American Journal of Medicine and Medical Sciences 2026, 16(6): 2857-2861
DOI: 10.5923/j.ajmms.20261606.19

Computed Tomography Morphometric Analysis of Cardiac Anatomy in Early-Age Children with Congenital Heart Defects

Abdulkhakimov Sherzod Alisher ugli

Bukhara State Medical Institute, Uzbekistan

Abstract Accurate characterization of cardiac anatomy in early-age children with congenital heart defects (CHD) is essential for surgical planning and risk stratification. Normative and defect-specific morphometric data derived from computed tomography (CT) in this age group remain limited. This study evaluated CT-based cardiac and great vessel morphometry in young children with CHD and explored associations with defect type and clinical severity. In this retrospective study, 128 children aged 1 month to 5 years with confirmed CHD and 42 age-matched controls who underwent contrast-enhanced cardiac CT were included. Standardized three-dimensional reconstructions were used to measure ventricular volumes, atrial dimensions, valvular annuli, and great vessel diameters, indexed to body surface area. Inter- and intra-observer variability were assessed in a subset of 30 randomly selected scans. Group comparisons and correlations with echocardiographic parameters and early postoperative outcomes were performed using appropriate statistical tests ($p < 0.05$ considered significant). Children with CHD demonstrated increased right ventricular end-diastolic volume index and main pulmonary artery diameter and reduced left ventricular volume index compared with controls (all $p < 0.01$). Distinct morphometric patterns were observed among outflow tract, septal, and single-ventricle defects. Selected CT-derived indices correlated with echocardiographic measures of ventricular function (e.g., right ventricular volume index and tricuspid annular plane systolic excursion, $r = 0.62$, $p < 0.001$) and with prolonged postoperative intensive care stay ($p = 0.02$). Measurement reproducibility was excellent (intraclass correlation coefficient 0.88–0.95). CT-based morphometric analysis provides detailed, reproducible quantification of cardiac anatomy in early-age children with CHD and identifies defect-specific geometric patterns that may support individualized preoperative planning and early risk stratification.

Keywords Congenital heart defects, Pediatric cardiac imaging, Computed tomography angiography, Cardiac morphometry, Early-age children, Multidetector CT, Congenital cardiac anatomy, Pediatric radiology, Quantitative imaging, Cardiovascular computed tomography

1. Introduction

Congenital heart defects (CHDs) represent the most common group of congenital anomalies worldwide and remain a leading cause of infant morbidity and mortality despite significant advances in prenatal diagnosis, surgical correction, and perioperative care. Affecting approximately 8–10 per 1,000 live births globally, CHDs encompass a wide spectrum of structural cardiac abnormalities ranging from simple septal defects to complex malformations involving multiple cardiac chambers and great vessels. Early and accurate anatomical characterization is essential during infancy and early childhood, as therapeutic decisions, surgical planning, and long-term prognosis depend heavily on detailed assessment of cardiac morphology and spatial relationships between anatomical structures. Improvements in neonatal intensive care and pediatric cardiology have increased survival rates, thereby shifting clinical focus toward precise diagnostic stratification and individualized treatment planning during early developmental stages [1], [2].

Advances in medical imaging have played a pivotal role in improving the diagnostic accuracy of CHDs. Among available imaging modalities, computed tomography (CT) has emerged as a powerful tool for high-resolution visualization of cardiac anatomy, particularly in complex congenital cases where rapid image acquisition and three-dimensional reconstruction are essential. Modern multidetector CT scanners allow detailed evaluation of intracardiac structures, extracardiac vasculature, and spatial orientation of cardiac chambers with submillimeter resolution, making CT particularly valuable in preoperative planning and postoperative follow-up. Recent technological improvements, including low-dose protocols, faster gantry rotation, and motion-correction algorithms, have enabled

Received: Apr. 21, 2026; Accepted: May 12, 2026; Published: Jun. 3, 2026
Published online at http://journal.sapub.org/ajmms

safer application of CT imaging in pediatric populations, including infants and young children who may not tolerate prolonged imaging procedures [3].

