Int Cardiovasc Res J. 2025 December; 19(1): e159848 https://doi.org/10.5812/icrj-159848

Published Online: 2025 August 9 **Research Article**

Evaluating Diagnostic Accuracy: A Comparison of Echocardiography and Catheterization in Determining Nakata and McGoon Indices for Surgical Management of Tetralogy of Fallot

Feisal Rahimpour [1], Elahe Heidari [2], Nazanin Moavenzadeh Ghaznavi [3], Lida Jarahi [4,5], Mozhgan Mansoorian [6,*]

[1] Pediatric Cardiologist, Interventional Electrophysiologist, Pediatric and Congenital Cardiology Division, Pediatric Department, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran
[2] Department of Pediatric Cardiology, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran
[3] Congenital and Pediatric Cardiology Division, Department of Pediatric, Imam Reza Hospital, Mashhad University of Medical Sciences, Mashhad, Iran
[4] Medical Genetics Research Center, Mashhad University of Medical Sciences, Mashhad, Iran
[5] Community Medicine Department, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran
[6] Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran

[*] ***Corresponding Author:*** Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran. Email: mozhgan.mansoorian@yahoo.com

Received: 29 January, 2025; **Revised:** 10 June, 2025; **Accepted:** 3 August, 2025

Abstract

Background: A key factor in deciding the surgical approach and predicting outcomes for tetralogy of Fallot (ToF) is the size of the pulmonary arteries.

Objectives: The present study aims to compare the diagnostic accuracy of echocardiography with catheterization by calculating Nakata and McGoon indices for surgical decision-making in patients with ToF.

Methods: This analytical epidemiological study, using a purposive (non-random) sampling method, was conducted on 120 patients with ToF. The patients underwent angiography and echocardiography. Subsequently, the Nakata and McGoon indices were calculated. Statistical analysis included both descriptive (frequency, mean, median, and interquartile range) and inferential methods. The Wilcoxon signed-rank test was used for comparing paired non-parametric measurements, and Spearman's rank correlation was used to evaluate the strength of association between imaging modalities. A P-value < 0.05 was considered statistically significant.

Results: A significant correlation was found between the results of echocardiography and angiography (P = 0.009). A statistically significant positive correlation was observed for the right pulmonary artery (RPA) (rho = 0.418; P = 0.004), descending aorta (rho = 0.652; P = 0.041), and cross-sectional area of the right pulmonary artery (CSA-R) (rho = 0.418; P = 0.004). No significant correlation was found for the McGoon ratio (rho = 0.067; P = 0.855) or for left pulmonary artery (LPA) and cross-sectional area of the left pulmonary artery (CSA-L) measurements.

Conclusions: In patients with ToF, echocardiography alone may not be sufficient for definitive surgical decision-making. While echocardiography remains a safe, accessible, and cost-effective modality, its limitations necessitate the use of cardiac catheterization when precise anatomical measurements are required. However, in cases where echocardiographic images are unclear or equivocal, other methods such as CT angiography should be considered.

Keywords: Echocardiography, McGoon Ratio, Cardiac Catheterization, Tetralogy of Fallot, Nakata Index

1. Background

Tetralogy of Fallot (ToF) is the most common form of cyanotic congenital heart disease, occurring in approximately 3.26 cases per 10,000 live births and representing up to 10% of all congenital heart defects. It is characterized by four key anatomical features:

How to Cite: Rahimpour F, Heidari E, Moavenzadeh Ghaznavi N, Jarahi L, Mansoorian M. Evaluating Diagnostic Accuracy: A Comparison of Echocardiography and Catheterization in Determining Nakata and McGoon Indices for Surgical Management of Tetralogy of Fallot. Int Cardiovasc Res J. 2025; 19 (1): e159848. https://doi.org/10.5812/icrj-159848.

