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Original Article

Comprehensive Evaluation of Tetralogy of Fallot: Superior Diagnostic Performance and Clinical Utility of MDCT Compared to Echocardiography

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Abstract

Objective: To assess the diagnostic accuracy, incremental value, and clinical impact of multi-detector computed tomography (MDCT) in patients with Tetralogy of Fallot compared with echocardiography.

Methodology: This Cross-sectional analytical study was conducted in the Department of Pediatric Cardiology, MTI, Hayatabad Medical Complex, Peshawar, Pakistan, from January 2024 to December 2025. We enrolled 182 patients with Tetralogy of Fallot. We performed transthoracic echocardiography and contrast-enhanced MDCT on all patients. We evaluated diagnostic performance using sensitivity, specificity, and predictive values against surgical or multidisciplinary consensus. We also considered incremental diagnostic value and clinical impact on management decisions.

Results: MDCT had better sensitivity (96.7%) and specificity (91.2%) than echocardiography (84.6% and 78.4%, respectively). MDCT accurately identified pulmonary artery anatomy in 96.7% of patients, compared with 78.0% on echocardiography. MDCT detected MAPCAs in 50.6% versus 26.4%, coronary anomalies in 25.3% versus 9.9%, and vascular abnormalities in 39.6% versus 18.7%. MDCT showed further clinically significant findings in a significant proportion of cases and influenced surgical or interventional planning in 52.8% of patients, including modification of the operative strategy.

Conclusion: MDCT has better diagnostic and clinical value in the overall evaluation of Tetralogy of Fallot than echocardiography.

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Introduction

One of the most prevalent forms of cyanotic congenital heart disease is known as Tetralogy of Fallot (TOF), which is characterized by a constellation of four anatomical abnormalities: ventricular septal defect, overriding aorta, obstruction of the right ventricular outflow tract, and hypertrophy of the right ventricle [1-3]. Although surgical correction and perioperative care have improved greatly, precise and comprehensive anatomical delineation remains central to optimal surgical planning, risk stratification, and improved long-term outcomes [4]. Historically, echocardiography has been the first-line imaging modality because it is widely available, non-invasive, and can be used to provide real-time functional assessment [5]. Nevertheless, it is usually limited by operator dependence, limited acoustic windows, and suboptimal visualization of extracardiac vascular structures.[6].Multi-detector Computed Tomography (MDCT) has emerged in recent years as a powerful imaging tool, characterized by high spatial resolution, rapid image acquisition, and superior imaging of complex intracardiac and extracardiac anatomy in a single comprehensive examination [7,8]. It is particularly useful in TOF, where accurate evaluation of the anatomy of the pulmonary valve, main and branch pulmonary arteries, presence of additional muscular VSD, the major aortopulmonary collateral arteries (MAPCAs), anomalies of the coronary artery, and the associated vascular malformations is crucial to preoperative decision-making and surgical planning [9,10]. In addition, MDCT has shown great benefit in identifying clinically relevant findings that conventional echocardiography may miss and that could change management strategies [11]. Improvements in CT technology such as dose reduction methods and shorter acquisition times have also improved its applicability, even in the pediatric population [12,13]. Despite these benefits, the automatic addition of MDCT to the diagnostic pathway for all TOF patients remains controversial. Concerns about radiation exposure, cost-effectiveness, and the availability of alternative modalities like cardiac magnetic resonance imaging still affect clinical practice. More importantly, strong evidence quantifying the incremental diagnostic yield and clinical outcomes of MDCT over standard echocardiography remains limited, especially regarding its impact on surgical planning and therapeutic decision-making. This uncertainty raises a critical clinical question: does MDCT provide indispensable

information that justifies routine use, or is it a reserve technique for selected cases where conventional imaging is inconclusive?