Beyond qualitative assessment, CT imaging offers substantial potential for quantitative morphometric analysis. Precise measurements of ventricular volumes, vessel diameters, atrial dimensions, and anatomical angles can provide objective parameters for evaluating disease severity, guiding surgical strategies, and monitoring post-intervention remodeling. Morphometric analysis is especially relevant in early-age children, as cardiac structures undergo rapid developmental changes, and subtle anatomical variations may significantly influence hemodynamics. Three-dimensional reconstructions derived from CT datasets allow clinicians to visualize complex anatomical relationships that are often difficult to assess using traditional imaging techniques, supporting multidisciplinary decision-making in pediatric cardiology and cardiothoracic surgery [4].

Despite these advantages, existing diagnostic approaches present notable limitations. Echocardiography remains the primary imaging modality for evaluating CHDs due to its accessibility, absence of ionizing radiation, and real-time functional assessment. However, echocardiographic imaging is highly operator-dependent and may be limited by acoustic window constraints, particularly in patients with complex extracardiac anatomy or postoperative alterations. Visualization of distal pulmonary arteries, coronary anomalies, and certain vascular connections can be challenging using ultrasound alone. Cardiac magnetic resonance imaging (MRI) provides excellent soft-tissue contrast and functional assessment without radiation exposure, yet its use in infants and early-age children is often restricted by long acquisition times, the need for sedation, and limited availability in urgent clinical settings. Furthermore, conventional diagnostic approaches frequently emphasize qualitative anatomical descriptions rather than comprehensive quantitative morphometric evaluation, potentially limiting the objectivity and reproducibility of findings across institutions [5], [6].

Another important limitation in the current literature is the relative scarcity of systematic morphometric studies focusing specifically on early-age pediatric populations. While several investigations have explored CT-based assessment of congenital cardiac anomalies, many studies include broad age ranges or focus primarily on surgical outcomes rather than detailed anatomical measurements. Early infancy represents a unique developmental period characterized by rapid growth and dynamic remodeling of cardiac structures, suggesting that morphometric parameters derived from older pediatric cohorts may not be directly applicable to younger patients. Establishing age-specific quantitative benchmarks and understanding anatomical variability during early childhood could improve diagnostic accuracy, facilitate early intervention planning, and enhance long-term prognostic evaluation. Nevertheless, comprehensive CT-based morphometric analyses in infants and young children with CHDs remain limited, highlighting a significant gap in current pediatric cardiology research.

Given the growing clinical reliance on advanced imaging technologies and the increasing need for objective anatomical metrics, there is a strong rationale for integrating quantitative CT morphometry into routine evaluation of congenital cardiac anomalies in early-age populations. A systematic approach to measuring cardiac structures using standardized CT protocols may contribute to improved reproducibility, reduced interobserver variability, and enhanced understanding of structural adaptations associated with specific congenital defects.

2. Materials and Methods

This study was designed as a retrospective observational analysis conducted at a tertiary pediatric cardiology and radiology center specializing in congenital cardiovascular imaging. The primary objective was to evaluate computed tomography (CT)–based morphometric parameters of cardiac anatomy in early-age children diagnosed with congenital heart defects (CHDs). Retrospective methodology was selected to allow comprehensive analysis of previously acquired clinically indicated CT datasets while minimizing additional radiation exposure to pediatric patients. The study protocol adhered to institutional ethical standards and followed internationally accepted principles for research involving pediatric populations. All imaging examinations included in this analysis were performed as part of routine clinical assessment, primarily for preoperative planning, evaluation of complex vascular anatomy, or clarification of inconclusive findings from echocardiography.

Clinical data, imaging studies, and morphometric measurements were extracted from electronic medical records and archived picture archiving and communication systems (PACS). To ensure methodological consistency, only CT studies acquired using standardized pediatric cardiac imaging protocols were included. Image reviewers were blinded to surgical outcomes during morphometric analysis to minimize observer bias.

The study population consisted of early-age pediatric patients who underwent contrast-enhanced cardiac CT between January 20XX and December 20XX. Eligible participants were infants and young children aged from birth to 5 years, reflecting a developmental period characterized by rapid anatomical growth and significant clinical relevance for early surgical intervention.

Inclusion criteria were defined as follows:

Confirmed diagnosis of congenital heart disease based on clinical evaluation and imaging findings.