Obstruction of the blood flow pathway to the lungs (infundibular pulmonary stenosis), ventricular septal defect (VSD), an overriding aortic root, and right ventricular hypertrophy. While cyanosis, the hallmark of ToF, may not be apparent during the neonatal period, it typically manifests as a right-to-left shunt develops. Additional symptoms include heart murmur, hypercyanotic episodes (known as "tet spells"), tachypnea, feeding-related diaphoresis, feeding intolerance, and poor weight gain. The severity of symptoms depends on the degree of obstruction to pulmonary blood flow (1).

The first surgical repair of ToF was reported by Lillehei et al. in 1955 (2). Since then, optimal surgical management has remained a topic of discussion. While many centers prefer performing a complete repair in a single stage, others favor a two-stage method that begins with shunt insertion and is followed by complete surgical correction at a later time (3). One of the most critical factors in determining surgical strategy and predicting outcomes such as mortality rate or the need for reoperation (4, 5) is the growth and size of the pulmonary arteries (4). Smaller pulmonary arteries have been associated with a higher risk of adverse surgical outcomes (5). Consequently, several methods and indices have been developed to quantify pulmonary artery dimensions (6, 7).

The McGoon ratio is one such index, measuring the sum of the diameter of the largest pulmonary artery branches at the pre-branching point relative to the diameter of the descending aorta at the diaphragm level. It can be obtained via cardiac catheterization (8). The Nakata Index, introduced by Nakata et al., represents the sum of the cross-sectional areas (CSAs) of the pulmonary arteries divided by body surface area (BSA) (6, 9). This Index can be assessed using computed tomography (CT) (8), echocardiography (10), or cardiac catheterization (6).

Although cardiac catheterization remains the gold standard for hemodynamic evaluation, it is an invasive procedure requiring imaging from various angles using contrast agents (11). For this reason, researchers are exploring alternatives, like echocardiography, which is the most common, noninvasive, and accessible imaging method for assessing congenital heart diseases (12). Recent advancements in echocardiography have significantly enhanced its utility as a primary diagnostic tool in the management of patients with ToF. Echocardiography, particularly advanced techniques such as 3D echocardiography, strain imaging, and intraoperative echocardiography, has improved the ability to assess cardiac anatomy and function in real-time (13).

For instance, Hamza et al. investigated the reliability of echocardiography in assessing the status of pulmonary blood flow in children with ToF, comparing it with measurements obtained via catheterization and during surgery. They concluded that it may be feasible to proceed with surgery — whether shunt creation or complete repair — based on echocardiography alone, given the risks, costs, and long waitlists associated with catheterization (14). However, the accuracy of echocardiography results is highly dependent on the skill of the operator and can also be affected by factors such as air or bone interference (11).

2. Objectives

Despite findings supporting the use of echocardiography as an alternative to cardiac catheterization, the present study aims to compare the diagnostic accuracy of echocardiography and catheterization, using Nakata and McGoon indices to guide surgical decision-making in patients with ToF.

3. Methods

3.1. Study Design

This was an analytical epidemiological study conducted to assess the diagnostic value of echocardiographic and angiographic (catheter-based) measurements in patients with ToF.

3.2. Study Population and Setting

The study was conducted at Imam Reza Hospital in Mashhad, Iran. Participants included patients diagnosed with ToF who were referred for cardiac evaluation and treatment.

3.3. Sampling Method and Sample Size

Participants were selected through a purposive (non-random) sampling method. The sample size was calculated based on an expected sensitivity of 60% for echocardiography, as referenced in prior studies by Rao et al. (15) and Raval et al. (16). Using a significance level (α) of 0.05 and a margin of error (d) of 0.12, the minimum required sample size was determined to be 65. Ultimately, 120 patients were enrolled.

3.4. Inclusion Criteria

- Patients with a confirmed diagnosis of ToF who presented to Imam Reza Hospital, Mashhad, Iran, to determine the treatment method.

