Comparative Analysis of the Coronary Arteries Flow Pattern in Secondary Myocardial Hypertrophies and by Sarcomeric Mutation

Análise Comparativa do Padrão de Fluxo de Artérias Coronárias das Hipertrofias Miocárdicas Secundárias e por Mutação Sarcomérica

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Abstract

Background: Coronary flow with a diastolic predominance increases two to five times in hyperemia, mediated by vasodilation (coronary flow reserve, CFR) and, in hypertrophy, relative ischemia may occur. In secondary hypertrophy (LVH), the flow, normal at rest, becomes ischemic due to increased demand. In hypertrophic cardiomyopathy (HCM) with perivascular fibrosis, collateral vessels appear to increase the irrigation of hypertrophied segments.

Objective: To determine the coronary flow pattern in patients with secondary hypertrophy and hypertrophic cardiomyopathy, evaluating the coronary flow reserve.

Methods: Coronary flow was evaluated in 34 patients with secondary hypertrophy, 24 with hypertrophic cardiomyopathy and in 16 controls. The anterior descending artery was detected with transthoracic Doppler with adequate equipment calibration. In the hypertrophic cardiomyopathy group, the flow of collaterals from the hypertrophic region was evaluated. In the control and secondary hypertrophy groups and in six patients in the hypertrophic cardiomyopathy group, the intravenous dipyridamole (0.84 mg) coronary flow reserve was calculated. The data were compared by variance with a significance of 5%.

Results: In secondary hypertrophy there was an increase in mass index and blood pressure, and in hypertrophic cardiomyopathy an increase in relative thickness predominated. Ejection fraction and diastolic dysfunction were higher in the hypertrophic cardiomyopathy group. The coronary flow reserve was lower in the hypertrophic cardiomyopathy group, and flow of collaterals was also detected, with a reduction in the coronary flow reserve.

Conclusion: the analysis of coronary circulation with transthoracic Doppler is possible in normal and hypertrophic individuals. Patients with secondary hypertrophy and hypertrophic cardiomyopathy have a decrease in the coronary flow reserve, and patients with hypertrophic cardiomyopathy show a hyper flow of dilated collateral vessels observed in the hypertrophic region, with a decrease in the coronary flow reserve.

Keywords: Fractional flow reserve, myocardial; Echocardiography Doppler; Cardiomegaly.

Resumo

Fundamento: *O fluxo coronariano com predomínio diastólico aumenta duas a cinco vezes na hiperemia, mediada por vasodilatação (reserva de fluxo coronariano), podendo, na hipertrofia, ocorrer isquemia relativa. Na hipertrofia secundária, o fluxo em repouso torna-se isquêmico pelo aumento da demanda. Na cardiomiopatia hipertrófica com fibrose perivascular, há funcionalização de vasos colaterais, para aumentar a irrigação dos segmentos hipertrofiados.*

Objetivo: *Determinar o padrão do fluxo coronariano em pacientes com hipertrofia secundária e cardiomiopatia hipertrófica, avaliando a reserva de fluxo coronariano.*

Métodos: *Avaliamos o fluxo coronariano em 34 pacientes com hipertrofia secundária, em 24 com cardiomiopatia hipertrófica e em 16 controles. A artéria descendente anterior foi detectada com Doppler transtorácico com calibração adequada do equipamento. Nos grupos controle e com hipertrofia secundária, foi calculada a reserva de fluxo coronariano com dipiridamol (0,84 mg/kg) endovenoso. O mesmo procedimento foi realizado em seis pacientes do grupo com cardiomiopatia hipertrófica, nos quais também foi avaliado o fluxo das colaterais da região hipertrófica. Os dados foram comparados por variância com significância de 5%.*

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Manuscript received 7/31/2020; revised 11/5/2020; accepted 11/9/2020

