and cardiac CT. Echocardiography is the preferred method for diagnosing pediatric CHD, but it has limitations in displaying both intracardiac structures and extracardiac vessels due to acoustic window restrictions, thus limiting its assessment of cardiac function as well.[11,12] In recent years, with the continuous development of CT technology, techniques such as multi-slice spiral CT, dual-source CT (DSCT), and spectral CT have been widely used, significantly improving image quality and diagnostic accuracy. Cardiac CT has become one of the important imaging methods for preoperative and postoperative assessment of CHD. CT scans are fast, with higher spatial resolution of cardiac anatomy, and can assess both cardiac function and myocardial tissue characteristics.[13,14]

The results of this study found that spiral CT detected 39 cases of intracardiac anomalies, 30 cases of abnormal connections of the great vessels, and 66 cases of extracardiac vascular anomalies, while echocardiography detected 33 cases of intracardiac anomalies, 29 cases of abnormal connections of the great vessels, and 43 cases of extracardiac vascular anomalies. Compared with surgical results, the detection rate of extracardiac vascular anomalies (98.59%) and the overall cardiovascular anomaly detection rate (98.54%) by spiral CT were significantly higher than those by echocardiography, with $P<0.05$. Spiral CT imaging can clearly display the cardiac anatomy, position, and connections between atria and ventricles and great vessels. Through post-processing reconstructed images, it can accurately present the anatomical morphology of cardiac vessels, distribution of abnormal collateral circulation, and possible complications, aiding in the formulation and refinement of preoperative surgical plans, which is of great significance for clinicians to develop detailed preoperative surgical plans and reduce surgical risks. Combining with previous related studies, echocardiography is cost-effective, easy to operate, radiation-free, and can perform real-time and dynamic two-dimensional imaging. However, due to limitations in chest anatomical structures and operator techniques, echocardiography's display effect on extracardiac vascular malformations is suboptimal, resulting in certain limitations in the diagnostic accuracy of extracardiac vascular malformations.[15,16] This is also reflected in the results of this study. Conversely, cardiac catheterization (CAG), once considered the "gold standard" for preoperative diagnosis of CHD, although it can display both intracardiac and extracardiac anomalies, is an invasive procedure with potential risks. It also requires a large contrast agent volume, long examination time, high X-ray dose, and is susceptible to positional effects, making it less applicable to infants, young children, and patients with compromised cardiac function. Additionally, overlapping images may lead to missed diagnoses. Magnetic resonance imaging (MRI), which plays an important role in CHD diagnosis, is limited by factors such as equipment availability, high examination costs, relatively low temporal and spatial resolutions, and the need for breath-holding cooperation, resulting in significant limitations in examining infants and young children with CHD.[17] Therefore, this study did not compare these two methods. In comparison, spiral CT is an excellent non-invasive technique with high diagnostic accuracy and the ability to perform dynamic observations.

While spiral CT has demonstrated superior ability in visualizing extracardiac vascular malformations due to its high spatial resolution and ability to reconstruct 3D images, echocardiography remains the go-to modality for assessing dynamic cardiac function and real-time evaluation of intracardiac abnormalities. The strengths of each modality are best realized when used in conjunction, with CT providing detailed anatomical information and echocardiography offering a functional overview, especially in pediatric patients where minimizing invasive procedures is paramount.[18] Spiral CT outperforms echocardiography in detecting extracardiac vascular malformations, largely due to its superior spatial resolution, ability to generate detailed 3D reconstructions, and its effectiveness in visualizing anatomical structures that may be obscured by bone or air in echocardiography. This is particularly critical when dealing with complex congenital vascular anomalies, which are difficult to assess with the limited acoustic window of ultrasound. Furthermore, the ability of CT to visualize the entire vascular system in a single scan without relying on operator skill enhances its diagnostic accuracy in these cases.

