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Angiographic Evaluation of Coronary Collateral Circulation Patterns in Patients with Coronary Artery Disease Requiring Surgical Revascularization

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Abstract

Background: Coronary artery disease is highly prevalent in India with onset at a younger age. Coronary collateral circulation plays an important role in protecting myocardium from infarction, preserving myocardial contractility and reducing cardiovascular events. The objective of the present study is to assess the pattern of coronary collateral circulation in known cases of coronary artery disease with correlation to age, gender and degree of occlusion. **Method:** This is a retrospective study done on 200 preoperative angiograms in patients with coronary artery disease. Patients were classified according to age, gender and degree of obstruction in major vessels. Collateral vessels were graded according to the Rentrop classification. Patients with collaterals were further classified on the basis of intensity of collaterals into 3 groups: those with no collateralization (Grade 0), poor collateralization (Grade 1) and those with adequate collateralization (Grade 2 - 3). **Results:** Collateral development was seen in 175 (87.5%) angiograms. Collaterals were seen in 66% for left anterior descending (LAD), 44.5% for circumflex (LCx) and 70.5% for right coronary artery (RCA) block. Coronary collaterals between LAD and posterior descending artery (PDA) via ventricular septal branches were most common pathways. Adequate collaterals were seen in 53% males and 29.3% females ($p < 0.001$), 53.14% in patients of age > 50 years and in 32% in cases with age < 50 years ($p = 0.014$) and 54.8% cases with arterial obstruction > 90%. **Conclusion:** Collateral circulation between LAD and PDA via ventricular septal branches is the commonest pathway to develop. Although prevalence of LAD occlusion is higher but collaterals develop more for RCA occlusion. Adequate

collaterals develop more frequently in males, cases above 50 years and in vessels with >90% obstruction.

Keywords

Coronary Collaterals, Coronary Circulation, Coronary Artery Disease, Angiography

1. Introduction

Coronary collaterals, or "natural bypasses", are anastomotic connections without an intervening capillary bed either between portions of the same coronary artery or different coronary arteries [1]. Although the existence of several coronary collateral pathways has been demonstrated in patients with significant coronary artery disease, it is still debatable whether blood flow through them is sufficient to meet the myocardial demand [2]. The human coronary collateral circulation is speculated to play an important role in preserving myocardial function in the presence of obstructive coronary artery disease [3] [4] [5]. It has also been reported that people suffering from coronary artery disease with significant coronary collaterals for the major arteries of the heart have a 36% less risk of mortality [6]. However, there is inter-individual difference of coronary collateral formation and the mechanisms responsible for the individual's ability to develop collateral circulation are still unclear. India is predicted to be the hub for coronary artery disease (CAD) and according to WHO, by 2020, the number of Indian citizens dying each year of heart disease will exceed 2.4 million and one of every four cardiac patients in world would be Indian [7]. The disease is reported to be more diffuse, severe and affects Indians at a much younger age and the prevalence of the disease is highest in young population in the North West region [8]. There is no study which describes any differences in pattern of coronary collateral circulation in patients with coronary artery disease requiring surgical revascularization in this region, hence the present study was planned with an objective to study the patterns of coronary collaterals pathways extensively and find their correlation with demographic features in North West region of India. The clinical relevance and correlation with comorbidities will be taken up in a separate study.

2. Material & Method

Preoperative angiograms of 200 consecutive patients with coronary artery disease were retrospectively studied for evaluation of pattern of coronary collaterals and correlation of demographic features which may affect collateral development on heart circulation. The angiograms were studied on compact discs with Philips Intruis Suit Lite program. The patients having cardio myopathies, valvular, congenital heart, diseases and history of prior coronary angioplasty or coro-

nary artery bypass surgery were not included in the study. Patients were classified according to age, sex and degree of obstruction in major vessels. The cases were classified into three major groups according to age: 1) 31 - 50 years; 2) 51 - 70 years; 3) >70 years; and into three groups according to degree of occlusion: 1) > 70%; 2) 70% - 90%; and 3) < 90%.