DOI: 10.47593/2675-312X/20213401eabc131

Resultados: *Na hipertrofia secundária, houve aumento do índice de massa e, na cardiomiopatia hipertrófica, predominou o aumento da espessura relativa. A fração de ejeção e a disfunção diastólica foram maiores no grupo com cardiomiopatia hipertrófica. A reserva de fluxo coronariano foi menor no grupo com cardiomiopatia hipertrófica, sendo detectado, também, fluxo de colaterais com redução da reserva de fluxo coronariano.*

Conclusão: *A análise da circulação coronariana com Doppler transtorácico é possível em indivíduos normais e hipertróficos. Pacientes com hipertrofia secundária e cardiomiopatia hipertrófica apresentam diminuição da reserva de fluxo coronariano, e aqueles com cardiomiopatia hipertrófica mostram fluxo de vasos colaterais dilatados observados na região hipertrófica, com diminuição da reserva de fluxo coronariano.*

Palavras-chave: *Reserva fracionada de fluxo coronário; Ecocardiografia Doppler; Cardiomegalia.*

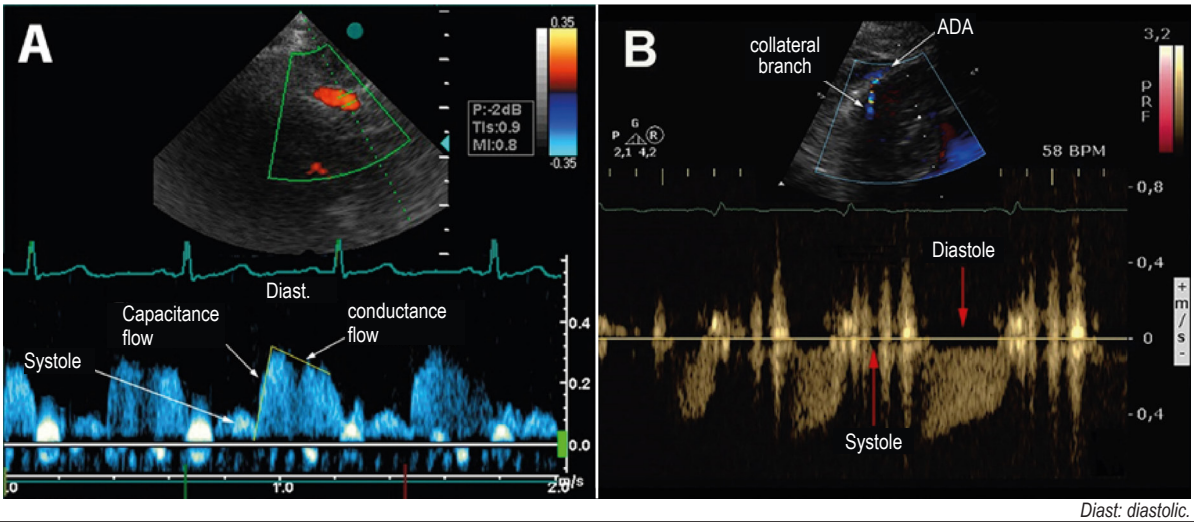
Introduction

Normal myocardial irrigation is provided by epicardial conductance vessels and intramural resistance vessels connected to an extensive serial and parallel capillary network. Capillaries are connected to post-capillary veins, venules, and epicardial veins that flow into the right atrium through the coronary sinus. Also, the collateral circulation vessels form an extensive anastomotic network that connects the various vascular compartments, usually in a non-functional state.[1]

Coronary flow is determined by the relationship between systemic blood pressure and the resistance of epicardial vessels, resistance vessels, capillaries, and the venous system, with the greatest resistance at the intramural vessel level.[2] Capillaries, which individually offer great resistance due to their parallel arrangement, have lower total resistance.[3] Collateral vessels, although non-functional, can be functionalized in acute situations (ischemia, sudden demand increase, or increased myocardial mass) and are present in patients and normal subjects.[4]

