VIA MEDICA

ORIGINAL ARTICLE

Folia Morphol.
Vol. 76, No. 2, pp. 191–196
DOI: 10.5603/FM.a2016.0051

ISSN 0015–5659
www.fm.viamedica.pl

Coronary artery dominance dependent collateral development in the human heart

N.O. Ajayi[1], E.A. Vanker[2], K.S. Satyapal[1]

[1]*Department of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, University of KwaZulu-Natal, Westville Campus, Durban, South Africa*
[2]*Specialist Cardio-Thoracic Surgeon, St. Augustine's Hospital, Chelmsford Medical Centre, KwaZulu Natal, Durban, South Africa*

[Received: 4 March 2015; Accepted: 28 May 2015]

Background: In obstructive coronary artery disease, coronary collateral arteries serve as alternative conduits for blood flow to the myocardial tissue supplied by the obstructed vessel(s). Therefore, they are a "natural coronary arterial bypass" to the region supplied by the obstructed vessels. This study aims to determine the influence of demographic and morphologic coronary arterial factors on coronary collateral development in coronary arterial obstruction.

Materials and methods: The study group was selected from the coronary angiographic records of 2029 consecutive patients (mean age: 59 ± 12 years). Coronary collaterals were graded from 0 to 3 based on the collateral connection between the donor and recipient arteries. The angiograms of the patients (n = 286) with total obstruction of the coronary arteries were selected for analysis.

Results: There were no significant association between patients' age and sex and the formation of excellent collaterals. However, the location of atherosclerotic lesion affected collateral development in the right coronary artery. In addition, the right coronary arterial dominant pattern significantly influenced the formation of excellent coronary collaterals.

Conclusions: Coronary collateral arteries are better developed in right dominant pattern. It may be concluded that coronary arterial morphological pattern influences coronary collateral artery development. (Folia Morphol 2017; 76, 2: 191–196)

Key words: coronary artery obstruction, coronary collateral artery, coronary arterial dominance

INTRODUCTION

An important cause of morbidity and mortality is the formation and rupture of atherosclerotic plaque with resultant occlusion of large and medium size arteries [13]. In obstructive coronary artery disease (CAD), coronary collateral arteries serve as alternative conduits for blood flow to the myocardial tissue supplied by the obstructed vessel(s) [2]. Therefore, they are a "natural coronary arterial bypass" to the region supplied by the obstructed vessels [6, 11, 21]. The coronary collaterals are anastomotic connections between portions of same or different coronary arteries without an intervening capillary bed [6]. A comprehensive appreciation of the anatomy of the coronary arterial system and the coronary collateral pathways is crucial in the management of cardiac patients.

Address for correspondence: Prof. K.S. Satyapal, Department of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, University of KwaZulu-Natal, Private Bag X54001, Durban, 4000, South Africa, tel: +27 31 260 7899, +27 83 777 8780, fax: + 27 31 260 7890, e-mail: satyapalk@ukzn.ac.za

The confirmation of the presence of coronary collateral circulation has left several questions such as the distribution, histology and anatomy of these vessels unanswered [10]. There is great variability in the pattern and the extent of these coronary collateral pathways among different population groups [10]. Variability also exists in an individual's ability to develop coronary collateral arteries; some individuals develop functional collateral vessels, while others do not [8, 12, 21]. The complex mechanism responsible for coronary collateral development is still not properly understood [19]. Hence, there is still much to understand in respect of the development, potential for manipulation and the haemodynamic effects of the collateral pathways [8]. Therefore, the aim of this study is to determine the influence of demographic parameters and morphologic coronary arterial factors on coronary collateral development in the presence of total coronary arterial obstruction.