Angiograms were studied meticulously and findings were counter checked by three observers including a senior cardiac surgeon. Each angiogram was viewed for the degree of occlusion and collateral circulation formation for major arteries like right coronary (RCA), left anterior descending (LAD) and Left circumflex artery (LCx). Collateral vessels were graded according to the Rentrop classification: grade 0 = no filling of collateral vessels; grade 1 = filling of collateral vessels without any epicardial filling of the artery to be dilated; grade 2 = partial epicardial filling of the artery to be dilated by collateral vessels; grade 3 = complete epicardial filling of the artery to be dilated by collateral vessels [9]. Based on angiographic data, patients were grouped into three categories—Group I: without collaterals (Grade 0); Group II: with collaterals (Grades 1 - 3), Group II was further divided into Group IIa: with poor collaterals (Grade 1); and Group IIb: those with adequate collateralization (Grade 2 - 3). Pattern of collateral development was compared among males and females, various age groups and degree of obstruction in coronary arteries. Mean with two standard deviations was calculated wherever required and statistical significance was found by applying paired/unpaired "*t* test" and chi square test wherever necessary using Microsoft excel and Epi Info 3.5.4 software. The study was approved by institutional committee.

3. Observations

Study was conducted on angiograms of 200 patients with coronary artery disease referred for surgical revascularization (154 males and 46 females). Angiograms of the patients with age ranging from 35 years to 84 years were studied with mean age 59.94 ± 10.13 years (59.36 ± 10.69 years in males and 60.89 ± 8.56 years in females). There were 134 (66.96%) cases with triple vessel disease (TVD), 55 (27.67%) with double vessel disease (DVD) and only 16 (8.04%) had single vessel disease (SVD). Among all cases 176 LAD, 136 LCx, & 157 RCA were found blocked (**Figure 1**) and among them 37% of LAD (65/176); 28% (38/136) LCx and 51% (80/157) RCA were having blockage > 90%. Group I included 25 (12.5%) cases while 175 (87.5%) cases were seen in Group II, however on further observation there were 73 (41.71%) cases in Group IIa and 102 (58.28%) cases in Group IIb.

Collateral Development: Collaterals developed in 66% cases with LAD disease (132/200), 44.5% of LCx (89/200) and 70.5% of RCA disease (141/200) as seen in **Figure 1**. Presence of coronary collaterals among various groups, divided on the basis of age, gender and percentage of occlusion was seen as per details mentioned in **Table 1**.

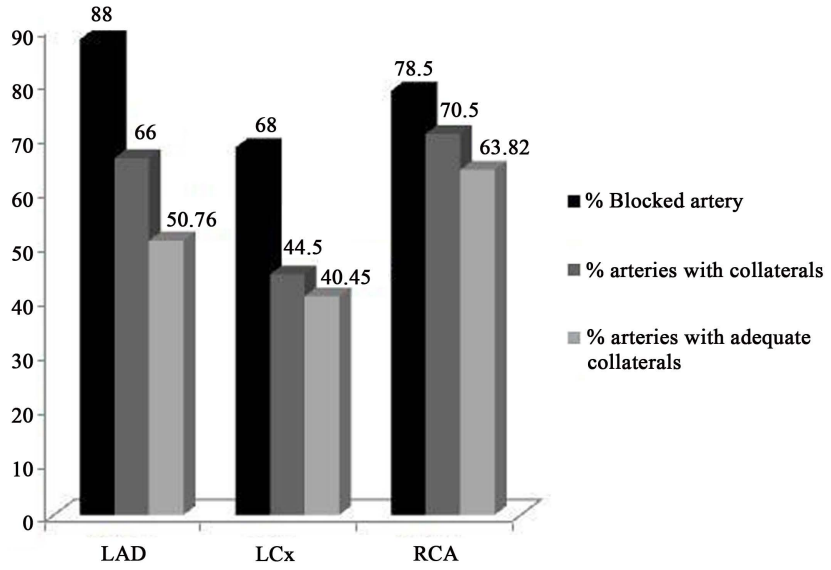


Figure 1. Comparison of occlusion and development of total and adequate collaterals in LAD, LCx and RCA.