The heart works in an almost exclusively aerobic regime, with high oxygen consumption and an exceptional capacity to extract this gas, but with limited anaerobic capacity; thus, a decreased oxygen supply (myocardial ischemia, for example) triggers a rapid cascade that can result in arrhythmia and cardiac arrest requiring constant self-regulation. The difference between basal flow and hyperemia is called coronary flow reserve (CFR), the vasodilation capacity of intramural vessels designed to increase myocardial flow and perfusion in cases of increased oxygen consumption, i.e., the quotient between flow velocity or volume at maximum hyperemia and at rest. Under normal conditions, CFR increases two- to five-fold compared to basal flow.[5] The coronary flow regime is biphasic and predominantly diastolic (Figure 1).[6]

Patients with ventricular hypertrophy due to increased myocardial mass have a greater need for oxygen. When the wall thickness is ≤15 mm as commonly happens in secondary hypertrophies (systemic arterial hypertension), the coronary flow at rest is normal but with a decreased CFR. In this condition, myocardial ischemia without coronary obstruction can occur when there is an increased cardiac output due to increased extravascular resistance caused by myocardial mass expansion, perivascular fibrosis, and a decreased number of capillaries per muscle area. In patients with significant ventricular hypertrophy and a wall thickness ≥17 mm, more common in forms caused by sarcomeric mutation (hypertrophic cardiomyopathy [HCM]), present a largely increased basal coronary flow. This phenomenon



Diast: diastolic.

Figure 1 – *(A) Coronary flow in a conductance artery (middle third of the anterior descending branch) obtained using pulsed Doppler from the parasternal position. There is a predominance of diastolic flow with capacitance and conductance or resistance flows. The ramp slope in this phase represents vascular tone. (B) Coronary flow in a collateral vessel in an intramural direction from the anterior descending artery. Note the systolic reverse flow moving away from the transducer during diastole.*

occurs because intramural resistance vessels do not dilate to supply the increased myocardial mass resulting from middle layer hypertrophy and intima hyperplasia, which reduce their lumen[7] and functionalize the collateral circulation vessels, which start to present flow.[8] CFR is also reduced.[9]

Objective

To determine the velocimetric coronary flow pattern and CFR in patients with secondary left ventricular hypertrophy (LVH) and HCM versus normal subjects.

Methods

Coronary flow was evaluated in 58 patients with secondary LVH separated into two groups: 34 patients with arterial hypertension (LVH group) with a mean age of 53 ± 10 years, 26 of whom were male; and 24 patients with HCM (HCM group) with a mean age of 47 ± 14 years, 15 of whom were male. A total of 16 subjects with no evidence of heart disease (control group) with a mean age of 48 ± 9 years, 11 of whom were male, were also evaluated.

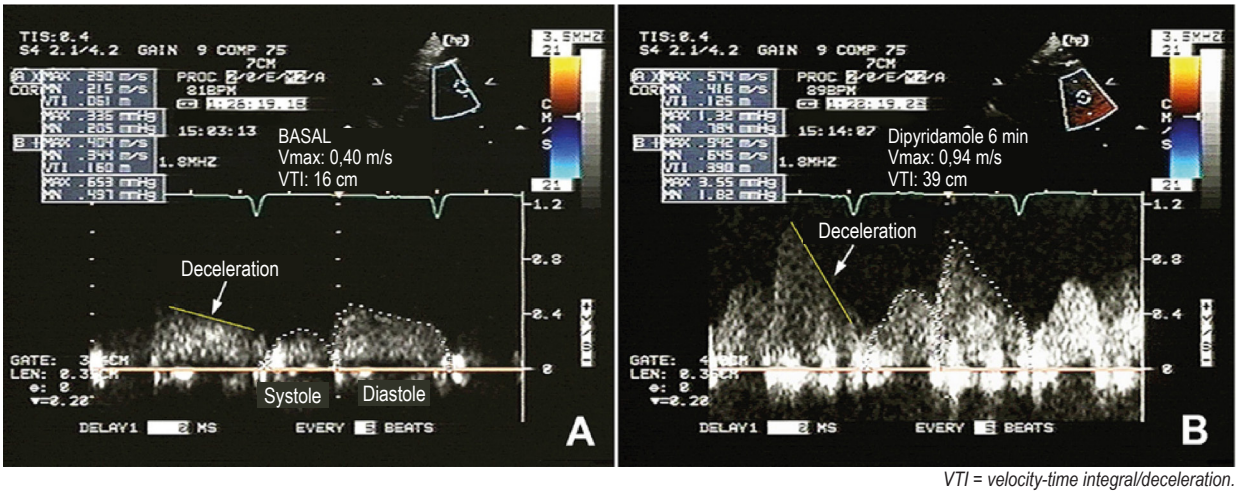
The LVH group consisted of patients with chronic systemic arterial hypertension and LVH. The HCM group was formed by patients with a disproportionately increased regional or global LV wall thickness with no apparent cause or increased afterload.