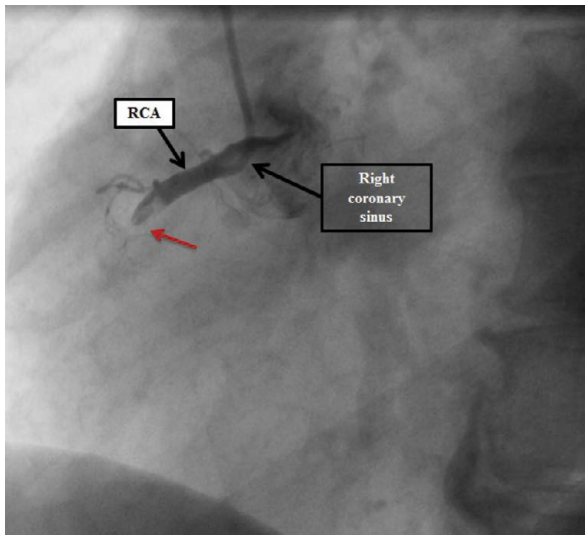

Figure 1. Coronary angiogram in the left anterior oblique view showing total obstruction of the right coronary artery (RCA; red arrows) without collateral vessels (grade 0; absent) to its distal segments.

MATERIALS AND METHODS

The study group was selected from the reviewed angiographic records of 2029 consecutive patients that had coronary catheterisation performed by interventional cardiologists for symptoms suggestive of CAD. Coronary angiograms of 286 patients (mean age: 59 ± 11 years) with the presence of total obstruction of the coronary arteries were selected for analysis. The angiograms were obtained from the cardiac catheterisation laboratories of hospitals within the private sector in the eThekwini Municipality region of KwaZulu-Natal, South Africa. Coronary arteriography was performed via the percutaneous trans-femoral approach by injecting radio-opaque contrast agent into the coronary blood vessels and the images were taken using X-ray fluoroscopy. These images were recorded on digital media in Digital Imaging and Communication in Medicine (DICOM) format and stored in the cardiac catheterization laboratories.

These angiograms were examined in the left anterior oblique, right anterior oblique and lateral projections with various degrees of cranial and caudal angulations. The coronary collateral pathways formed in these angiograms were observed and documented. All the connections within the same vessel and between different vessels were documented. The influence of the patients' sex and age (divided into two age group which are ≤ 60 years and > 60 years based on the patients' mean age) on the development of the collaterals was examined. The relationship between the location of atherosclerotic lesions and the coronary collateral grades were examined in these angiograms. The locations of atherosclerotic lesions were determined by dividing the coronary arteries into proximal, middle and distal regions. Furthermore, the effect of coronary arterial dominant patterns on collateral development was examined. Ethical approval (Ethics number BE 196/13) for the study was obtained from the University of KwaZulu-Natal Biomedical Research Ethics Committee.

The grading of the functional capacity of the coronary collaterals in the present study was based on the grading system used by Werner et al. [23]. This system centred on the collateral connection between the donor and the recipient arteries. Therefore, in the present study, Werner et al.'s [23] grading of the coronary collateral connections was modified and the coronary collaterals were graded as: Grade 0 (absent collateralisation): no collaterals to the distal region of the obstructed vessel (Fig. 1); Grade 1 (poor collateralisation): collateral arteries showing no continuous connection between the donor and recipient arteries; Grade 2 (good collateralisation): the presence of continuous threadlike connections between the donor and recipient arteries (Fig. 2); Grade 3 (excellent collateralisation): the presence of continuous prominent connections with side branches between the donor and recipient arteries (Fig. 3). Data was analysed with Statistical Package for the Social Sciences (SPSS) ver-

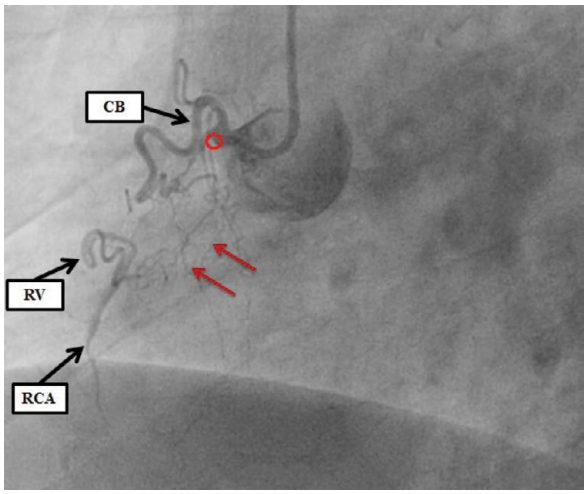

Figure 2. Coronary angiogram in the left anterior oblique view (caudal angulation) showing filling of the right ventricular (RV) branch of the right coronary artery (RCA) by grade 2 (good) collateral vessels (red arrows) originating from the conal branch (CB) of an obstructed RCA (red ring).