Materials and Methods

Study Design and Setting

This Cross-sectional analytical study was conducted in the Department of Pediatric Cardiology, MTI, Hayatabad Medical Complex, Peshawar, Pakistan, from January 2024 to December 2025.182 patients diagnosed with Tetralogy of Fallot. We also used a non-probability consecutive sampling method, in which we included all eligible patients presented during the study period. We included patients of any age and gender with a confirmed diagnosis of Tetralogy of Fallot who underwent both transthoracic echocardiography and contrast-enhanced MDCT. The patients with contraindications to contrast-enhanced CT, such as severe renal insufficiency or known contrast allergy, incomplete imaging records, and those who refused participation in the study were excluded.MDCT scans were performed with a multi-slice CT scanner (Toshiba 128 Aquilion) with intravenous contrast injection. We extensively evaluated intracardiac and extracardiac structures, especially the pulmonary artery, major aortopulmonary collateral arteries (MAPCAs), coronary artery anomalies, right ventricular outflow tract obstruction, and associated vascular abnormalities. We regularly used three-dimensional and multiplanar reconstructions to enhance anatomical delineation and improve diagnostic accuracy. Intraoperative findings, where available, were considered the primary reference standard. When surgical information was unavailable, a multidisciplinary team of a Pediatric cardiologist and pediatric cardiac surgeon served as the reference standard for anatomical accuracy. The main findings were the diagnostic accuracy of MDCT compared with echocardiography in terms of sensitivity, specificity, positive predictive value, and negative predictive value. Secondary outcomes included the influence of MDCT findings on surgical or interventional planning, the detection rate of extracardiac vascular anomalies, and interobserver agreement among pediatric cardiologists.The Institutional Review Board of Hayatabad Medical Complex approved the study. All patients or their guardians were informed and provided informed consent before inclusion, and we ensured confidentiality of patient data throughout the study.

Data Collection Procedure

All patients underwent thorough clinical assessment, followed by standardized transthoracic echocardiography and contrast-enhanced MDCT. We collected data using a structured proforma to record demographic and clinical information. Two experienced pediatric cardiologists independently reviewed the MDCT images. Pediatric cardiologists also performed echocardiographic evaluations independently.

Statically Analysis

We checked data using SPSS version 25. We presented continuous variables as mean ± standard deviation and categorical variables as frequencies and percentages. We compared sensitivity, specificity, positive predictive value, and negative predictive value using the diagnostic performance of MDCT and echocardiography against the reference standard of intraoperative findings or multidisciplinary consensus. We used the chi-square test to compare modalities for paired categorical data and the McNemar test. We evaluated interobserver and intermodality agreement using Cohen's kappa statistic. We used a significance level of 0.05 for all analyses.

Results

Table 1 presents the demographic and clinical characteristics of the 182 patients with Tetralogy of Fallot. Most patients were aged ≤10 years (102, 56%), while 61 (33.5%) were 11–20 years and 19 (10.4%) were >20 years. Male patients predominated, with 104 cases (57.14%), whereas females accounted for 78 cases (42.86%). Regarding clinical status, 126 patients (69.23%) were in the preoperative stage of Tetralogy of Fallot, while 56 patients (30.77%) had undergone previous surgical intervention.

Table 1: Demographic and Clinical Characteristics of Patients (n = 182)

Category	Variable	Frequency (n)	Percentage (%)
Age Distribution	≤10 years	102	56
	11–20 years	61	33.6
	>20 years	19	10.4

Gender Distribution	Male	104	57.14
	Female	78	42.86

Table 2: Detection of Key Anatomical Findings (MDCT vs Echocardiography) with Statistical Comparison (n = 182)

Anatomical Parameter	Echo n (%)	MDCT n (%)	p-value
RVOT Obstruction	170 (93.41)	178 (97.80)	0.041
Pulmonary Artery Anatomy	142 (78.02)	176 (96.70)	<0.001
MAPCAs	48 (26.37)	92 (50.55)	<0.001
Coronary Anomalies	18 (9.89)	46 (25.27)	<0.001
Vascular Anomalies	34 (18.68)	72 (39.56)	<0.001

Table 2 compares the detection of key anatomical findings between echocardiography and MDCT. MDCT demonstrated significantly higher detection rates across all parameters. MDCT identified pulmonary artery anatomy in 176 patients (96.70%), compared with 142 (78.02%) on echocardiography (p < 0.001). MDCT identified MAPCAs in 92 patients (50.55%), whereas echocardiography identified them in only 48 (26.37%) (p < 0.001). Similarly, coronary anomalies were diagnosed in 46 patients (25.27%) using MDCT in comparison to 8 (9.89%) by echocardiography (p < 0.001).

