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Radiological Evaluation of Coronary Artery Anatomical Variations and Their Association with Coronary Artery Disease in the Pakistani Population

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ABSTRACT

Background: Coronary artery disease (CAD) remains a leading cause of morbidity and mortality worldwide. With advances in radiological imaging techniques, particularly coronary angiography and CT coronary angiography, coronary artery anatomical variations are increasingly recognized as important determinants of cardiovascular outcomes.

Objective: To evaluate the association between radiologically detected coronary artery anatomical variations and the risk of CAD in a Pakistani population.

Methods: A cross-sectional analytical study was conducted on 220 patients undergoing diagnostic coronary angiography and radiological assessment of coronary anatomy. Coronary artery variations, including anomalies of origin, course, and dominance patterns, were identified through imaging. CAD severity was assessed based on ≥50% luminal stenosis. Statistical analysis included chi-square testing and logistic regression.

Results: Coronary artery variations were identified in 34.5% of patients using radiological imaging modalities. The presence of these variations was significantly associated with CAD ($p < 0.001$). Patients with anatomical variations demonstrated higher odds of significant CAD (OR = 2.38, 95% CI: 1.45–3.91).

Conclusion: Radiologically detected coronary artery anatomical variations are significantly associated with increased risk and severity of CAD. Incorporating advanced cardiac imaging techniques into routine evaluation may improve early detection and risk stratification in clinical practice.

Keywords: Coronary artery disease, Anatomical anomalies, Radiological coronary imaging, Cardiovascular risk, CT coronary angiography.

INTRODUCTION

Coronary artery disease (CAD) remains a leading cause of morbidity and mortality worldwide, particularly in low- and middle-income countries such as Pakistan (1). Recent advances in radiological imaging modalities, including coronary angiography and CT coronary angiography, have significantly improved the detection and characterization of coronary artery disease and its anatomical determinants (2).

Coronary artery variations include anomalies in origin, course, and branching patterns, which may alter hemodynamics and predispose individuals to atherosclerosis (3). Studies suggest that abnormal coronary anatomy can lead to turbulent blood flow, endothelial dysfunction, and plaque formation (4).

Globally, the prevalence of coronary artery anomalies ranges from 1% to 35%, depending on the population studied and diagnostic modality used (5). In South Asian populations, the burden of CAD is particularly high, necessitating identification of novel risk factors (6).

Recent literature (2021–2026) indicates a growing interest in anatomical determinants of CAD, particularly with the expanding role of non-invasive cardiac imaging techniques. CT coronary angiography, as a key radiological tool, allows high-resolution visualization of coronary anatomy, enabling accurate identification of variations such as myocardial bridging, anomalous origin, and coronary dominance patterns (7,8).

From a pathophysiological perspective, altered coronary geometry can significantly influence coronary flow reserve, wall shear stress, and endothelial function, all of which are critical regulators of atherogenesis (9). Disturbed flow patterns promote oxidative stress, inflammation, and vascular remodeling, thereby accelerating plaque progression. Moreover, radiological assessment of coronary anatomy provides not only structural but also functional insights, aiding in the evaluation of ischemia and disease severity (10)...

Despite global evidence, data from Pakistan remain limited and fragmented. The integration of radiological evaluation of coronary anatomy into clinical research is essential for improving early diagnosis, risk stratification, and management strategies in the local population.

METHODOLOGY

This cross-sectional analytical study was conducted a tertiary care hospital in Pakistan, from January 2024 to December, 2024 after taking IRB and informed consent. A total of 220 patients aged between 30 and 75 years undergoing radiological evaluation with coronary angiography and/or CT coronary angiography were included through non-probability consecutive sampling. Patients with a history of prior coronary artery bypass grafting or congenital heart disease were excluded. Coronary anatomy was assessed using standard radiological imaging protocols, and anatomical variations, including anomalies of origin, course, coronary dominance and myocardial bridging, were identified through detailed image interpretation. The presence and severity of coronary artery disease (CAD) were determined based on radiological evidence of ≥50% luminal stenosis in any major coronary artery. Demographic and clinical data were recorded using a structured proforma. Statistical analysis was performed using SPSS version 26. Categorical variables were analyzed using the chi-square test, and logistic regression was applied to assess the association between coronary artery variations and CAD risk. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 220 patients were included in the study. The mean age was 54.2 ± 10.8 years, with a male predominance (62.7%). Baseline characteristics are summarized in Table 1.