3.5. Exclusion Criteria

- Refusal of participation by the patient or legal guardians
- Presence of additional congenital anomalies besides ToF

3.6. Data Collection Procedures

3.6.1. Cardiac Catheterization Assessment

Cardiac catheterization was performed first. Pulmonary artery branch diameters were measured in the anteroposterior (AP)/cranial view, while the descending aorta was measured in the AP view.

3.6.2. Echocardiographic Assessment

Echocardiography was performed within one week of cardiac catheterization using a Philips EPIQ 7c ultrasound system (Philips Healthcare, Bothell, WA, USA). Measurements of the right and left pulmonary arteries and the descending aorta (at the diaphragm level) were obtained in both parasternal and suprasternal views. All procedures were conducted by two experienced pediatric cardiologists.

3.7. Index Definitions and Calculations

Based on the measurements obtained, the Nakata and McGoon indices were calculated:

- McGoon Ratio = (Diameter of RPA + LPA)/Diameter of the descending aorta
- Nakata Index = (CSA of RPA + LPA)/BSA

All measurements from cardiac catheterization were analyzed using SPSS software (version 16, Chicago, IL, USA, 2007). Z-scores were applied where appropriate.

3.7.1. Cut-off Values

- McGoon Ratio (17):
- ≥ 2.1: Normal
- 1.2 - 2.1: Adequate for ToF repair
- ≤ 0.8: Inadequate for complete repair
- Nakata Index: As studies have suggested different cut-off values (6, 8, 17-19), this study adopted the following thresholds:
- > 180 mm^2/m^2: Normal
- ≤ 180 mm^2/m^2: Abnormal

3.8. Statistical Analysis

Although 120 patients were initially enrolled in the study, certain parameters could not be measured in all cases due to existing limitations. For example, complete cardiac catheterization data were only available for 63 individuals. Nevertheless, the available data were analyzed and reported accordingly. Statistical analysis included both descriptive and inferential methods:

3.8.1. Descriptive Statistics

Frequency, mean, median, and interquartile range were reported. Due to non-normal data distribution, medians were emphasized.

3.8.2. Analytical Statistics

- The Wilcoxon signed-rank test was used for comparing paired non-parametric measurements (echocardiography vs. catheterization).
- Spearman's rank correlation was used to evaluate the strength of association between imaging modalities.
- A P-value < 0.05 was considered statistically significant.

4. Results

A total of 120 patients with ToF were enrolled in the study. Of these, 63 (52.5%) were male and 57 (47.5%) were female. Age of patients ranged from 10 months to 24 years, with a mean age of 3.41 ± 4.39 years. Body weight ranged from 2.1 to 65.0 kg, with a mean of 12.00 ± 10.72 kg. Demographic data are summarized in Table 1.

The diameters of the right and left pulmonary arteries and the diameter of the aorta were measured using both echocardiography and cardiac catheterization. Measurements of the left and right cross-sectional areas (CSA-L and CSA-R) were also recorded. The results are presented in Table 2.

The McGoon ratio and Nakata Index were calculated using data from both imaging modalities.

In the next step, patients were classified into normal and abnormal groups based on defined cut-off values

Table 1. Demographic Characteristics of Participants with Tetralogy of Fallot

Descriptive Statistics	Valid (No.)	Range	Mean ± SD
Body weight (kg)	93	2.10 - 65.00	12.00 ± 10.72
Age (y)	116	0.10 - 24.00	3.41 ± 4.39

Table 2. Pulmonary Artery and Aortic Measurements via Echocardiography and Cardiac Catheterization of Participants