Table 3: Incremental Diagnostic Yield of MDCT (McNemar Test Analysis)

Finding	Discordant Pairs (MDCT positive / Echo negative)	p-value (McNemar)
MAPCAs	44	<0.001
Coronary anomalies	28	<0.001
Pulmonary artery abnormalities	34	<0.001
Other vascular anomalies	38	<0.001

Table 3 demonstrates the incremental diagnostic yield of MDCT using McNemar test analysis. MDCT detected a significant number of lesions not detected by echocardiography, including MAPCAs in 44 cases, coronary anomalies in 28 cases, pulmonary artery anomalies in 34 cases, and other vascular anomalies in 38 cases. The p-value for all

comparisons was <0.001, which is statistically significant and confirms the superior diagnostic contribution of MDCT over echocardiography.

Table 4: Diagnostic Accuracy of MDCT vs Echocardiography (Reference: Surgical/Consensus Standard)

Modality	Sensitivity (%) [95% CI]	Specificity (%) [95% CI]	PPV (%)	NPV (%)
Echocardiography	84.62 (79.1–89.0)	78.43 (72.0–83.8)	88.25	72.09
MDCT	96.70 (93.2–98.6)	91.18 (86.5–94.6)	94.62	93.55

Table 4 below shows that MDCT and echocardiography differ in accuracy based on surgery and multidisciplinary consensus. In terms of sensitivity, MDCT was more accurate at 96.70% (95% CI: 93.2-98.6) than echocardiography, which had a sensitivity of 84.62% (79.1-89.0). Furthermore, specificity was higher for MDCT (98.65- 94.6%) compared to echocardiography, with a specificity of 78.43% 8.43% ((72.0–83.8). Moreover, MDCT showed better predictive values (PPV 94.62% and NPV 93.55%), making it a more reliable diagnostic tool.

Figure 1: Impact of MDCT on Surgical/Interventional Planning

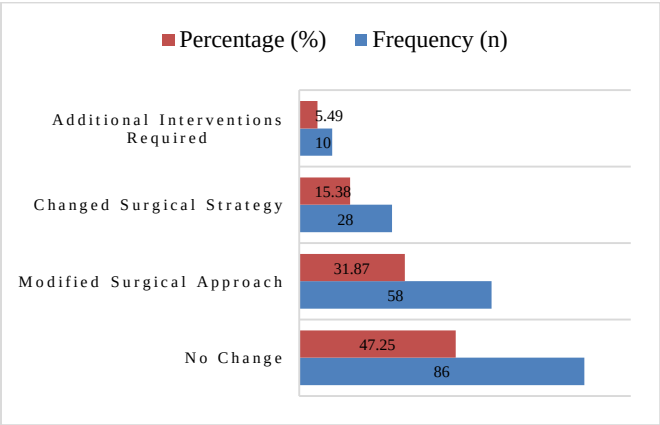


Figure 1 illustrates MDCT's impact on surgical and interventional planning. MDCT resulted in no change in management in 86 patients (47.25%), while 58 patients (31.87%) required modification of surgical approach. A change in surgical strategy was observed in 28 patients (15.38%), and 10 patients (5.49%) required additional interventions. Overall, MDCT influenced clinical decision-making in 52.75% of cases.

Figure 2: Interobserver Agreement for MDCT Findings

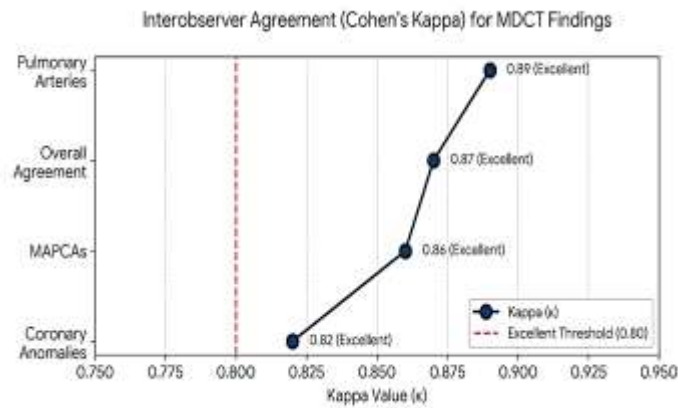


Figure 2 presents interobserver agreement for MDCT findings using Cohen's kappa statistics. Excellent agreement was observed for pulmonary artery assessment ($\kappa = 0.89$), MAPCAs detection ($\kappa = 0.86$), and coronary anomalies ($\kappa = 0.82$). Overall interobserver agreement was also excellent ($\kappa = 0.87$), indicating high reproducibility of MDCT interpretation.