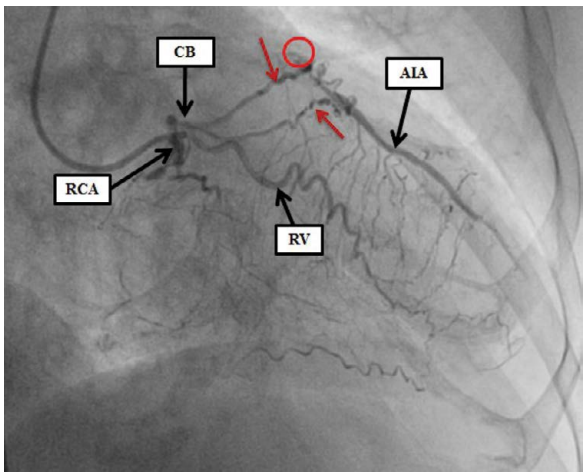

Figure 3. Coronary angiogram in the right anterior oblique view showing the filling of the anterior interventricular artery (AIA) obstructed at its proximal segment (red ring) by grade 3 (excellent) collateral vessels (red arrows) originating from the conal branch (CB) of right coronary artery (RCA); RV — right ventricular branch.

sion 21 for Windows (IBM SPSS, NY, USA). A p value < 0.05 was considered as statistically significant.

RESULTS

Grades of coronary collaterals in relation to age

The grades of the collateral pathways to the obstructed arteries were documented and compared with respect to the different age groups (≤ 60 years and > 60 years). There was no significant difference in the prevalence of the grades of coronary collaterals in the different age groups in the obstructions of the main coronary arteries (Table 1).

Grades of coronary collaterals in relation to sex

In the obstruction of the main coronary arteries, males were observed to have developed more excellent coronary collaterals than females. However, there was no statistically significant difference in the prevalence of the grades of coronary collaterals between females and males (Table 2).

Grades of coronary collaterals in relation to atherosclerotic lesion location

With respect to the effect of atherosclerotic lesion location on the formation of well-developed coronary collaterals, it was found that there was a significant difference in the formation of well-developed coronary collaterals in right coronary artery (RCA) obstructions ($p = 0.02$). There was no significant difference in the formation of these collaterals in anterior interventricular artery (AIA) and circumflex artery (Cx) obstructions (Table 3).

Grades of coronary collaterals in relation to coronary arterial dominance

Coronary arterial dominance was observed to have significantly influenced the formation of excellent coronary collateral pathways in the Cx and RCA

Table 1. Grading of the coronary collateral pathways in the different age groups in the obstructions of the main coronary arteries

Coronary artery	Age group	Grades of collateral vessel (%)				P
		Absent	Poor	Good	Excellent	
Anterior interventricular artery	≤ 60 years	33.3	17.9	30.8	17.9	0.38
	> 60 years	22.6	9.7	35.5	32.3	
Circumflex artery	≤ 60 years	22.5	22.5	30	25	0.1
	> 60 years	47.4	18.4	23.7	10.5	
Right coronary artery	≤ 60 years	18	12.4	30.3	39.3	0.06
	> 60 years	22.1	8.8	47.1	22.1	

Table 2. Grading of the coronary collateral pathways in females and males in the obstruction of the main coronary arteries

Coronary artery	Sex	Grades of collateral vessel (%)				P
		Absent	Poor	Good	Excellent	
Anterior interventricular artery	Female	31.3	6.3	43.8	18.8	0.64
	Male	30	15	30	25	
Circumflex artery	Female	40	20	36	4	0.21
	Male	30.6	19.4	27.4	22.6	
Right coronary artery	Female	22.6	12.9	48.4	16.1	0.28
	Male	18.5	10.4	37	34.1	

Table 3. Grading of the coronary collateral pathways in the obstruction of the proximal, middle and distal regions of the main coronary arteries