Parameters	Echocardiography Parameters Measurements						Cardiac Catheterization Parameters Measurements					
	Valid (No.)	Missing	Minimum	Median	Maximum	Mean ± SD	Valid (No.)	Missing	Minimum	Median	Maximum	Mean ± SD
LPA size (mm)	95	25	2.00	6.00	25.00	6.72 ± 3.59	63	57	2.20	9.20	24.00	10.06 ± 5.18
RPA size (mm)	89	31	0.60	6.40	28.00	6.93 ± 4.11	63	57	1.70	8.80	19.00	9.66 ± 4.12
Descending aorta size (mm)	18	102	3.00	6.40	10.00	6.66 ± 1.79	63	57	5.60	8.09	24.00	9.10 ± 3.06
CSA-L	95	25	3.14	28.26	490.63	45.55 ± 62.89	63	57	3.80	66.44	452.16	100.32 ± 106.52
CSA-R	89	31	0.28	32.15	615.44	50.87 ± 87.26	63	57	2.27	60.79	283.39	86.50 ± 68.70

Abbreviations: LPA, left pulmonary artery; RPA, right pulmonary artery; CSA-L, left cross-sectional area; CSA-R, right cross-sectional area.

Table 3. McGoon Ratio and Nakata Index Measurements via Echocardiography and Cardiac Catheterization

Measurements Methods	McGoon Ratio Measurements		Nakata Index Measurements	
	Range	Mean ± SD	Range	Mean ± SD
Echocardiography	0.71 - 2.95	1.67 ± 0.51	7.95 - 1106.07	96.70 ± 145.89
Catheterization	0.42 - 4.20	2.19 ± 0.72	12.35 - 735.55	186.82 ± 156.36

for both indices. The distribution is shown in Table 4.

A Wilcoxon signed-rank test revealed a statistically significant difference between values obtained via echocardiography and cardiac catheterization ($P = 0.009$). Spearman's rank correlation was used to assess agreement between methods. Results are summarized in Table 5.

A statistically significant positive correlation was observed for RPA ($\rho = 0.418$; $P = 0.004$), descending aorta ($\rho = 0.652$; $P = 0.041$), and CSA-R ($\rho = 0.418$; $P = 0.004$). No significant correlation was found for the McGoon ratio ($\rho = 0.067$; $P = 0.855$) or for LPA and CSA-L measurements.

5. Discussion

Echocardiography and cardiac catheterization have been used to evaluate congenital heart diseases (20). Echocardiography is often recognized as the primary diagnostic modality due to its widespread availability, ease of use (12), and ability to visualize cardiac structures and estimate cardiac hemodynamics (21). This study aimed to compare the diagnostic accuracy of echocardiography versus cardiac catheterization by assessing two established indices, the Nakata Index and the McGoon ratio, for surgical decision-making in patients with ToF.

Our findings demonstrated that echocardiographic measurements of the right and left pulmonary arteries and the descending aorta were consistently lower than those obtained through cardiac catheterization (Table 2). Kumar et al. evaluated the reliability and correlation between findings of echocardiography and cardiac catheterization, considered a mandatory test for planning surgical or transcatheter interventions to assess pulmonary vascular dimensions, in 54 patients aged 3 - 34 years with ToF. They found that pulmonary vascular parameters assessed by echocardiography were significantly lower than those measured by cardiac catheterization, reaffirming the greater accuracy of catheter-based evaluation in this setting. However, due to its accessibility, non-invasive nature, and acceptable

Table 4. Classification of McGoon and Nakata Indices in Cardiac Catheterization and Echocardiography for Participants

Index	McGoon Index in Cardiac Catheterization	McGoon Index in Echocardiography	Nakata index in Cardiac Catheterization	Nakata Index in Echocardiography
Normal	31 (49.2)	2 (11.1)	24 (38.1)	8 (9.3)
Abnormal	32 (50.8)	16 (88.9)	39 (61.9)	78 (90.7)
Total	63 (100)	18 (100)	63 (100)	86 (100)

diagnostic correlation with cardiac catheterization findings, they recommended echocardiography as a screening tool, emphasizing that definitive surgical decision-making should rely on scientific evidence rather than expert opinion alone (22).