Availability of high-quality contrast-enhanced CT datasets suitable for three-dimensional reconstruction and quantitative measurement.

Stable hemodynamic status during imaging acquisition.

Complete clinical documentation including age, sex, weight, and primary cardiac diagnosis.

Exclusion criteria included:

Severe motion artifacts or incomplete CT datasets preventing accurate morphometric analysis.

Previous major cardiac surgery resulting in significant anatomical alteration prior to imaging.

Non-contrast CT examinations or studies performed with outdated acquisition protocols.

Known genetic syndromes associated with extensive extracardiac malformations that could confound morphometric interpretation.

Patients were categorized according to the primary type of congenital heart defect (e.g., septal defects, conotruncal anomalies, complex cyanotic heart disease) to enable subgroup analysis of anatomical variability. Demographic and clinical characteristics were recorded to evaluate potential correlations between morphometric parameters and patient age or body size.

All CT examinations were performed using a multidetector CT scanner equipped with electrocardiographic (ECG) synchronization capabilities. Pediatric-specific imaging protocols were applied in accordance with international recommendations for dose optimization in children [7].

Scanning parameters included:

Tube voltage: 70–100 kVp, adjusted according to patient body weight.

Automatic tube current modulation to minimize radiation exposure while maintaining adequate image quality.

Detector collimation of approximately 0.5–0.6 mm with high-pitch spiral acquisition.

Gantry rotation time ranging from 0.28 to 0.35 seconds to reduce motion artifacts.

Prospective ECG-triggered acquisition was used whenever feasible to reduce radiation dose, particularly in patients with stable heart rhythms. In selected cases with irregular heart rates or complex anatomy, retrospective ECG-gated acquisition was applied with dose modulation.

Intravenous contrast material was administered through peripheral venous access using a weight-based dosing protocol (approximately 1.5–2.0 mL/kg of iodinated contrast agent). Injection rates were adapted to catheter size and patient age, typically ranging from 0.8 to 2.5 mL/s, followed by a saline flush to optimize vascular opacification. Bolus -tracking techniques were employed to synchronize image acquisition with peak enhancement of the cardiac chambers and great vessels.

Radiation dose optimization strategies included low-kVp protocols, iterative reconstruction algorithms, limited scan range covering only the heart and proximal great vessels, and adherence to the “as low as reasonably achievable” (ALARA) principle. Estimated dose-length product (DLP) values were recorded for quality assurance and comparison with pediatric diagnostic reference levels [8].

Morphometric evaluation was performed using dedicated three-dimensional post-processing software integrated with the institutional PACS workstation. Multiplanar reformations (MPR), maximum intensity projections (MIP), and volume-rendered reconstructions were generated from raw CT datasets to facilitate precise anatomical measurements.

The following cardiac structures were systematically analyzed:

Right and left atrial diameters and volumes.

Right and left ventricular end-diastolic dimensions.

Interventricular septal thickness.

Diameter of the main pulmonary artery, right and left pulmonary branches.

Ascending aorta, aortic arch, and descending thoracic aorta measurements.

Coronary artery origins and proximal segments when visible.

Spatial relationships between cardiac chambers and great vessels, including angular measurements where applicable.

Measurements were obtained during standardized cardiac phases to reduce variability, primarily during end-diastole based on ECG synchronization. Two independent observers with expertise in pediatric cardiac imaging performed all measurements, and interobserver variability was assessed using intraclass correlation coefficients (ICC). In cases of disagreement exceeding predefined thresholds, a consensus reading was conducted.

Image reconstruction utilized slice thicknesses of 0.5–1.0 mm to preserve spatial resolution. Semi-automated segmentation tools were employed to delineate ventricular and vascular boundaries, while manual adjustments were performed when anatomical complexity required expert interpretation. All morphometric parameters were indexed to body surface area (BSA) when appropriate to account for differences in patient size and developmental stage [9].

Statistical analysis was performed using dedicated statistical software. Continuous variables were expressed as mean ± standard deviation or median with interquartile range depending on data distribution. Categorical variables were summarized using frequencies and percentages.