Coronary artery	Region	Grading of collateral vessel (%)				P
		Absent	Poor	Good	Excellent	
Anterior interventricular artery	Proximal	27.1	10.4	37.5	25	0.44
	Middle	38.5	15.4	26.9	19.2	
	Distal	–	50	–	50	
Circumflex artery	Proximal	45	15	25	15	0.32
	Middle	26.7	26.7	33.3	13.3	
	Distal	17.6	17.6	35.3	29.4	
Right coronary artery	Proximal	21.7	5.8	29	43.5	0.02
	Middle	15.4	16.9	43.1	24.6	
	Distal	21.9	9.4	53.1	15.6	

Table 4. Grading of the coronary collateral pathways in the different dominant patterns of the main coronary arteries

Coronary artery	Dominance	Grades of collateral vessel (%)				P
		Absent	Poor	Good	Excellent	
Anterior interventricular artery	Co-dominance	33.3	66.7	–	–	0.09
	Left	27.3	18.2	45.5	9.4	
	Right	30.6	9.7	32.3	27.4	
Circumflex artery	Co-dominance	–	–	100	–	0.05
	Left	10.5	26.3	47.4	15.8	
	Right	40.9	18.2	22.7	18.2	
Right coronary artery	Co-dominance	25	–	37.5	37.5	0.01
	Left	50	–	30	20	
	Right	14.5	13	40.6	31.9	

obstructions. It was significantly higher in the right coronary arterial dominant patterns (Table 4).

DISCUSSION

The most potent stimulus and important predictor for the development of coronary collaterals is coronary arterial stenosis [11, 17] and the resultant change in pressure gradient between the high pre-occlusive and the low post-occlusive pressure regions interconnected by coronary collaterals [16]. However, there are other factors that also contribute to this process, and these include the size and condition

of the distal segmental lumen of the vessel, blood viscosity, myocardial contractility, coronary vascular resistance [9], and physical activity of the subject [18]. Medical conditions such as high blood pressure [7] and diabetes mellitus [1, 20] have been reported to adversely affect the development of functional coronary collateral circulation. Contrary to the latter finding, Zbinden et al. [25] found that there was no difference in the coronary collateral flow between diabetic and non-diabetic patients. In addition, the recanalisation of an occluded coronary vessel results in the regression of coronary collaterals supplying the myocardial territory of the occluded vessel [24].

The richest collateral supply was to the RCA with a prevalence of excellent collaterals of 30.7% recorded in its obstructions; this was followed by the AIA (23.7%), and the least was in Cx (17.2%). The result of the present study confirmed previous reports that coronary collateral arteries are better developed in patients with RCA obstructions than in obstructions of other coronary vessels [5, 19, 20]. Therefore, it may be deduced that the quality of coronary collaterals developed is dependent on the morphology of the obstructed coronary artery and collateralisation from other vessels [19].

With respect to the influence of age on coronary artery collateral development, the prevalence of excellent collaterals was higher in the patients > 60 years of age than in those ≤ 60 years of age (32.3% vs. 17.9%) in the AIA obstructions. This is contrary to the findings of the prevalence of excellent collaterals (10.5% vs. 25%) and (22.1% vs. 39.3) for the patients > 60 years and those ≤ 60 years age in the Cx and RCA obstructions, respectively. However, there was no statistically significant difference in the prevalence of excellent coronary collateral arteries with respect to age in coronary arteries examined. Therefore, the present study found no association between patients' age and the development of excellent or well-functioning collaterals. The result of the present study corroborated the finding of Fujita et al. [4] who also used a cut-off age of 60 years and reported that the extent of coronary collateral development was similar in patients regardless of their age. Furthermore, van der Hoeven et al. [22] in their study divided patients into two groups (≤ 64 years and ≥ 65 years) and also found no association between higher age and the development of poor collaterals. Conversely, it differed from the reports of Nakae et al. [14] and Sun et al. [19] who stated that well-developed collaterals were significantly lower in patients older than > 65 years of age. The disparity in the results may be explained by the difference in the methods of coronary collateral assessment and grading of these channels. In addition, Cohen et al. [3] suggested the likelihood of genetic predisposition to the development of functional coronary collaterals because these anastomotic channels are laid down in utero.