LV size and function were determined by measuring the diastolic septum and wall thickness and the diastolic and systolic LV diameters. Left atrial (LA) diameter and indexed volume were also determined according to current guidelines.[10] The LV Global Longitudinal Strain (GLS) was calculated in all participants in the control group, 27 in the LVH group, and 20 in the HCM group.

The flow of the anterior descending artery (ADA) was obtained by transthoracic color Doppler in the spectral pulsatile modality, with color flow velocity calibrated from 20 to 30 cm/s, a high persistence level, and low filtration. The spectral Doppler velocity was calibrated to obtain low flow velocities.[11] The transverse parasternal window modified at or below the papillary muscles was used to obtain the tracings. The maximum diastolic velocity (cm/s) and diastolic velocity integral (cm) were calculated in the spectral pulsed wave Doppler tracing (Figure 2) as well as in the dilated intramural vessels (probably collateral) found in the hypertrophic region in the HCM group (Figure 1B).

All participants in the control group, all patients in the LVH group, and six of the 24 patients in the HCM group had the CFR calculated with a slow intravenous bolus of dipyridamole 0.84 mg/kg administered over a 4-min interval.[5] As the test was not performed to analyze pharmacological stress, atropine was not infused, but in all cases aminophylline was administered at a dose of 120–240 mg at 8–10 min after the dipyridamole injection, to finish the examination. The intramural vessel flow present in the hypertrophic segments was also recorded in patients of the HCM group. The intramural vessel CFR was calculated in the six patients who received the dipyridamole infusion.

Since CFR may be influenced by microcirculation changes and epicardial vessel stenosis, there were some inclusion criteria for patients with hypertrophy to enter the control group. Control group participants were recruited among kidney donors undergoing coronary angiography without obstructive changes (seven subjects); patients undergoing cineangiography for diagnostic purposes without evidence of coronary stenosis, or valve and myocardial changes (five subjects); patients undergoing pharmacological stress echocardiography with no evidence of segmental contractility changes or clinical data suggestive of coronary stenosis (four subjects). All participants were normotensive with no kidney, valve or myocardial disease, and four had controlled type 2 diabetes mellitus. The LVH group included systemic arterial hypertension and myocardial hypertrophy patients undergoing



VTI = velocity-time integral/deceleration.