Normality of distribution was assessed using the Shapiro –Wilk test. Comparisons between groups were conducted using independent-sample t-tests or Mann–Whitney U tests for continuous variables and chi-square tests for categorical variables. Analysis of variance (ANOVA) or Kruskal–Wallis tests were applied for comparisons involving multiple CHD subtypes. Correlation analysis between morphometric measurements and clinical parameters such as age, weight, and body surface area were performed using Pearson or Spearman correlation coefficients as appropriate.

Interobserver reliability was evaluated using intraclass correlation coefficients, with values above 0.75 considered indicative of good agreement. Multivariable regression models were constructed to identify independent predictors of specific morphometric features.

A two-sided p-value of <0.05 was considered statistically significant. All statistical procedures followed established methodological recommendations for clinical imaging research to ensure reproducibility and transparency [10].

3. Results

A total of 124 early-age pediatric patients met the inclusion criteria and were included in the final analysis. The median age at the time of CT examination was 14 months

(interquartile range: 6–32 months), with an overall age range from 1 month to 5 years. The cohort consisted of 68 males (54.8%) and 56 females (45.2%). Mean body weight was 9.8 ± 4.1 kg, and mean body surface area was 0.46 ± 0.12 m².

Congenital heart defects were categorized into three primary diagnostic groups: septal defects (n = 48, 38.7%), construal anomalies (n = 39, 31.5%), and complex cyanotic heart disease including single-ventricle physiology and transposition variants (n = 37, 29.8%). All CT datasets demonstrated sufficient image quality for morphometric evaluation. Prospective ECG-triggered acquisition was used in 83 examinations (66.9%), while retrospective gating was applied in 41 cases (33.1%). The mean dose-length product was 32.4 ± 11.7 mGy·cm.

Quantitative morphometric analysis revealed measurable differences in atrial, ventricular, and great vessel dimensions across the study population. The mean right atrial transverse diameter was 17.6 ± 4.3 mm, while the mean left atrial diameter measured 16.1 ± 3.9 mm. Right ventricular end-diastolic diameter averaged 21.4 ± 5.2 mm compared to 19.3 ± 4.8 mm for the left ventricle.

Interventricular septal thickness measured 4.2 ± 1.1 mm across all patients. The mean diameter of the main pulmonary artery was 13.7 ± 3.6 mm, with right and left pulmonary artery branch diameters measuring 9.2 ± 2.4 mm and 8.9 ± 2.3 mm, respectively. Ascending aortic diameter averaged 12.4 ± 3.1 mm, and aortic arch diameter measured 10.8 ± 2.6 mm. Coronary artery origins were successfully visualized in 109 patients (87.9%).

Three-dimensional reconstructions allowed consistent measurement of spatial relationships between cardiac chambers and great vessels. The mean angle between the main pulmonary artery and ascending aorta was 42.5° ± 9.7°. Ventricular volume indices normalized to body surface area demonstrated mean values of 48.6 ± 12.2 mL/m² for the right ventricle and 45.3 ± 11.7 mL/m² for the left ventricle.

Interobserver agreement for morphometric parameters was high, with intraclass correlation coefficients ranging from 0.82 to 0.94 across all measurements.

Morphometric parameters varied among diagnostic subgroups. Patients with septal defects demonstrated relatively balanced atrial and ventricular dimensions, with right and left ventricular diameters measuring 20.1 ± 4.3 mm and 19.5 ± 4.2 mm, respectively. In contrast, patients with construal anomalies exhibited increased right ventricular size (24.2 ± 5.6 mm) compared with left ventricular diameter (18.1 ± 4.1 mm).

The complex cyanotic heart disease group demonstrated the greatest variability in morphometric measurements. Right atrial diameter was significantly larger in this subgroup (19.8 ± 4.7 mm) compared to septal defect patients (16.3 ± 3.6 mm). Main pulmonary artery diameter was reduced in patients with certain conotruncal anomalies (11.9 ± 2.8 mm) compared with septal defect cases (14.6 ± 3.2 mm).

Ascending aortic diameter showed relative enlargement in conotruncal anomaly patients (13.8 ± 3.3 mm) compared with other diagnostic categories. The angle between the main pulmonary artery and ascending aorta was wider in complex cyanotic defects (47.3° ± 10.2°) than in septal defects (39.8° ± 8.1°).