In the present study, the prevalence of excellent collaterals was higher in males in the obstructions of the main coronary arteries. However, there was no statistically significant difference in the prevalence of excellent collaterals between males and females; therefore, there was no association between the patients' sex and the development of excellent collaterals. Although, the present finding differed from the report of Sun et al. [19] who stated that well-developed collaterals was significantly lower in female patients, it confirmed the reports of Fujita et al. [4] and Nakae et al. [14] who also found no significant difference.

In the study by Piek et al. [15], the proximal location of atherosclerotic lesion was reported to be a significant predictor of the development of coronary collateral arteries. They stated that the *'proximal location will result in a lower threshold for the development of myocardial ischaemia owing to the larger size of the myocardium "at risk" and, hence, to the stimulation of collateral vascular development'*. The current study also found a significant association between the development of excellent collaterals and the proximal location of lesions in the RCA. However, in the AIA and Cx, no significant association was recorded with respect to the location of atherosclerotic lesions.

From the literature reviewed, it is apparent that there are no reports on the influence of coronary arterial dominance on development of functional coronary collaterals. In the present study, the prevalence of excellent coronary collaterals was higher in patients with right coronary arterial dominant pattern than in the left dominant pattern. A significant association was found between right coronary arterial dominant pattern and the development of excellent coronary collaterals in Cx and RCA obstructions. The higher prevalence of excellent collaterals found in the right dominant pattern may be related to the fact noted earlier that the development of coronary collaterals is influenced by the morphology of the obstructed vessel. With the RCA also supplying the left ventricle in the right dominant pattern, the development of excellent collaterals may be amplified by this coronary

arrangement. Therefore, this morphological pattern of the coronary arterial tree has a significant effect on coronary collateral development.

CONCLUSIONS

A significant association was recorded between right coronary arterial dominance and the development of excellent collaterals in the Cx and the RCA. Therefore, coronary collateral arteries are better developed on the inferior myocardial surface due to this coronary arterial arrangement. It may be concluded that coronary arterial morphological pattern influences coronary collateral artery development.