On radiological evaluation using coronary angiography and/or CT coronary angiography, Coronary artery anatomical variations were identified in 76 patients (34.5%), while 144 (65.5%) had normal coronary anatomy (Table 2). Among the variations, myocardial bridging 32 (14.5%) was the most frequent, followed by left coronary dominance 20 (9.1%) and anomalous origin 15 (6.8%) (Table 3).

The prevalence of significant CAD was markedly higher in patients with anatomical variations (68.4%) compared to those with normal anatomy (42.4%). This difference was statistically significant ($\chi^2 = 14.76$, $p < 0.001$) (Table 4).

Further radiological assessment of disease extent revealed that multivessel disease was significantly more common in patients with coronary variations (46.1% vs 25.0%, $p = 0.01$) (Table 5). Similarly, triple vessel disease was observed more frequently in the variation group, indicating greater disease severity on imaging.

Logistic regression analysis demonstrated that radiologically detected coronary artery variations were independently associated with CAD, with an odds ratio (OR) of 2.38 (95% CI: 1.45–3.91, $p = 0.0006$) after adjusting for age and gender (Table 6).

Table 1: **Demographic and Baseline Characteristics (n = 220)**

Variable	Value
Age (years)	54.2 ± 10.8
Male	138 (62.7%)
Female	82 (37.3%)

Table 2: **Prevalence of Coronary Artery Variations**

Category	**Frequency (n)**	**Percentage (%)**
Variations Present	76	34.5%
Normal Anatomy	144	65.5%

Table 3: **Distribution of Coronary Artery Variations**

Type of Variation	**Frequency (n)**	**Percentage (%)**
Myocardial Bridging	32	14.5%
Left Dominance	20	9.1%
Anomalous Origin	15	6.8%
Others	9	4.1%
Total	**76**	**34.5%**

Table 4: **Association between Coronary Variations and CAD**

Group	**CAD Present**	**CAD Absent**	**Total**	**% CAD**
Variations Present	52	24	76	68.4%
Normal Anatomy	61	83	144	42.4%

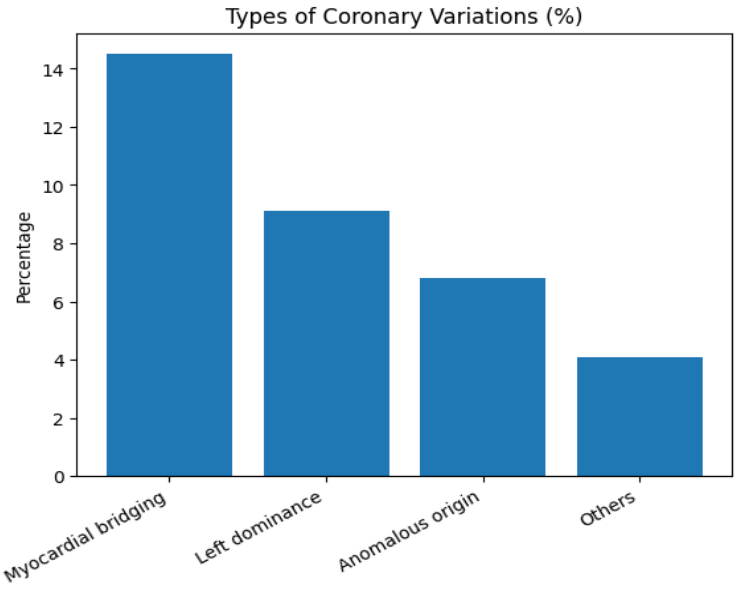
Chi-square = 14.76, p < 0.001

Table 5: **Severity of CAD (Vessel Involvement)**

Severity Level	**Variations (n=76)**	**Normal (n=144)**	**p-value**
Single Vessel Disease	17 (22.4%)	40 (27.8%)	0.32
Double Vessel Disease	24 (31.5%)	48 (33.3%)	0.78
Triple Vessel Disease	35 (46.1%)	36 (25.0%)	**0.01**