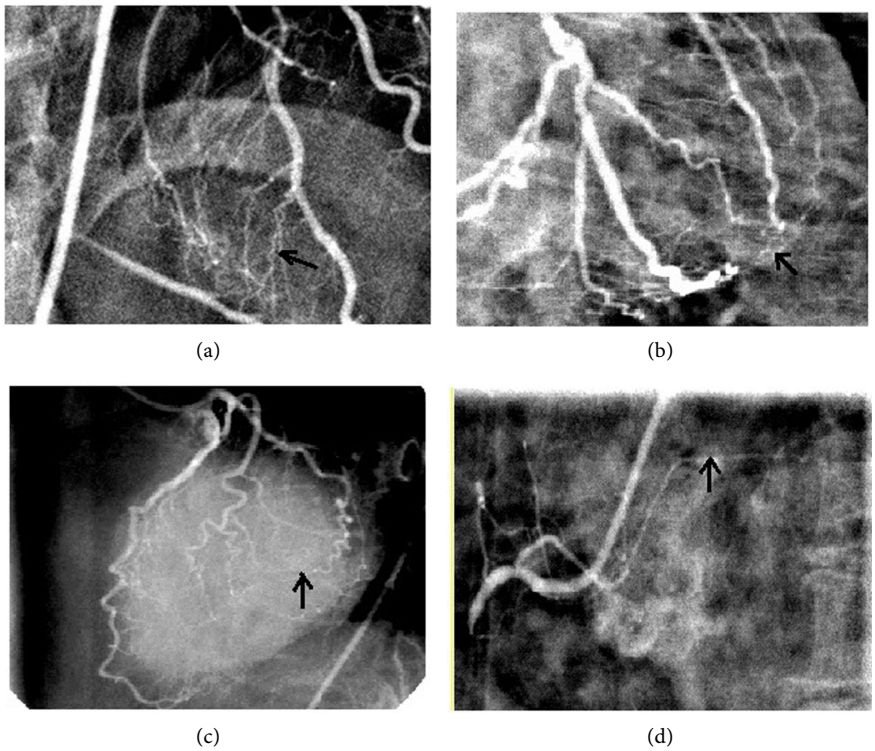
Table 1. Distribution of coronary collaterals in various groups.

Variables	Groups of variables	Group I (no collaterals)	Group II (poor collaterals)	Group III (Adequate collaterals)
Age	1) <50 (n = 25)	5 (20%)	12 (48%)	8 (32%)
	2) 50 - 70 (n = 139)	15 (10.8%)	51 (36.69%)	73 (52.52%)
	3) >70 (n = 36)	7 (19.4%)	9 (25%)	20 (55.6%)
Gender	Male (n = 154)	20 (13%)	66 (49.25%)	68 (50.75%)
	Females (n = 46)	5 (10.87%)	32 (78.05%)	9 (22%)
Arterial occlusion	1) <70% (n = 10)	4 (40%)	6 (60%)	0
	2) 70% - 90% (n = 100)	15 (17.64%)	48 (56.47%)	37 (43.52%)
	3) >90% (n = 90)	6 (7.14%)	38 (45.2%)	46 (54.8%)

Group IIb (Adequate Collaterals development): In present study Rentrops grade 2 and grade 3 collaterals were considered adequate collaterals (Group IIb). Adequate collaterals were observed in 54.8% (46/84) and 40.7% (37/91) cases in arterial obstruction > 90% and <90% respectively and in angiograms of 53% (71/134) males and 29.3% (12/41) females and this difference was significant (Table 1). A significantly higher number of adequate collaterals were seen in cases above 50 years (Table 2). Collaterals were adequate in 90/141 (63.82%) cases with RCA disease, 67/132 (50.76%) with LAD and 36/89 (40.45%) with LCX (Figure 1). RCA developed significantly higher number of collaterals in comparison to LAD ($p = 0.03$) and LCX ($p = 0.003$).

Collateral Pathways: Various pathways were observed for all three arteries. Intracoronary Collaterals across the block in RCA was the most common pathway followed by collaterals among PDA and LAD via ventricular septal branches (Table 3 & Figure 2(a)).

Right coronary artery: Collateral development was seen maximum in right



(a) (b) (c) (d)

Figure 2. Collateral distribution in various arteries: (a) LAD to PDA via ventricular septal branches (Grade 3); (b) Ramus to LAD (Grade 2); (c) Tortuous Diagonal branch of LAD communicating with OM branch of LCx (Grade 3); (d) SA nodal to LA Cx (Grade 1).

Table 2. Development of adequate collaterals in various groups.

