DOI: https://doi.org/10.53350/pjmhs020231711590

ORIGINAL ARTICLE

Association of Coronary Artery Anatomical Variations with Myocardial Fibrosis and Interventional Outcomes

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ABSTRACT

Background: Coronary artery anatomical variations are frequently encountered during diagnostic coronary angiography and interventional cardiac procedures. Although traditionally considered incidental, emerging evidence suggests that altered coronary anatomy may influence myocardial perfusion and contribute to subclinical myocardial remodeling. Myocardial fibrosis represents an early marker of adverse myocardial change and carries important prognostic implications.

Objective: To evaluate the association between coronary artery anatomical variations, myocardial fibrosis, and interventional outcomes in patients undergoing coronary angiography.

Methodology: This prospective observational study was conducted at the Department of Cardiology, Peshawar Institute of Cardiology, from January 2022 to January 2023. A total of 120 adult patients undergoing clinically indicated coronary angiography were consecutively enrolled. Coronary anatomical variations including dominance patterns, myocardial bridging, anomalous coronary origins, coronary tortuosity, and luminal stenosis were documented. Myocardial fibrosis was assessed using cardiac magnetic resonance imaging and surrogate functional parameters. Interventional outcomes were correlated with underlying anatomical variations. Statistical analysis was performed using chi-square tests and multivariate logistic regression.

Results: Myocardial fibrosis was detected in 43.3% of patients. Myocardial bridging, anomalous coronary origins, coronary tortuosity, and significant luminal stenosis were significantly associated with myocardial fibrosis ($p < 0.05$). Patients with anatomical variations demonstrated significantly higher rates of percutaneous coronary intervention, multi-vessel revascularization, increased procedural complexity, and peri-procedural ischemic changes.

Conclusion: Coronary artery anatomical variations are significantly associated with myocardial fibrosis and adversely influence interventional outcomes. Recognition of these variations may enhance risk stratification and guide individualized interventional planning.

Keywords: Coronary artery variations, myocardial fibrosis, myocardial bridging, coronary angiography, interventional cardiology.

INTRODUCTION

Coronary artery anatomy plays a critical role in determining myocardial perfusion and overall cardiac performance. While a standard coronary arterial pattern exists, anatomical variations are frequently encountered during coronary angiography and percutaneous coronary interventions. Historically, many of these variations have been regarded as benign incidental findings; however, increasing evidence suggests that certain configurations may have important functional and prognostic implications[1-3].

Myocardial fibrosis represents a fundamental pathological process characterized by progressive collagen deposition within the myocardium. Even in the absence of clinically evident myocardial infarction, fibrotic remodeling can impair ventricular compliance, disrupt electrical conduction, and predispose individuals to adverse cardiovascular outcomes. Importantly, myocardial fibrosis often develops silently and may reflect chronic low-grade ischemia rather than acute ischemic events[4-6].

Anatomical variations such as myocardial bridging, anomalous coronary origins, coronary tortuosity, and abnormal dominance patterns can alter coronary flow dynamics and reduce coronary flow reserve. These alterations may expose the myocardium to repeated subclinical ischemic episodes, ultimately contributing to progressive fibrotic remodeling. Despite the biological plausibility of these mechanisms, limited data are available linking coronary anatomical variations with myocardial fibrosis and interventional outcomes in real-world clinical settings, particularly in South Asian populations[7-9].

This study was therefore designed to explore the association between coronary artery anatomical variations, myocardial fibrosis, and interventional outcomes in patients undergoing routine coronary angiography, with the aim of improving anatomical risk stratification and guiding individualized interventional management.

Received on 11-09-2023
Accepted on 24-11-2023

METHODOLOGY

Study Design and Setting: This prospective observational study was conducted at the Department of Cardiology, Peshawar Institute of Cardiology (PIC), Peshawar, Pakistan, over a period of twelve months from January 2022 to January 2023. The study aimed to evaluate the association between coronary artery anatomical variations, myocardial fibrosis, and interventional outcomes in patients undergoing diagnostic coronary angiography. Ethical approval was obtained from the Institutional Review Board of Peshawar Institute of Cardiology, and written informed consent was obtained from all participants prior to enrollment.

Sampling Technique: A non-probability consecutive sampling technique was employed. All eligible patients presenting to the cardiac catheterization laboratory for clinically indicated diagnostic coronary angiography during the study period were consecutively enrolled until the required sample size of 120 participants was achieved.