Figure 2 – *Coronary flow reserve in a subject with no evidence of heart disease. (A) Biphasic basal flow with diastolic predominance showing a slow deceleration ramp, indicating high flow progression resistance with a maximum diastolic velocity of 0.40 m/s and a velocity integral of 16 cm. (B) Flow obtained 6 min after the infusion of a bolus of dipyridamole 0.84 mg/kg showing increased deceleration velocity (decreased resistance) and increased diastolic (0.94 m/s) flow and integral (39 cm) velocity, estimating a CFR of 2.35 for velocity and 2.44 for the integral.*

hemodialysis without evidence of significant stenosis on coronary angiography. The patients in the HCM group had generalized ventricular (five patients), asymmetric septal (obstructive in six, non-obstructive in three), mid-ventricular (five patients; two with intraventricular gradient), apical (seven patients; one with intraventricular gradient), and lateral wall (one patient) hypertrophy. None of these patients had systemic arterial hypertension or segmental contractility changes related to the coronary territories. Twelve patients underwent coronary angiography without evidence of significant obstruction. Sixteen patients underwent clinical research with evidence of HCM or sudden death in the family. Eight patients had controlled type 2 diabetes mellitus. Other exclusion criteria were fascicular or atrioventricular blocks of any degree, aortic valve disease greater than mild severity, coronary artery disease clinically or hemodynamically recognized, dilated cardiomyopathies, and infiltrative myocardial diseases.

The data were compared between groups by the parametric analysis of variance test complemented by the Tukey analysis to determine sample mean differences at a 5% statistical significance.

Results

Increased mass index (mean 207.6 g/m² ± 49 g/m²) and relative thickness (mean 0.45 ± 0.09), characterizing LV concentric hypertrophy, was predominant in patients with systemic arterial hypertension (LVH group). The patients in the HCM group presented a lower mass index increase (mean 176.2 g/m² ± 78.5 g/m²) and a greater relative wall thickness increase (0.75 ± 0.32). The ejection fraction (59.6% ± 4.7% versus 56.5% ± 10.4%, $p < 0.0001$) and the E/e' ratio (11.7 ± 4.4 versus 6.5 ± 1.8, $p < 0.0001$) were higher in the HCM group. The increased LA size and indexed volume in patients with LVH were significantly greater in the HCM group. The LV GLS was slightly decreased in the LVH group (-17.5% ± 2.8%) and moderately decreased in the HCM group (-14.9% ± 3.63%). Table 1 shows the demographic data, LV and LA sizes, and LV function parameters. Table 2 shows the coronary flow results at baseline and after dipyridamole infusion, with a more reduced CFR in the six HCM patients than in the LVH patients (1.75 ± 0.58 versus 2.08 ± 0.61). Patients in the HCM group also presented intramural vessel flow, probably collateral, with a decreased CFR both in epicardial and intramural vessels in the six patients receiving dipyridamole.

Discussion

Conductance epicardial vessels travel across the surface of the heart, and a few perforate it. Intramural resistance vessels present a proximal pre-arteriolar compartment with an intramural pathway and a distal arteriolar compartment connected to an extensive capillary network at a ratio of one capillary to each myocardial fiber in a serial and parallel arrangement. There are about 4,000 capillaries/mm² of myocardium. In turn, the capillaries connect to the post-capillary veins, followed by venules and epicardial veins, which flow into the coronary sinus. There are also collateral circulation vessels with no muscle fibers forming an extensive anastomotic network that connect the various vascular compartments with intramural pathway, from the epicardial to the endocardial region, normally in a non-functional state.[12]

Coronary flow resistance is distributed in percentages as epicardial vessels with <5% of the total resistance, pre-arteriolar vessels with 30%, and distal (arteriolar) compartment with 40%. Capillaries provide great individual resistance, but due to their parallel arrangement, the capillary network offers the least resistance in the entire system.[13] The venous network offers approximately 7% of the total coronary resistance. Collateral circulation vessels can be functionalized in acute situations (ischemia, suddenly increased demand, or increased myocardial mass). As they have no muscle layer, these vessels do not contract, possibly playing an important role in the flow balance between different coronary territories. Their number decreases with age.[14] Of the blood volume contained by the myocardium (12 mL/100 g of muscle), 90% are contained in the capillary bed.

Table 1 – Patients' demographic data and cavity size and function.