Variables		Total cases	Cases with adequate collaterals	*P* values
Gender	Males	154	68	0.004
	Females	46	09	
Degree of arterial obstruction	>90%	90	46	0.019
	<90%	110	37	
Age group	Above 50 years	175	93	0.048
	Below 50 years	25	8	

coronary artery (RCA) and 19 types of collateral pathways were observed for this artery (Table 3, Figure 2(a) and Figure 2(d)). Collaterals across the block were most commonly seen pathways but adequate collaterals were most commonly in PLV-OM (Table 3). Collaterals between RCA and LAD were most commonly seen via ventricular septal branches of LAD and PDA (Figure 2(a)).

Left Anterior Descending: In obstruction of Left Anterior Descending (LAD) 8 types of collaterals were observed and collaterals from PDA to LAD were the commonest to develop (Table 3). In two cases ramus branch of left coronary artery was observed which formed collateral for LAD (Figure 2(b)).

Circumflex: We observed seven types of collaterals for circumflex artery ob-

struction and collateral vessels between diagonal to obtuse marginal artery were the commonest to develop (Table 3, Figure 2(c)).

4. Discussion

The mean age in the present study was a 59.94 ± 10.13 year which was comparable to that of only diabetic cases in a study from Turkey (in diabetic patients—59.09 ± 8.49 years, in non diabetic patients—58.89 ± 11 years) while CAD was observed at a higher average age in Swiss (64 years) and Japanese studies (62 ± 11 years) [10] [11] [12]. Therefore, it is evident that Indians are being affected at an earlier age. Well defined collaterals were observed for left anterior descending, circumflex and right coronary artery similar to those observed in an American study by Levin *et al.* [2], but the prevalence of development of collateral pathways was significantly higher ($p = 0.005$) in our study. A few pathways not reported by Levin have also been observed in present study (Table 3) [2]. In present study, although overall collaterals development was more in females, however prevalence of adequate collaterals was significantly higher ($p = 0.004$) in males (Table 1 and Table 2). Mouquet *et al.* [13] also observed poor coronary collateral circulation in women which was thought to be related to the fact that 96% of the female population was older than 50 years and therefore post-menopausal. Evidence suggests that estrogen directly modulates angiogenesis via effects on endothelial cells under physiological and pathophysiological conditions and that its loss in post-menopausal women is associated with a decreased angiogenic response [14]. In our study, population average age of female patients was 60.89 ± 8.56 years and there was only one woman with age less than 50 years who was also suffering from diabetes mellitus while remaining female patients were above fifty years, therefore development of adequate collaterals in less number of females could be due to decreased angiogenic response in post-menopausal women. Our findings are similar to those found in another study done on diabetes and non-diabetics which stated that Grade 3 collaterals were more prevalent when collateral development was in males < 55 years than in females of same age [15]. This probably can be the explanation for the higher mortality in women after first MI and those who survive have higher rise of recurrence of MI, heart failure or death [16]. On analyzing collateral development with age, it was observed that though the prevalence of coronary collaterals was highest in Group B (51 to 70 years), but prevalence of adequate collaterals were seen to be increasing with age (Table 1). In cases with age > 50 years, collaterals were significantly more prevalent compared to less than 50 years (Table 2). Nakae *et al.* [12] also observed higher prevalence of collaterals among cases with age ranging from 55 - 63 years, but well developed collaterals were documented less in older patients in their study group while Pohl *et al.* [17] did not find any significant correlation between age and collateral development (measured by coronary flow index). Increasing prevalence of coronary collaterals with age in present study was supported by an experimental study on pigs which has re-