Figure 3: MDCT Image Quality and Diagnostic Adequacy

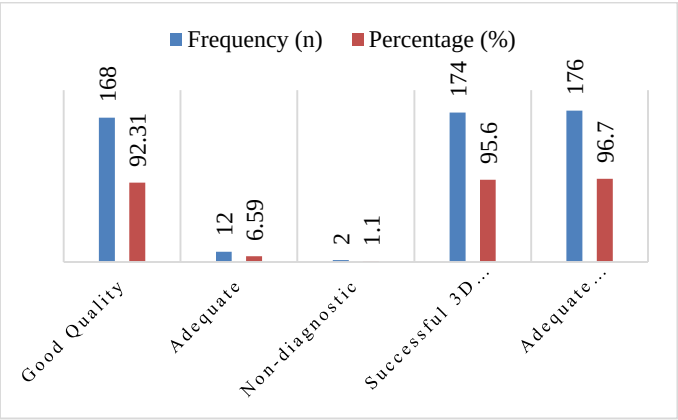


Figure 3 below shows MDCT image quality and diagnostic adequacy. Imaging quality was good in 168 patients (92.31%). In 12 cases (6.59%), image quality was adequate, and in 2 cases (1.10%), the images could not be used for diagnosis. The 3-D reconstruction was successfully done in 174 patients (95.60%). Adequate extracardiac imaging was achieved in 176 patients (96.70%), thereby confirming the reliability of the MDCT technique.

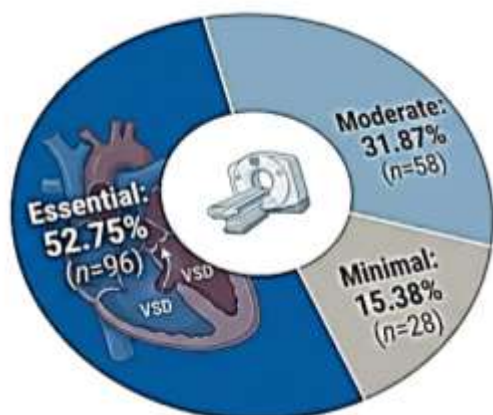
Figure 4: Overall Clinical Utility of MDCT

Figure 4 below depicts the clinical utility of MDCT in patients with Tetralogy of Fallot. MDCT made an essential diagnostic contribution in 96 (52.75%) patients, a moderate contribution in 58 (31.87%), and a minimal contribution in 28 (15.38%), underscoring its importance in clinical decision-making.

Discussion

In the current study, MDCT showed better diagnostic results in Tetralogy of Fallot (TOF) patients, with sensitivity of 96.70% and specificity of 91.18%, compared with echocardiography sensitivity of 84.62% and specificity of 78.43%. These results suggest MDCT provides greater anatomical clarity in complicated congenital heart disease. Previous research reported similar high diagnostic accuracy and found MDCT superior for delineating extracardiac anatomy and surgical-relevant structures in TOF patients, especially the pulmonary arteries and collateral vessels, supporting its complementary role in preoperative evaluation [14,15]. Pulmonary artery anatomy was detected significantly more often with MDCT (96.70%) than with echocardiography (78.02%, $p < 0.001$). This is in line with earlier results, which have reported that MDCT is superior in assessing the morphology of the pulmonary arteries and supravalvular stenosis, with kappa of up to 0.6-0.8 in cases of TOF [16,17]. The improved imaging in our study also confirms MDCT's superiority for spatial reconstruction of the complex anatomy of the right ventricular outflow tract. For MAPCAs, we found a 50.55% detection rate with MDCT versus 26.37% with echocardiography, with an additional 44 cases ($p < 0.001$). These results align with the previous study, which noted that