Table 6: **Logistic Regression Analysis for CAD Risk**

Variable	**Odds Ratio (OR)**	**95% CI**	**p-value**
Coronary Variations Present	2.38	1.45 – 3.91	0.0006
Age	1.04	1.01 – 1.07	0.02
Male Gender	1.32	0.78 – 2.21	0.29



DISCUSSION

The present study demonstrates a statistically significant association between coronary artery anatomical variations and the presence as well as severity of coronary artery disease (CAD), reinforcing the concept that anatomical factors contribute meaningfully to coronary pathophysiology. The observed prevalence of coronary variations (34.5%) aligns with recent imaging-based studies utilizing CT coronary angiography, which report a wide but increasingly recognized spectrum of coronary anomalies in contemporary cohorts (11,12).

From a mechanistic standpoint, coronary artery variations can alter local hemodynamic forces, particularly endothelial shear stress, which plays a central role in atherogenesis. Regions exposed to low or oscillatory shear stress are prone to endothelial dysfunction, increased permeability to lipoproteins, and inflammatory activation, thereby accelerating plaque formation (13). This provides a plausible biological explanation for the significantly higher frequency of CAD observed in patients with anatomical variations in our study.

Among the variations identified, myocardial bridging was the most common, consistent with prior literature highlighting its dual role as both a benign anatomical variant and a potential pathological entity. Compression of the tunneled coronary segment during systole can lead to disturbed flow patterns in the proximal segment, predisposing to atherosclerosis and ischemia (9,14). This phenomenon may partly explain the increased burden of CAD seen in our variation-positive group.

Furthermore, anomalies in coronary origin and dominance patterns can significantly influence myocardial perfusion. Left-dominant circulation, for instance, places a larger myocardial territory at risk in the event of stenosis, potentially contributing to more severe disease presentations. Meta-analytic evidence supports the association between certain coronary anomalies and increased risk of adverse cardiac outcomes (15).

The odds ratio of 2.38 observed in our study indicates that patients with coronary anatomical variations have more than double the likelihood of developing significant CAD. This finding is consistent with emerging clinical evidence suggesting that anatomical variations should be considered alongside traditional risk factors such as hypertension, diabetes, and dyslipidemia in comprehensive cardiovascular risk assessment (14,16).

Ethnic and regional factors may further modulate this relationship. South Asian populations, including Pakistanis, are known to have a higher baseline risk of CAD due to genetic predisposition, metabolic factors, and lifestyle influences (17). The coexistence of anatomical variations in such high-risk populations may exert a synergistic effect, amplifying disease risk and severity.

Importantly, the higher prevalence of multivessel and severe CAD among patients with anatomical variations in our cohort underscores the clinical relevance of these findings. Previous studies have also identified anatomical and structural factors as predictors of extensive coronary involvement (18). This has implications for both diagnostic strategies and therapeutic decision-making, particularly in the context of revascularization planning.

Advances in imaging modalities, especially CT coronary angiography and standardized reporting systems such as CAD-RADS, have improved the detection and classification of coronary anomalies (19). Early identification of such variations

may facilitate targeted surveillance and preventive strategies in high-risk individuals.

Despite these strengths, the cross-sectional nature of this study limits causal inference. Longitudinal studies are needed to establish temporal relationships and evaluate the prognostic significance of specific anatomical variations. Nonetheless, the findings contribute to the growing body of evidence emphasizing the importance of coronary anatomy in CAD pathogenesis and clinical outcomes (20).

In summary, coronary artery anatomical variations are not merely incidental findings but may represent significant anatomical risk modifiers that influence both the development and progression of CAD, particularly in high-risk populations.

CONCLUSION

Coronary artery anatomical variations are significantly associated with increased risk and severity of CAD in the Pakistani population. Recognition of these variations should be integrated into routine cardiovascular assessment.

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Authors' Contribution:

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