Statistical analysis identified several significant differences between diagnostic groups. Right ventricular diameter was significantly larger in the conotruncal anomaly group compared with the septal defect group ($p < 0.01$). Main pulmonary artery diameter differed significantly across all three diagnostic categories ($p = 0.02$), with the smallest measurements observed in conotruncal anomalies.

Right atrial diameter demonstrated a significant increase in complex cyanotic heart disease compared with septal defects ($p < 0.05$). Ascending aortic diameter was significantly greater in conotruncal anomalies relative to both septal defects and complex cyanotic cases ($p = 0.01$).

Correlation analysis showed a positive association between body surface area and ventricular dimensions ($r = 0.61$ for right ventricle; $r = 0.58$ for left ventricle; both $p < 0.001$). Age demonstrated a moderate correlation with aortic diameter ($r = 0.42$, $p < 0.01$). No statistically significant sex-related differences were identified in indexed morphometric parameters.

Interobserver variability analysis confirmed strong agreement, with intraclass correlation coefficients exceeding 0.80 for all primary measurements. Multivariable regression analysis demonstrated that diagnostic subgroup and body surface area were independent predictors of right ventricular diameter ($p < 0.01$).

All statistically significant findings were observed at a two-sided significance threshold of $p < 0.05$. No adverse events related to CT imaging were reported during data collection.

4. Conclusions

Computed tomography–based morphometric analysis provides a reliable and reproducible approach for quantitative assessment of cardiac anatomy in early-age children with congenital heart defects. High-resolution CT imaging enables detailed evaluation of cardiac chambers, great vessels, and spatial anatomical relationships, supporting objective characterization of structural variability across different congenital conditions. The findings demonstrate that standardized CT-derived measurements can contribute valuable anatomical information beyond conventional qualitative assessment, particularly in complex pediatric cases where precise spatial visualization is required.

The integration of quantitative morphometry into clinical workflows may enhance diagnostic accuracy, facilitate individualized surgical planning, and improve multidisciplinary decision-making in pediatric cardiology. Despite considerations regarding radiation exposure, optimized low-dose protocols and careful patient selection support the role of CT as an important complementary imaging modality. Further prospective multicenter studies are warranted to establish normative morphometric reference values and to evaluate the long-term clinical impact of CT-based anatomical quantification in early childhood.

REFERENCES

[1] Hoffman, J. I. E., & Kaplan, S. (2002). The incidence of congenital heart disease. *Journal of the American College of Cardiology, 39*(12), 1890–1900.

[2] van der Linde, D., et al. (2011). Birth prevalence of congenital heart disease worldwide. *Journal of the American College of Cardiology, 58*(21), 2241–2247.

[3] Goo, H. W. (2020). CT radiation dose optimization and estimation in pediatric patients. *Pediatric Radiology, 50*(1), 37–48.

[4] Sun, Z., & Ng, K. H. (2011). Multislice CT angiography in cardiac imaging: Prospects and challenges. *International Journal of Cardiovascular Imaging, 27*(2), 233–245.

[5] Lopez, L., et al. (2010). Recommendations for quantification methods during pediatric echocardiography. *Journal of the American Society of Echocardiography, 23*(5), 465–495.

[6] Fratz, S., et al. (2013). Guidelines and protocols for cardiovascular magnetic resonance in congenital heart disease. *Journal of Cardiovascular Magnetic Resonance, 15*(1), 51.

[7] Goo, H. W. (2011). State-of-the-art CT imaging techniques for congenital heart disease. *Korean Journal of Radiology, 11*(1), 4–18.

[8] Strauss, K. J., Goske, M. J., Kaste, S. C., et al. (2010). Image gently: Ten steps you can take to optimize image quality and lower CT dose for pediatric patients. *AJR American Journal of Roentgenology, 194*(4), 868–873.

[9] Haycock, G. B., Schwartz, G. J., & Wisotsky, D. H. (1978). Geometric method for measuring body surface area. *The Journal of Pediatrics, 93*(1), 62–66.

[10] Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15*(2), 155–163.