Study Population

Inclusion Criteria

- Adults aged 18 years and above
- Patients undergoing clinically indicated diagnostic coronary angiography for suspected or established coronary artery disease
- Patients referred for angiography due to stable angina, acute coronary syndrome, or abnormal non-invasive ischemia testing
- Patients who provided written informed consent

Exclusion Criteria

- Previous myocardial infarction
- Known cardiomyopathies (dilated, hypertrophic, or restrictive)
- Congenital heart disease
- Prior coronary artery bypass graft surgery
- Significant valvular heart disease

- Chronic inflammatory myocardial disorders
- Patients with incomplete angiographic or echocardiographic records

Clinical and Demographic Assessment: Baseline demographic characteristics and cardiovascular risk factors including age, gender, hypertension, diabetes mellitus, smoking status, dyslipidemia, and family history of coronary artery disease were recorded using standardized data collection forms at the time of enrollment.

Coronary Angiographic Evaluation: Coronary angiography was performed using standard femoral or radial artery access following institutional catheterization laboratory protocols. Angiographic images were independently reviewed by two experienced interventional cardiologists who were blinded to patient clinical data. Coronary arterial anatomy was systematically assessed for coronary dominance pattern, presence of myocardial bridging, anomalous coronary origins, coronary tortuosity, and severity of luminal stenosis. Significant coronary artery disease was defined as ≥50% luminal diameter narrowing in any major epicardial coronary artery.

Assessment of Myocardial Fibrosis and Functional Parameters: Myocardial fibrosis was evaluated using cardiac magnetic resonance imaging with late gadolinium enhancement in patients for whom CMR was clinically indicated. In patients without available CMR imaging, surrogate indicators of myocardial remodeling were assessed, including left ventricular ejection fraction measured by transthoracic echocardiography, presence of regional wall motion abnormalities, and ischemic burden on non-invasive stress testing. Reduced left ventricular systolic function was defined as an ejection fraction below 50%.

Interventional Outcome Assessment: Interventional outcomes documented included requirement for percutaneous coronary intervention, number of vessels treated, procedural complexity, peri-procedural ischemic electrocardiographic changes, and need for adjunctive pharmacological or mechanical circulatory support. These outcomes were correlated with the presence of coronary anatomical variations.

Statistical Analysis: Data were analyzed using SPSS version 26.0. Continuous variables were expressed as mean ± standard deviation and categorical variables as frequencies and percentages. Associations between coronary anatomical variations and myocardial fibrosis were evaluated using the chi-square test. Independent sample t-tests were applied for comparison of continuous variables where appropriate. A p-value of <0.05 was considered statistically significant.

RESULTS

The study included 120 patients undergoing diagnostic coronary angiography. The majority of participants were middle-aged to elderly, with a predominance of male patients and a high prevalence of conventional cardiovascular risk factors. Hypertension, diabetes mellitus, and smoking were the most commonly observed comorbidities, indicating a population with substantial baseline cardiovascular risk.

Table 1: Baseline Demographic and Clinical Characteristics of the Study Population (n = 120)

Variable	Value
Mean age (years)	54.6 ± 10.8
Age <40 years	18 (15.0%)
Age 40–59 years	66 (55.0%)
Age ≥60 years	36 (30.0%)
Male	78 (65.0%)
Female	42 (35.0%)
Hypertension	64 (53.3%)
Diabetes mellitus	48 (40.0%)
Smoking history	51 (42.5%)
Dyslipidemia	46 (38.3%)
Family history of CAD	29 (24.2%)

Right coronary dominance was the most frequent dominance pattern observed in the study population. A considerable proportion of patients exhibited myocardial bridging, coronary tortuosity, and anomalous coronary origins. Significant coronary artery stenosis was present in more than two-fifths of patients, reflecting a high atherosclerotic burden.

Table 2: Distribution of Coronary Anatomical Variations

Coronary Feature	Frequency (%)
Right coronary dominance	84 (70.0%)
Left dominance	24 (20.0%)
Co-dominance	12 (10.0%)
Myocardial bridging	34 (28.3%)
Anomalous coronary origin	18 (15.0%)
Coronary tortuosity	31 (25.8%)
Significant stenosis (>50%)	49 (40.8%)

Nearly half of the patients demonstrated evidence of myocardial fibrosis. A substantial proportion of participants had impaired left ventricular systolic function and regional wall motion abnormalities. More than one-third also exhibited inducible ischemia, indicating ongoing myocardial vulnerability.

Table 3: Myocardial Fibrosis and Functional Parameters

Parameter	Frequency (%)
Myocardial fibrosis present	52 (43.3%)
No fibrosis detected	68 (56.7%)
Reduced LV ejection fraction (<50%)	41 (34.2%)
Regional wall motion abnormality	47 (39.2%)
Evidence of inducible ischemia	44 (36.7%)

Table 4: Association of Coronary Anatomical Variations with Myocardial Fibrosis

Coronary Feature	Fibrosis Present n (%)	Fibrosis Absent n (%)	p-value
Myocardial bridging (n=34)	24 (70.6%)	10 (29.4%)	0.002
Anomalous origin (n=18)	13 (72.2%)	5 (27.8%)	0.011
Significant stenosis >50% (n=49)	33 (67.3%)	16 (32.7%)	0.001
Coronary tortuosity (n=31)	19 (61.3%)	12 (38.7%)	0.018