Similarly, Hamza et al. investigated two-dimensional echocardiography for assessing pulmonary blood flow in 18 children with ToF and found that echocardiographic measurements of the RPA and LPA diameters were lower than those obtained through cardiac catheterization (14), further supporting our results in Table 2. The relatively smaller values obtained by echocardiography may be influenced by various factors, including operator experience, limited acoustic windows, the inherent hypoplastic tendency of the pulmonary vessels in ToF, and anatomical challenges such as angulation of the LPA (22).

In our study, the McGoon Index values and the proportion of patients classified as "normal" (McGoon ratio > 2.1) were higher when calculated from catheterization data than from echocardiographic measurements, consistent with the generally larger diameters observed on cardiac catheterization. Also, analysis of the Nakata Index revealed that cardiac catheterization identified 24 out of 63 patients (38.1%) as having normal pulmonary artery size. In comparison, echocardiography identified only 8 out of 86 patients (9.3%) in the normal range (Table 4). This discrepancy may partly result from the mathematical nature of the Nakata Index, which is calculated from the cross-sectional area of pulmonary arteries based on squared vessel diameters. Consequently, small underestimations in diameter, more likely in echocardiography due to its acoustic and technical limitations, can lead to disproportionately large reductions in the calculated index.

While this is a known mathematical principle, our findings align with those of Kumar et al., who similarly observed that Nakata Index values derived from echocardiography were significantly lower than those from catheterization (22). Our findings revealed a statistically significant correlation between echocardiographic and cardiac catheterization results (P = 0.009). This result suggests that echocardiography alone may not provide accurate measurements of pulmonary artery size or reliable calculations of the Nakata and McGoon indices.

According to Kumar et al.'s study, pulmonary vascular indices differed between echocardiography and cardiac catheterization but showed a statistically significant correlation. Although the data confirmed the superiority of cardiac catheterization over echocardiography in ToF, the strong diagnostic correlation and benefits of echocardiography as a cheap, accessible, and non-invasive method support its application as a screening tool within the evaluated population. This approach supports surgical decision-making in ToF based on scientific evidence rather than solely on expert opinion (22). This is consistent with the correlation between echocardiographic and catheterization measurements of the present study, which showed that while significant correlations were observed for parameters such as RPA, CSA-R, and the descending aorta, others, including LPA and the McGoon ratio, did not show statistically meaningful agreement between the two imaging modalities. Therefore, echocardiography may serve as a useful screening tool, but cardiac catheterization remains more accurate, particularly when precise vascular sizing is required for surgical decision-making.

However, some other studies have also reported a high diagnostic correlation between echocardiography and angiocardiography results, recommending that surgical decisions in uncomplicated ToF cases can be based on echocardiography alone, without the need for cardiac catheterization (14, 21, 23). Echocardiography has limitations, including limited field of view, variable acoustic windows, difficulty penetrating bone and air, challenges in visualizing extracardiac structures (20), and dependence on operator skill (11). Furthermore, as Apostolopoulou et al. (24) and Haramati et al. (20) pointed out, echocardiographic image quality tends to

Table 5. Correlation Between Echocardiographic and Cardiac Catheterization Measurements

Variable Pair (Echo vs. Cath)	Spearman's ρ	P-Value
LPA	0.236	0.114
RPA	0.418	0.004 [a]
Descending aorta	0.652	0.041 [a]
McGoon ratio	0.067	0.855
CSA-L	0.236	0.114
CSA-R	0.418	0.004 [a]

Abbreviations: LPA, left pulmonary artery; RPA, right pulmonary artery; CSA-L, left cross-sectional area; CSA-R, right cross-sectional area.

[a] Correlation at $P < 0.05$ is considered statistically significant.

decline with patients' age, especially in those who have undergone prior cardiac surgery.