REFERENCES

1. Abaci A, Oğuzhan A, Kahraman S, et al. Effect of diabetes mellitus on formation of coronary collateral vessels. Circulation. 1999; 99(17): 2239–2242, indexed in Pubmed: 10226087.
2. Berry C, Balachandran KP, L'Allier PL, et al. Importance of collateral circulation in coronary heart disease. Eur Heart J. 2007; 28(3): 278–291, doi:10.1093/eurheartj/ehl446, indexed in Pubmed: 17218452.
3. Cohen M, Sherman W, Rentrop KP, et al. Determinants of collateral filling observed during sudden controlled coronary artery occlusion in human subjects. J Am Coll Cardiol. 1989; 13(2): 297–303, indexed in Pubmed: 2521503.
4. Fujita M, Nakae I, Kihara Y, et al. Determinants of collateral development in patients with acute myocardial infarction. Clin Cardiol. 1999; 22(9): 595–599, doi: 10.1002/clc.4960220911.
5. Ilia R, Carmel S, Cafri C, et al. Coronary collaterals in patients with normal and impaired left ventricular systolic function. Int J Cardiol. 1998; 63(2): 151–153, indexed in Pubmed: 9510488.
6. Koerselman J, van der Graaf Y, de Jaegere PP, et al. Coronary collaterals: an important and underexposed aspect of coronary artery disease. Circulation. 2003; 107(19): 2507–2511, doi: 10.1161/01.CIR.0000065118.99409.5F, indexed in Pubmed: 12756191.
7. Koerselman J, de Jaegere PP, van der Graaf Y, et al. SMART Study Group. High blood pressure is inversely related with the presence and extent of coronary collaterals. J Hum Hypertens. 2005; 19(10): 809–817, doi: 10.1038/sj.jhh.1001917, indexed in Pubmed: 16107856.
8. Ladwiniec A, Hoye A. Coronary collaterals: a little give and take, and a few unanswered questions. J Clin Exp Cardiol. 2013; 4(4), doi: 10.4172/2155-9880.1000e124.
9. Levin DC. Pathways and functional significance of the coronary collateral circulation. Circulation. 1974; 50(4): 831–837, indexed in Pubmed: 4425386.
10. Loukas M, Bilinsky S, Bilinsky E, et al. The clinical anatomy of the coronary collateral circulation. Clin Anat. 2009; 22(1): 146–160, doi:10.1002/ca.20743, indexed in Pubmed: 19097064.
11. Meier P, Indermuehle A, Pitt B, et al. Coronary collaterals and risk for restenosis after percutaneous coronary interventions: a meta-analysis. BMC Med. 2012; 10: 62, doi: 10.1186/1741-7015-10-62, indexed in Pubmed: 22720974.
12. Meier P, Schirmer SH, Lansky AJ, et al. The collateral circulation of the heart. BMC Med. 2013; 11: 143, doi: 10.1186/1741-7015-11-143, indexed in Pubmed: 23735225.
13. Myers JG, Moore JA, Ojha M, et al. Factors influencing blood flow patterns in the human right coronary artery. Ann Biomed Eng. 2001; 29(2): 109–120, indexed in Pubmed: 11284665.
14. Nakae I, Fujita M, Miwa K, et al. Age-dependent impairment of coronary collateral development in humans. Heart Vessels. 2000; 15(4): 176–180, doi:10.1007/pl00007269.
15. Piek JJ, van Liebergen RA, Koch KT, et al. Clinical, angiographic and hemodynamic predictors of recruitable collateral flow assessed during balloon angioplasty coronary occlusion. J Am Coll Cardiol. 1997; 29(2): 275–282, indexed in Pubmed: 9014978.
16. Schaper W. Collateral circulation: past and present. Basic Res Cardiol. 2009; 104(1): 5–21, doi: 10.1007/s00395-008-0760-x, indexed in Pubmed:19101749.
17. Seiler C. The human coronary collateral circulation. Heart. 2003; 89(11): 1352–1357, doi: 10.1136/heart.89.11.1352.
18. Senti S, Fleisch M, Billinger M, et al. Long-term physical exercise and quantitatively assessed human coronary collateral circulation. J Am Coll Cardiol. 1998; 32(1): 49–56, indexed in Pubmed: 9669248.
19. Sun Z, Shen Y, Lu L, et al. Clinical and angiographic features associated with coronary collateralization in stable angina patients with chronic total occlusion. J Zhejiang Univ Sci B. 2013; 14(8): 705–712, doi: 10.1631/jzus.BQICC704, indexed in Pubmed: 23897789.
20. Tatli E, Altun A, Büyüklü M, et al. Coronary collateral vessel development after acute myocardial infarction. Exp Clin Cardiol. 2007; 12(2): 97–99, indexed in Pubmed: 18650990.
21. Turgut O, Yilmaz MB, Yalta K, et al. Prognostic relevance of coronary collateral circulation: clinical and epidemiological implications. Int J Cardiol. 2009; 137(3): 300–301, doi: 10.1016/j.ijcard.2008.06.016, indexed in Pubmed: 18684526.
22. van der Hoeven NW, Teunissen PF, Werner GS, et al. Clinical parameters associated with collateral development in patients with chronic total coronary occlusion. Heart. 2013; 99(15): 1100–1105, doi: 10.1136/heartjnl-2013-304006, indexed in Pubmed: 23716567.
23. Werner GS, Ferrari M, Heinke S, et al. Angiographic assessment of collateral connections in comparison with invasively determined collateral function in chronic coronary occlusions. Circulation. 2003; 107(15): 1972–1977, doi: 10.1161/01.CIR.0000061953.72662.3A, indexed in Pubmed:12665484.
24. Werner G. The role of coronary collaterals in chronic total occlusions. Curr Cardiol Rev. 2014; 10(1): 57–64, doi:10.2174/1573403x10666140311123814.
25. Zbinden R, Zbinden S, Billinger M, et al. Influence of diabetes mellitus on coronary collateral flow: an answer to an old controversy. Heart. 2005; 91(10): 1289–1293, doi: 10.1136/hrt.2004.041236, indexed in Pubmed: 16162618.