Children with congenital heart disease often present with symptoms of rapid heart rate and rapid breathing, which can easily result in significant motion and respiratory artifacts on conventional equipment. However, multi-slice spiral CT

devices have fast scanning speeds, allowing image acquisition within one cardiac cycle, and they possess high spatial resolution, enabling clear visualization of the anatomical structure of the cardiac great vessels. Moreover, due to the continuous beating of the heart, CT cardiac imaging requires high temporal resolution to reduce artifacts caused by high heart rates and arrhythmias.[17,19] Cardiac CT can capture images within one cardiac cycle, achieving high-quality artifact-free imaging under conditions of free breathing and rapid heart rates. Combined with similar studies, it is known that multi-slice spiral CT has characteristics such as rapid scanning speed, wide scanning range, high temporal and spatial resolution, as well as being non-invasive, convenient, and safe, making it one of the most promising and valuable methods in non-invasive cardiovascular examination.[20,21] Similar studies have demonstrated the effectiveness of spiral CT in the diagnosis of congenital heart disease. For example, a study by Shiraishi[6] reported that CT significantly improved the detection of extracardiac vascular malformations in pediatric CHD patients, particularly in cases where echocardiography was inconclusive due to limited imaging quality. These findings support the results of the present study, further highlighting the role of CT as an invaluable tool in the comprehensive assessment of CHD.

While spiral CT is considered a safe imaging modality, it is essential to acknowledge the potential risks associated with radiation exposure, particularly in pediatric patients who are more sensitive to radiation. To minimize these risks, modern CT technologies, such as the 128-slice CT used in this study, utilize low-dose protocols that significantly reduce radiation exposure while maintaining high diagnostic accuracy. Additionally, careful selection of scan parameters and limiting unnecessary imaging help ensure that radiation exposure is kept to a minimum. It is important to balance the diagnostic benefits of CT with these safety considerations, particularly in pediatric populations.[22]

Multi-slice spiral CT angiography can complete a full chest scan in a single breath-hold, with a scan time usually not exceeding 30 seconds, and most children can tolerate this examination process. Furthermore, multi-slice spiral CT can simultaneously display the positions of the heart, extracardiac great vessels, trachea, bronchi, as well as the liver and spleen, which is of significant importance for segmental analysis of complex congenital heart diseases. For uncooperative children, scanning can be performed while they are asleep, and due to the short scan time and the difficulty of waking the child during the examination process, it is significantly more operator-friendly than echocardiography and is more easily accepted by the child's family. Especially in this study, the spiral CT used was the high-end 128-slice CT from GE, the Optima CT660 (128T). It achieves improved image quality by using lower radiation doses and equipment consumption while supporting the application of four-dimensional imaging technology. Compared to traditional 128-slice CT scans, which often encounter technical issues with inconsistent temporal, spatial, and density resolutions in cardiac imaging, this innovative technology achieves "three rates in one". This means that it can achieve high levels of temporal, spatial, and density resolutions in the same scan, accurately displaying the structure of the cardiac great vessels, microvessels, and stent details, and providing clear visualization of low-density contrast tissues, such as coronary soft plaques. Additionally, under conditions of high heart rates, it can almost guarantee a 100% examination success rate. This not only improves the success rate of cardiac examinations but also greatly enhances the diagnostic accuracy of cardiac examinations, corroborating the results of this study.

However, there are still some limitations in this study, such as the observation and analysis being limited to a small number of patients, potential limitations in the study design leading to insufficient persuasive power of the study conclusions, possible methodological shortcomings or limitations in data analysis, and potential biases or confounding factors that were not considered, affecting the objectivity and reliability of the study results. Therefore, improvements and enhancements are needed in future research to increase the credibility and practical value of the study conclusions.

Conclusion

Spiral CT is a high-resolution, fast, and non-invasive imaging technique that offers detailed anatomical visualization and is particularly useful in the diagnosis of congenital heart disease in children. It provides clear imaging of complex cardiac structures and spatial relationships between lesions, making it a valuable tool for cases that require rapid, accurate diagnosis and intervention. While the results of this study suggest that spiral CT may be superior to echocardiography in detecting extracardiac vascular malformations and overall cardiovascular anomalies, it is important to note that echocardiography remains a crucial diagnostic tool, especially for its real-time, dynamic capabilities and non-invasive nature.

The complementary use of both imaging methods could enhance diagnostic accuracy, particularly in complex cases. However, further large-sample, multicenter studies are needed to validate the clinical utility of spiral CT and to confirm

its role in the early diagnosis and treatment of congenital heart disease in pediatric patients. This would provide more robust evidence for integrating spiral CT into clinical.

Data Sharing Statement

All data generated or analysed during this study are included in this published article.

Ethics and Consent Statements

This study was approved by the ethics committee of Children's Hospital of Soochow University. Informed consent was obtained from all study participants. All the methods were carried out in accordance with the Declaration of Helsinki.

Funding

There is no funding to report.

Disclosure

The authors declare that they have no competing interests in this work.

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