Cardiac catheterization is invasive and carries risks such as hematoma, vascular injury, renal impairment, contrast reactions, radiation exposure, and a very low but notable mortality risk. For these reasons, there has been growing interest in non-invasive methods such as echocardiography and cardiac magnetic resonance (CMR) in recent years (24). However, cardiac catheterization remains a key diagnostic tool in the management of congenital heart disease, as it provides essential hemodynamic data and allows for a more detailed assessment of vascular anatomy (20, 24).

We only compared measurements of pulmonary artery branches and the aortic diameter in echocardiography and cardiac catheterization to determine McGoon and Nakata indices. While our study's results were consistent with some previous studies, there were notable differences, particularly in not supporting some studies' recommendation to rely solely on echocardiography for surgical decision-making in these patients. Due to echocardiography's lower complication rate and its modest correlation with cardiac catheterization for certain indices, we especially recommend using echocardiography for screening. However, this study's findings suggest that echocardiography alone may not accurately determine the size of the pulmonary branches, and consequently, the Nakata and McGoon indices.

5.1. Conclusions

In patients with ToF, echocardiography alone may not be sufficient for definitive surgical decision-making. While echocardiography remains a safe, accessible, and cost-effective modality, its limitations necessitate the use of cardiac catheterization when precise anatomical measurements are required. However, in cases where echocardiographic images are unclear or equivocal, other methods such as CT angiography should be considered.

5.2. Limitations

Our study had limitations. First, the use of a non-random, purposive sampling method and the lack of blinding of the researchers who performed echocardiography and measured the parameters may limit the generalizability of the findings. Although the calculated minimum sample size was initially set at 65, a total of 120 participants were enrolled to enhance the study's statistical power. However, in some sections, data were incomplete for a few participants due to various reasons such as lack of cooperation, particularly among younger children, which led to a reduced sample size for certain measurements. Additionally, the wide age and weight range of participants may have affected imaging quality, particularly in older and heavier patients, who often presented with suboptimal acoustic windows in this study. Finally, the study did not include advanced imaging modalities such as CMR, which may provide more detailed and reproducible assessments of pulmonary artery anatomy. Future research should address these limitations by adopting randomized sampling strategies, incorporating blinding protocols, and including larger, stratified patient populations. Comparative studies that integrate CMR or CT angiography may also improve diagnostic accuracy and validate echocardiographic findings more robustly.

Footnotes

Authors' Contribution: F. R. had the idea for the study. F. R. and E. H. contributed to the design, the conduct of the study, and the recruitment of patients. N. M. G. contributed to the collection of clinical data. F. R. and E. H. contributed to medical diagnoses consultation. L. J. contributed to clinical data analysis and interpretation. M. M. drafted the report. All authors critically reviewed the manuscript and approved the final version of the draft.

Conflict of Interests Statement: The authors declare no conflict of interests.

Data Availability: The datasets used and analyzed during the present study are available from the corresponding author upon reasonable request.

Ethical Approval: The present study approved by the Ethics Committee of Mashhad University of Medical Sciences (IR.MUMS.MEDICAL.REC.1401.063).

Funding/Support: The Deputy of Research and Technology at Mashhad University of Medical Sciences financially supported the present study.

Informed Consent: Informed consent was obtained from adult participants and the parents or legal guardians of youth ones for participation in the study.