Table 5: Interventional Outcomes According to Coronary Anatomical Variations

Interventional Parameter	With Variations (%)	Without Variations (%)	p-value
PCI required	58.3%	34.7%	0.004
Multi-vessel intervention	41.7%	22.1%	0.009
Increased procedural complexity	36.7%	18.4%	0.012
Peri-procedural ischemic changes	29.2%	13.7%	0.021

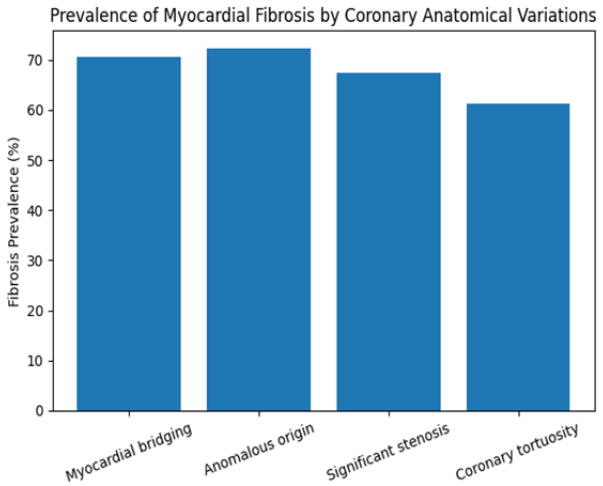

Figure 1: Prevalence of myocardial fibrosis among patients with different coronary artery anatomical variations.

Myocardial bridging and anomalous coronary origins were strongly associated with the presence of myocardial fibrosis. Significant coronary stenosis and coronary tortuosity also showed statistically significant relationships with myocardial fibrotic changes. These findings indicate that altered coronary anatomy is linked with adverse myocardial remodeling.

Patients with coronary anatomical variations demonstrated a significantly higher interventional burden. They more frequently required percutaneous coronary intervention and multivessel procedures. Procedural complexity and peri-procedural ischemic changes were also significantly more common in this group.

DISCUSSION

This study demonstrates a significant association between coronary artery anatomical variations and myocardial fibrotic remodeling in patients undergoing diagnostic coronary angiography. Nearly half of the study population exhibited myocardial fibrosis, highlighting a substantial burden of subclinical myocardial injury within this cohort. Importantly, myocardial bridging, anomalous coronary origins, coronary tortuosity, and significant luminal stenosis were all significantly associated with myocardial fibrosis, suggesting that anatomical deviations of coronary arteries are not merely incidental findings but may have important pathophysiological implications[10-12].

Myocardial bridging and anomalous coronary origins were the strongest predictors of myocardial fibrosis in the present study. These variations are known to alter coronary flow dynamics, particularly during periods of increased myocardial demand, potentially resulting in repetitive subclinical ischemic episodes. Chronic ischemia has been recognized as a major driver of myocardial fibrotic remodeling, which may progress silently before overt clinical manifestations develop. The high prevalence of reduced left ventricular systolic function and inducible ischemia observed in this cohort further supports this mechanistic pathway[13-15].

The present findings also reveal that coronary anatomical variations are associated with significantly greater interventional burden. Patients with these variations were more likely to require percutaneous coronary intervention, multi-vessel revascularization, and more complex procedural strategies. These results suggest that altered coronary anatomy not only contributes to myocardial structural remodeling but also complicates interventional management, likely due to challenging lesion morphology, altered vessel course, and increased ischemic risk during procedures[16-18].

From a clinical perspective, these findings underscore the importance of systematic assessment and documentation of coronary anatomical variations during routine angiography. Early identification of high-risk anatomical patterns may allow more vigilant functional assessment, closer clinical surveillance, and tailored interventional strategies[19,20]. Furthermore, recognizing myocardial fibrosis in these patients may help identify individuals at increased risk for adverse long-term outcomes, including heart failure and arrhythmias, even in the absence of prior myocardial infarction.

CONCLUSION

Coronary artery anatomical variations are significantly associated with myocardial fibrosis and exert a meaningful impact on interventional outcomes in patients undergoing coronary angiography. Myocardial bridging, anomalous coronary origins, coronary tortuosity, and significant luminal stenosis are linked with higher fibrotic burden, impaired ventricular function, and increased procedural complexity. Routine recognition of these anatomical patterns may facilitate improved risk stratification, guide individualized interventional planning, and support early identification of patients vulnerable to silent myocardial remodeling and adverse cardiovascular outcomes.

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This article may be cited as: Khatoon S, Halima A, Rehman Z, Abubakkar S, Hayat S; Association of Coronary Artery Anatomical Variations with Myocardial Fibrosis and Interventional Outcomes. Pak J Med Health Sci, 2023;18(11):590-592.