	Controls	LVH	HCM	$p_{(1-2)}$	$p_{(1-3)}$	$p_{(2-3)}$
Age, years	48.38 ± 9.52	53.32 ± 10.07	47.42 ± 14.04	< 0.0001	0.20	< 0.0001
Sex (M, F)	11 M. 5 F	26 M. 8 F	15 M. 9 F	-	-	-
LA volume, mL/m²	27.00 ± 9.6	33.1 ± 11.3	48.1 ± 22.9	< 0.0001	< 0.0001	< 0.0001
LA diameter, mm	31.0 ± 4.1	36.2 ± 5.8	40.0 ± 7.2	0.004	< 0.0001	< 0.0001
LVEF, %	56.44 ± 4.84	56.50 ± 10.43	59.62 ± 4.74	0.47	< 0.0001	< 0.0001
Mass index, g/m²	104.22±13.95	207.57 ± 49.22	176.19 ± 78.46	< 0.0001	< 0.0001	< 0.0001
Relative thickness	0.30 ± 0.04	0.45 ± 0.09	0.75 ± 0.32	0.04	0.0006	0.006
LV GLS, %	-19.1 ± 3.2	-17.5 ± 2.8	-14.9 ± 3.6	0.002	< 0.0001	< 0.0001
Mitral E wave, cm/s	77.14 ± 15.44	63.38 ± 11.89	82.24 ± 34.70	< 0.0001	0.0014	< 0.0001
E/A ratio	1.18 ± 0.35	0.90 ± 0.28	1.26 ± 0.60	0.05	0.36	0.02
Tissular e' wave, cm/s	13.60 ± 2.99	10.33 ± 2.30	7.36 ± 2.95	< 0.0001	< 0.0001	< 0.0001
E/e' ratio	5.79 ± 1.17	6.46 ± 1.81	11.75 ± 4.38	0.04	< 0.0001	< 0.0001
SBP, mmHg	128.75 ± 12.32	151.47 ± 12.88	138.33 ± 10.94	< 0.0001	< 0.0001	< 0.0001
DBP, mmHg	78.13 ± 9.64	92.79 ± 8.98	87.92 ± 6.20	< 0.0001	< 0.0001	< 0.0001

F, female; DBP, diastolic blood pressure; GLS, global longitudinal strain; HCM, hypertrophic cardiomyopathy; LA, left atrium; LVEF, left ventricular ejection fraction; LV, left ventricle; LVH, hypertensive hypertrophy; M, male; SBP, systolic blood pressure

Table 2 – Coronary flow and coronary flow reserve in normal subjects and in patients with acquired ventricular hypertrophy and hypertrophic cardiomyopathy.

	Controls	LVH	HCM	$p_{(1-2)}$	$p_{(1-3)}$	$p_{(2-3)}$
Baseline HR, bpm	72.44 ± 11.19	71.53 ± 12.87	69.25 ± 18.17	0.20	0.008	0.02
Dipyridamole HR, bpm	78.94 ± 10.68	77.88 ± 12.84	69.00 ± 16.97	0.16	< 0.0001	< 0.0001
Baseline Vmax, cm/s	34.56 ± 12.29	31.32 ± 10.96	36.28 ± 18.66	0.001	0.01	< 0.0001
Dipyridamole Vmax, cm/s	133.37 ± 50.43	65.24 ± 18.06	67.30 ± 22.16	< 0.0001	< 0.0001	0.04
CFR Vmax	3.86±0.31	2.08±0.61	1.75± 0.58	< 0.0001	< 0.0001	0.06
Baseline VTI, cm	16.66 ± 6.85	13.14 ± 3.58	17.97 ± 4.86	< 0.0001	0.05	< 0.0001
Dipyridamole VI, cm	64.91 ± 25.87	29.42 ± 13.25	27.00 ± 7.34	< 0.0001	< 0.0001	0.004
CFR VTI	3.91 ± 0.18	1.99 ± 0.71	1.54 ± 0.17	< 0.0001	< 0.0001	0.005
Collateral Vmax, cm/s	-	-	60.22 ± 29.31	-	-	-
Collateral dipyridamole Vmax, cm/s		-	98.65 ± 43.86	-	-	-
Collateral CFR, Vmax	-	-	1.66 ± 0.44	-	-	-
Collateral baseline VTI, cm	-	-	24.11 ± 8.54	-	-	-
Collateral dipyridamole VTI, cm	-	-	33.92 ± 18.49	-	-	-
Collateral CFR VTI	-	-	1.56 ± 0.47	-	-	-