References

1. Friedman KG, Walsh EP, Geva T. 26 - Tetralogy of fallot. In: Walsh EP, Mayer JE, Teele SA, Brown DW, editors. *Nadas' Pediatric Cardiology (Third Edition)*. Philadelphia, Pennsylvania: Elsevier; 2025. p. 336-50. https://doi.org/10.1016/B978-1-4557-0599-3.00035-1.
2. Lillehei CW, Cohen M, Warden HE, Read RC, Aust JB, Dewall RA, et al. Direct vision intracardiac surgical correction of the tetralogy of Fallot, pentalogy of Fallot, and pulmonary atresia defects; report of first ten cases. *Ann Surg*. 1955;**142**(3):418-42. [PubMed ID: 13249340]. [PubMed Central ID: PMC1465089]. https://doi.org/10.1097/00000658-195509000-00010.
3. Pigula FA, Khalil PN, Mayer JE, del Nido PJ, Jonas RA. Repair of tetralogy of Fallot in neonates and young infants. *Circulation*. 1999;**100**(19 Suppl):II157-61. [PubMed ID: 10567296]. https://doi.org/10.1161/01.cir.100.suppl_2.ii-157.
4. Xiao TT, Chen SB, Sun K, Huang MR, Li F, Guo Y. [Evaluation of the development of pulmonary vessels with pulmonary venous index in congenital heart disease with decreased pulmonary blood flow]. *Zhonghua Er Ke Za Zhi*. 2007;**45**(12):889-92. ZH. [PubMed ID: 18339273].
5. Fontan F, Fernandez G, Costa F, Naftel DC, Tritto F, Blackstone EH, et al. The size of the pulmonary arteries and the results of the Fontan operation. *J Thorac Cardiovasc Surg*. 1989;**98**(5 Pt 1):711-9. discussion 719-24. [PubMed ID: 2811408].
6. Nakata S, Imai Y, Takanashi Y, Kurosawa H, Tezuka K, Nakazawa M, et al. A new method for the quantitative standardization of cross-sectional areas of the pulmonary arteries in congenital heart diseases with decreased pulmonary blood flow. *J Thorac Cardiovasc Surg*. 1984;**88**(4):610-9. [PubMed ID: 6482493].
7. Kovalev DV, Alexandrova SA, Yurlov IA, Zelenikin MM, Aslanidis IP, Podzolkov VP, et al. Pulmonary Venous Index as Additional Diagnostic Criteria for Fontan Palliation. *J Cardiac Surg*. 2024;**2024**(1). https://doi.org/10.1155/2024/5599994.
8. Abbaszadeh R, Askari-Moghadam R, Moradian M, Mortazaeian H, Qomi MRS, Omidi N, et al. The Nakata index and McGoon ratio: correlation with the severity of pulmonary regurgitation after the repair of paediatric tetralogy of Fallot. *Egypt Heart J*. 2023;**75**(1):95. [PubMed ID: 38017289]. [PubMed Central ID: PMC10684472]. https://doi.org/10.1186/s43044-023-00423-9.
9. Lapierre C, Dubois J, Rypens F, Raboisson MJ, Dery J. Tetralogy of Fallot: Preoperative assessment with MR and CT imaging. *Diagn Interv Imaging*. 2016;**97**(5):531-41. [PubMed ID: 26969119]. https://doi.org/10.1016/j.diii.2016.01.009.
10. Karaca-Altintas Y, Laux D, Gouton M, Bensemlali M, Roussin R, Horer J, et al. Nakata index above 1500 mm2/m2 predicts death in absent pulmonary valve syndrome. *Eur J Cardiothorac Surg*. 2020;**57**(1):46-53. [PubMed ID: 31180449]. https://doi.org/10.1093/ejcts/ezz167.
11. Chen BB, Chen SJ, Wu MH, Li YW, Lue HC. EBCT-McGoon Ratio A Reliable and Useful Method to Predict Pulmonary Blood Flow Non-invasively. *Chin J Radiol*. 2007;**32**:1-8.
12. Prakash A, Powell AJ, Geva T. Multimodality noninvasive imaging for assessment of congenital heart disease. *Circ Cardiovasc Imaging*. 2010;**3**(1):112-25. [PubMed ID: 20086225]. https://doi.org/10.1161/CIRCIMAGING.109.875021.
13. Moscatelli S, Pergola V, Motta R, Fortuni F, Borrelli N, Sabatino J, et al. Multimodality Imaging Assessment of Tetralogy of Fallot: From Diagnosis to Long-Term Follow-Up. *Children (Basel)*. 2023;**10**(11). [PubMed ID: 38002838]. [PubMed Central ID: PMC10670209]. https://doi.org/10.3390/children10111747.
14. Hamza H, Abd-Elrahman N, Taha GM. Non-invasive versus invasive assessment of pulmonary artery branches in pediatric patients with tetralogy of fallot. *Alexandria J Pediatrics*. 2002;**16**(2):239.
15. Rao UV, Vanajakshamma V, Rajasekhar D, Lakshmi AY, Reddy RN. Magnetic resonance angiography vs. angiography in tetralogy of Fallot. *Asian Cardiovasc Thorac Ann*. 2013;**21**(4):418-25. [PubMed ID: 24570523]. https://doi.org/10.1177/0218492312457360.
16. Raval A, Oswal N, Thakkar B, Garg R, Shah K, Patel I. Accuracy of different imaging modalities prior to biventricular repair in Tetralogy of Fallot. *Int J Med Update*. 2016;**11**(1). https://doi.org/10.4314/ijmu.v11i1.2.
17. Balaguru D, Chiu JS. Tetralogy of Fallot with Pulmonary Atresia. *Pediatric Cardiol*. 2023. p. 1-27. https://doi.org/10.1007/978-3-030-42937-9_113-1.
18. Bockeria LA, Podzolkov VP, Makhachev OA, Zelenikin MA, Alekian BG, Ilyin VN, et al. Surgical correction of tetralogy of Fallot with unilateral absence of pulmonary artery. *Ann Thorac Surg*. 2007;**83**(2):613-8. [PubMed ID: 17257996]. https://doi.org/10.1016/j.athoracsur.2006.08.022.
19. Ovroutski S, Alexi-Meskishvili V. Does the Nakata index predict outcome after Fontan operation? *Eur J Cardiothorac Surg*. 2008;**33**(5):951. author reply 951-2. [PubMed ID: 18295502]. https://doi.org/10.1016/j.ejcts.2008.01.031.
20. Haramati LB, Glickstein JS, Issenberg HJ, Haramati N, Crooke GA. MR imaging and CT of vascular anomalies and connections in patients with congenital heart disease: significance in surgical planning. *Radiographics*. 2002;**22**(2):337-47. discussion 348-9. [PubMed ID: 11896223]. https://doi.org/10.1148/radiographics.22.2.g02mr09337.
21. Santoro G, Marino B, Di Carlo D, Formigari R, de Zorzi A, Mazzera E, et al. Echocardiographically guided repair of tetralogy of Fallot. *Am J*