ported significantly greater collateral development in older pigs [18]. Although arterial narrowing was seen more commonly in left anterior descending artery (88%) in comparison to right coronary artery (78.5%) & circumflex artery (68%), but collateral development was more prevalent in RCA (89.8%) in comparison to LAD (75%) and LCx (65.4%) (**Figure 3**). Levin [2] also reported collateral formation to be more prevalent in RCA. The explanation may be that LAD and circumflex arteries supply only left ventricular myocardium, a relatively high-resistance bed. The RCA, on the other hand, serves both left and right ventricular myocardium, latter being a relatively low-resistance bed. It is likely that the resistance in the RCA bed remains lower in the presence of an occlusion proximal to the acute marginal branches and flow of blood from high to low resistance area occurs through collateral channels. The presence of the two different myocardial resistance beds in the RCA territory may well explain why collateral circulation is more common with RCA than with LAD or circumflex occlusion [19]. Although both LAD and LCx are serving left ventricular myocardium, a high resistance bed, but there was significant difference in development of collaterals for LAD than for LCx ($p < 0.001$). The reason for that could be due to presence of preexisting anastomosing channels in these arteries which are seen more frequently for LAD than for LCx [20]. Levin [2] reported collaterals only in arteries with obstructions > 90%, however in our study, though a significant proportion of coronary arteries having > 90% arterial obstruction developed adequate collaterals, but 85% collaterals with 43.52% adequate collaterals were seen in the 70% - 90% occlusion and in 60% (6/10) cases collaterals with <70% narrowing. All collaterals seen in later group however were poorly developed (group IIa). Thus our finding suggests that collaterals can develop with even <90% of obstruction but adequate collaterals are significantly higher in cases with arterial obstruction > 90% (**Table 2**). Therefore it is concluded that coronary artery disease although affecting Indians at younger age, is associated

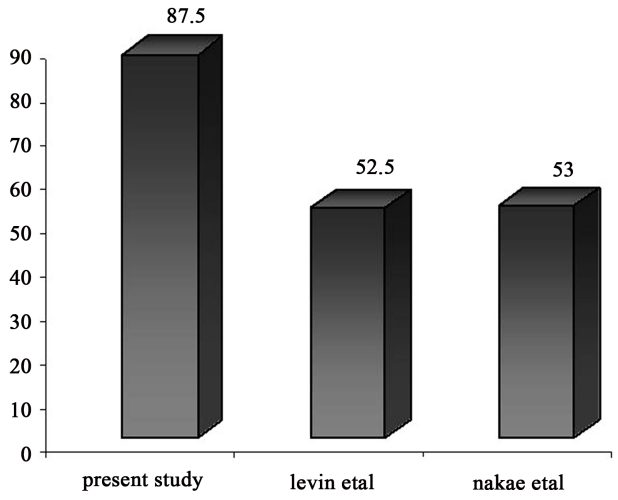


Figure 3. Prevalence of development of coronary collaterals: A comparison of present study with previous studies.

with higher prevalence of collateral development. Adequate collaterals develop more frequently in males and cases above 50 years. Collaterals, although more frequent in vessels with >90% occlusion, can be also seen in arteries with lesser degree of obstruction but in this group they are usually not well developed. Collateral circulation between LAD and PDA via ventricular septal branches is the commonest pathway to develop. Although blockage of LAD is more prevalent but more collaterals develop for blocked RCA (Table 3).

Table 3. Comparison of subjects with coronary collaterals.

Serial no	Collateral pathway	Present study	Levin *et al.*
	Collaterals for RCA		
1.	LAD → PDA via Ventricular septal Branch	26	28
2.	LCx → RCA (Distal)	5	24
3.	OM → PLV	17	17
4.	AM (Prox)→ AM (Distal)	1	9
5.	LAD →PDA	12	9
6.	AM → PDA	3	6
7.	SA NODAL → RCA VIA LACx	3	2
8.	RV (LAD) → AM	1	2
9.	LAD → CONUS (RCA)	3	-
10.	KUGAL's ARTERY	1	9
11.	RAMUS → PLV	9	-
12.	RCA (D) → PDA	2	-
13.	SA NODAL → AM	2	-
14.	LCx → PLV	2	-
15.	AM → RCA	2	-
16.	OM → PDA	2	-
17.	RCA (Prox) → RCA (Distal)	46	-
18.	LACx → AV NODAL	2	6
19.	CONUS (RCA) → AM	4	-
	Collaterals for LAD		
1.	AM → LAD	4	28
2.	PDA → LAD	37	3
3.	Proximal septal → Distal Septal	2	27
4.	OM → LAD	23	17
5.	D → LAD (Distal)	15	3
6.	PDA → LAD VIA Ventricular Septal	35	3
7.	OM → D	2	17
8.	CONUS (RCA) → LAD	11	-
9.	RAMUS → LAD	3	-
	Collaterals for LCx		
1.	LACx → LCx	4	7
2.	OM (Prox) → OM (Distal)	11	6
3.	D → OM	32	5
4.	RCA (Distal) → LCx (Distal)	4	2
5.	PLV → OM	27	2
6.	CONUS (RCA) → Cx	4	-
7.	RAMUS → LCx	7	-

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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