CFR, coronary flow reserve; Collateral, collateral artery; HCM, hypertrophic cardiomyopathy; HR, heart rate; LVH, hypertensive hypertrophy; Vmax, maximum coronary velocity; VTI, velocity-time integral

As the heart works in an almost exclusively aerobic regime, with exceptional oxygen extraction capacity, it has limited anaerobic capacity. For this reason, a decreased oxygen supply triggers a rapid ischemic cascade, which can culminate in arrhythmia and cardiac arrest. Due to these characteristics, a reduced myocardial reserve (<25%) demands constant self-regulation, which can increase coronary flow up to five times to supply the needs. As the myocardium responds immediately to an increased oxygen demand with a proportionally increased flow, this increase (hyperemia), or the CFR, is mediated by mechanical and metabolic factors. The mechanical factors include greater myocyte compression on the vessels during systole in the subendocardial region, where the intramural vessel diameter decreases about 20% during systole without changes in subepicardial vessel diameter.[15] This determines a biphasic flow regimen that is predominantly diastolic, with a smaller systolic component and an important diastolic component formed by a first phase of rapid increase (capacitance phase, intended to quickly fill the vessels emptied during the compression phase), followed by a slower descending ramp (perfusion), whose inclination depends on vascular tone (Figure 1).

Metabolic factors regulate the myogenic activity of vessels by releasing vasodilators (the main being adenosine and K^{+}_{ATP} and nitric oxide channels). This self-regulating mechanism keeps coronary perfusion constant in the different compartments despite pressure variations. Thus, the pressure is approximately 90 mmHg in epicardial arteries, 45 mmHg in the arteriolar network, 30 mmHg in the capillary network, and 5 mmHg in the venules. The autonomic nervous system also plays an important role in self-regulating coronary flow, especially with increased demand (exercise), when sympathetic stimulation causes vasodilation mediated by beta-adrenergic receptors and vasoconstriction mediated by alpha-adrenergic receptors. The endothelium also significantly contributes to coronary flow self-regulation.

Thus, CFR is the vasodilation ability of the intramural vessels to increase flow and myocardial perfusion in cases of increased oxygen consumption, i.e., the quotient between flow velocity or volume at maximum hyperemia versus at rest. Under normal conditions, CFR increases two- to five-fold compared to basal flow.

Some factors can change these mechanisms, whether due to epicardial vessel stenosis (coronary artery disease), microcirculation changes (diabetes), or even in ventricular hypertrophy.

In ventricular hypertrophy, the mechanism differs between forms. Patients with secondary ventricular hypertrophy (systemic arterial hypertension) with an overall wall thickness ≤ 15 mm have decreased coronary flow at rest with a decreased CFR and may present with myocardial ischemia without coronary obstruction in cases of increased cardiac output (relative ischemia). The mechanism of this decrease is due to the increased extravascular resistance caused by an increased myocardial mass, increased perivascular fibrosis, and decreased capillary density by muscle area, whose reduction is proportional to an increased myocyte volume. Some authors[16,17] suggest that microvascular and diastolic dysfunction increases baseline coronary flow reduction in hypertrophic ventricles. These patients predominantly present with an increased ventricular mass with normal-sized cavities (concentric hypertrophy).