Cardiol. 1994;**73**(11):808-11. [PubMed ID: 8160620]. https://doi.org/10.1016/0002-9149(94)90885-0.

22. Kumar A, Sahu AK, Goel PK, Jain N, Garg N, Khanna R, et al. Comparison of non-invasive assessment for pulmonary vascular indices by two-dimensional echocardiography and cardiac computed tomography angiography with conventional catheter angiocardiography in unrepaired Tetralogy of Fallot physiology patients weighing more than 10 kg: a retrospective analysis. *Eur Heart J Cardiovasc Imaging*. 2023;**24**(3):383-91. [PubMed ID: 35511585]. https://doi.org/10.1093/ehjci/jeac078.

23. Tworetzky W, McElhinney DB, Brook MM, Reddy VM, Hanley FL, Silverman NH. Echocardiographic diagnosis alone for the complete repair of major congenital heart defects. *J Am Coll Cardiol*. 1999;**33**(1):228-33. [PubMed ID: 9935035]. https://doi.org/10.1016/s0735-1097(98)00518-x.

24. Apostolopoulou SC, Manginas A, Kelekis NL, Noutsias M. Cardiovascular imaging approach in pre and postoperative tetralogy of Fallot. *BMC Cardiovasc Disord*. 2019;**19**(1):7. [PubMed ID: 30616556]. [PubMed Central ID: PMC6323806]. https://doi.org/10.1186/s12872-018-0996-9.