MDCT provides detailed mapping of MAPCA origin, distribution, and stenosis, which is usually underestimated on echocardiography [18,19]. This supports using MDCT in surgical planning, particularly for complex TOF variants with pulmonary atresia. In our cohort, coronary artery anomalies were identified in 25.27% of patients on MDCT as compared to 9.89% on echocardiography. Taha et al. (2022) reported similar trends and showed that MDCT significantly improves the identification of abnormal coronary courses, which is crucial for preventing intraoperative complications during TOF repair [20]. Our higher detection rate reinforces MDCT's superiority in coronary mapping. Clinically, MDCT changed surgical or interventional planning in 52.75% of cases, including 15.38% that required significant change in surgical or interventional strategy. A previous study reported similar results, finding that MDCT influenced operative decisions in more than half of TOF patients by revealing vascular and extracardiac anomalies not seen on echocardiography [21]. This supports its use as a decision-modifying imaging modality. In our study, interobserver agreement was excellent, with Cohen's kappa values of 0.82-0.89, especially for the pulmonary arteries and MAPCAs. Previous studies have reported similar high reproducibility of CT angiography for consistent and reliable assessment of pulmonary and coronary anatomy in pediatric TOF patients [22]. This reliability also supports the diagnostic reliability of MDCT in the normal routine clinical practice. This study has several strengths that contribute to its reliability and clinical relevance. This is a relatively strong analytical design of 182 Tetralogy of Fallot (TOF) patients: a prospective cross-sectional analytical design with a relatively high level of statistical power. Observer bias was reduced by having two independent Pediatric cardiologists interpret the images separately, and diagnostic validation was enhanced by including a multidisciplinary reference standard (surgical findings or expert consensus) [23]. The study also provided a multidimensional analysis of MDCT performance using comprehensive statistical methods, including the McNemar test, Cohen's kappa, and diagnostic accuracy measures (sensitivity, specificity, PPV, NPV). It also evaluated, in addition to anatomical detection, the real-world clinical impact on surgical decision-making (52.75% of cases influenced), and the findings were therefore highly applicable to clinical practice. Nevertheless, several limitations warrant consideration. As a single-center study, the findings may be difficult to generalize to other populations and healthcare settings. The lack of universal surgical confirmation in all cases creates the potential for verification bias, since some diagnoses

were based on multidisciplinary consensus rather than findings during surgery. Also, the radiation exposure associated with MDCT was not quantitatively assessed, and long-term effects following MDCT-guided management changes were not measured. Lastly, although standard, using echocardiography as the comparator may undervalue its performance in highly specialized centers.

Conclusion

Multi-detector computed tomography (MDCT) shows unequivocal superiority over conventional echocardiography for overall anatomical evaluation of Tetralogy of Fallot, especially for defining complex intracardiac and extracardiac structures such as the pulmonary arteries, coronary anatomy, and major aortopulmonary collateral vessels. Its high-resolution, three-dimensional visualization makes it highly beneficial for increasing diagnostic confidence and identifying clinically relevant findings that could be missed on echocardiography. Incorporating MDCT into the diagnostic pathway significantly impacts surgical and interventional decision-making and, ideally, preoperative planning for a significant proportion of patients. In general, MDCT can be a most valuable adjunct imaging modality in Tetralogy of Fallot, particularly where detailed anatomical characterization is critical to optimal management.

Ethical Approval

Ethical approval for this study was obtained from the **Hospital Research and Ethics Committee (IREB), MTI-Hayatabad Medical Complex**, under **Doc. No. 2632**, dated **07 August 2023**, before the study began.

Informed Consent

We obtained written informed consent from all participants before enrollment. Participants and their parents/guardians were informed about the study purpose and procedures, and participation was voluntary.

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This study received no external funding. The research used available institutional resources.

Conflict of Interest

The authors declare that they have no competing interests or conflicts of interest related to this study.

Authors' Contributions

Ziaullah: Conceptualization, study design, data collection, interpretation of findings, manuscript drafting, critical revision of the manuscript, final approval of the version to be published, and accountability for all aspects of the work.

Kamran Khattak: Study design, data collection, data curation, literature review, interpretation of data, manuscript revision, final approval of the version to be published, and accountability for all aspects of the work.

Tayyaba: Conceptualization, study supervision, clinical assessment, interpretation of findings, critical revision of the manuscript for important intellectual content, final approval of the version to be published, and accountability for all aspects of the work.

All authors: Reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work in accordance with ICMJE authorship criteria.

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