Patients with more severe ventricular hypertrophy, usually caused by a sarcomeric mutation, with a wall thickness ≥ 17 mm have a predominantly increased relative wall thickness, with smaller LV cavities than the group with secondary hypertrophy, who also present with a higher ejection fraction but a lower GLS. In this group, diastolic function parameters show a significantly higher E/e' ratio, which, associated with greater LA size and volume, indicates a greater increase in LV filling pressure. A higher baseline coronary flow velocity is observed, especially when compared to the LVH group, probably due to higher oxygen consumption under baseline conditions. As intramural resistance vessels are unable to expand to supply the increased myocardial mass due to

mid-layer hypertrophy and intimal hyperplasia, which reduce their lumen, the collateral circulation vessels apparently become functional and start to present a detectable flow on Doppler. These vessels, located in regions with greater hypertrophy, have no muscle layer; rather, they present a predominantly retrograde systolic flow due to muscle compression and increased anterograde diastolic flow velocity suggestive of hyperflow. It is important to highlight that the retrograde coronary flow found in epicardial vessel stenosis is associated with decreased diastolic flow only in the epicardial arteries, usually with no intramural vessel flow. Patients with HCM present with a normal or increased velocity intramural vessel flow (Figure 1). Despite the increase in velocity, however, a decreased CFR is observed in the epicardial and intramural vessels.

These coronary flow characteristics seem to corroborate the differences among the analyzed groups: hypertensive patients with LVH seem to have a more homogeneous hypertrophy distribution, with lower wall thickness, larger cavities, and a less decreased CFR than patients with HCM, which present segmental hypertrophy distribution with a myofibrillar disarray changing the physiology of intramural vessels, decreasing their vasodilation capacity and apparently functionalizing the collateral vessels, which show regional hyperflow and greater CFR decrease.

No patient or control showed signs of myocardial ischemia during the examination using dipyridamole, but 71% of them complained of respiratory distress (12 in the control group, 15 in the LVH group, and 14 in the HCM group), with tachypnea, shortness of breath, and expiratory wheezes, all of which improved after aminophylline administration.

Several studies[18-20] emphasized the prognostic value of CRF in patients with myocardial hypertrophy, and its decrease is considered a strong predictor of cardiovascular complications such as atrial fibrillation, sustained arrhythmias, heart failure progression, and death of cardiac cause.

Limitations

The main limitations of this study are technical problems with properly registering the ADA flow from the left coronary artery due to heart translation during the cardiac cycle and the patients' chest conditions as well as the small number of patients studied, mainly with HCM, which makes larger-scale studies necessary to validate the findings presented here.

Conclusion

When the appropriate technique is used, the study of coronary circulation using transthoracic Doppler is possible in normal subjects and patients with secondary or genetic hypertrophy. Patients with secondary hypertrophy due to systemic arterial hypertension or HCM due to a sarcomeric mutation present with a CFR below the normal range after dipyridamole infusion, which is more evident in HCM. Patients with HCM also show flow in dilated intramural vessels, probably in the collateral vessels, that can be visualized in most hypertrophic segments, with a CFR below the normal range and characteristically not showing systolic anterograde flow, maintaining an increased velocity anterograde diastolic flow in these vessels. This suggests collateral-mediated baseline hyperflow due to the inability to vasodilate intramural arterioles. This increased intramural circulation was not detected in the control group or in the secondary LVH group, being detected only in patients with HCM.

Authors' contributions

Research conception and design, data collection, analysis and interpretation, statistical analysis, manuscript writing, critical review of the manuscript for important intellectual content: CG Souza, JM Del Castillo; data analysis and interpretation, critical review of the manuscript for important intellectual content: M Mazzarollo; critical review of the manuscript for important intellectual content: S Alburqueque, ADM Sena, D Brindeiro Filho, CAM Silveira.

Conflict of interest

The authors have declared that they have no conflict of interest.

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