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# Increased Wasted Myocardial Work as an Indicator of Significant Coronary Lesion

## Aumento do Trabalho Miocárdico Desperdiçado como Indicador de Lesão Coronariana Significativa

Márcio Mendes Pereira[1], Amanda Castro Barroso[1], Marco Túlio Hercos Juliano[1], Márcio Mesquita Barbosa[1], Gustavo Travassos Gama[1], Rodrigo de Jesus Louzeiro Melo[1], José Bonifácio Barbosa[1], Carlos Alberto Vieira Gama[1], José Xavier de Melo Filho[1], Auridesio Cutrim de Araujo[1]

[1]UDI Hospital Rede D'Or São Luiz, São Luís, MA, Brazil.

## Abstract

**Introduction:** The assessment of global myocardial work indices under baseline conditions may be useful for the clinical stratification of patients with suspected coronary obstruction.

**Objective:** To correlate the value of global myocardial work indices and the presence of significant obstructive coronary lesions.

**Method:** Cross-sectional study, with patients referred for elective coronary angiography. An echocardiogram was performed to obtain measurements to calculate the value of myocardial work and evaluated the presence or presence of significant obstructive coronary lesions at coronary angiography.

**Results:** The sample consisted of 30 patients, with a mean age of 64.2±12.8 years, the majority being male (63.3%), of which 68.4% had significant obstructive coronary lesions. The global myocardial work indices was 1,876mmHg%±253.8 in the group with significant obstructive coronary lesions and 2,054.2mmHg%±417.3 in those without significant lesions (p=0.089). Global constructive myocardial work in patients without significant obstructive coronary lesions was higher (2,329.3mmHg%±462.9) than in those with significant obstructive coronary lesions (2,109.5mmHg%±332.3; p=0.064). Global wasted myocardial work was higher in patients with significant obstructive coronary lesions (103.7mmHg%±47.1 versus 68.3mmHg%±33.8; p=0.038). The cutoff point of 115 mmHg% was the one with the best area under the curve (0.625), with a sensitivity of 83.3%.

**Conclusion:** The increase in global wasted myocardial work correlated with the presence of significant obstructive coronary lesions in our sample.

**Keywords:** Cardiac function; Echocardiography; Heart defects, congenital; Coronary stenosis.

## Resumo

**Introdução:** A avaliação dos índices de trabalho miocárdico global em condições basais pode ser útil para a estratificação clínica de pacientes com suspeita de obstrução coronariana.

**Objetivo:** Correlacionar o valor do índice de trabalho miocárdico global e a presença de lesões obstrutivas coronarianas significativas.

**Método:** Estudo transversal, com pacientes encaminhados para cinecoronarioangiografia eletiva. Foi realizado ecocardiograma com obtenção das medidas para cálculo do valor do trabalho miocárdico, sendo avaliada a presença de lesões obstrutivas coronarianas significativas à cinecoronarioangiografia.

**Resultados:** A amostra foi composta de 30 pacientes, com a idade média de 64,2±12,8 anos, sendo a maioria do sexo masculino (63,3%), dos quais 68,4% apresentaram lesões obstrutivas coronarianas significativas. O índice de trabalho miocárdico global foi de 1.876mmHg%±253,8 no grupo com lesões obstrutivas coronarianas significativas e de 2.054,2mmHg%±417,3 naqueles sem lesões significativas (p=0,089). O trabalho miocárdio construtivo global nos pacientes sem lesões obstrutivas coronarianas significativas foi maior (2.329,3mmHg%±462,9) do que naqueles com lesões obstrutivas coronarianas significativas (2.109,5mmHg%±332,3; p=0,064). O trabalho miocárdio desperdiçado global foi maior nos pacientes com lesões obstrutivas coronarianas significativas (103,7mmHg%±47,1 versus 68,3mmHg%±33,8; p=0,038). O ponto

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de corte de 115mmHg% foi aquele com a melhor área sob a curva (0,625), com sensibilidade de 83,3%.

**Conclusão:** O aumento do trabalho miocárdio desperdiçado global se correlacionou com a presença de lesões obstrutivas coronarianas significativas em nossa amostra.

**Palavras-chave:** Função cardíaca; Ecocardiografia; Cardiopatias congênitas; Estenose coronária.

## Introduction

The early detection of coronary artery disease (CAD) is crucial for its proper treatment. However, it remains challenging in echocardiography since the left ventricular ejection fraction (LVEF) is usually normal in the early disease stages. Stress echocardiography is a widely accepted method for such investigations, but it features the disadvantages of subjectivity and the need to achieve the target heart rate.[1]

Ventricular systolic function evaluation is an essential part of the echocardiogram, with LVEF being the most often used parameter.[2] LV global longitudinal strain (GLS) has gained attention, as it can detect subclinical abnormalities in patients with a normal LVEF.[3] However, it is afterload-dependent, which can reduce the GLS, causing regional and global contractile function interpretation errors.[4]

Myocardial work is a proposed new tool used to study LV performance,[5] surpassing LVEF and GLS when used alone.[6] Myocardial work incorporates LV pressure and adds information to LVEF and strain,[7] integrating the afterload to the LV function parameter.

Myocardial work is obtained by multiplying the GLS by the wall stress since work is the multiplication of force by distance.[6] Noninvasive myocardial work measurements showed a strong correlation with invasive measurements both experimentally and clinically.[8] Russell *et al.* reported that the LV strain curve pressure area was significantly reduced in areas supplied by an occluded coronary artery compared to those with normal perfusion assessed by angiography.[8]

This study aimed to assess the correlation between the noninvasive myocardial work value assessed by echocardiography and the presence of severe CAD assessed by cineangiography (CAG).

## Methods

### Echocardiographic assessment

This single-center cross-sectional study included prospectively recruited patients electively referred for CAG for CAD assessment. The exclusion criteria were chest pain at the time of the echocardiogram, previous history of acute myocardial infarction, LVEF < 50%, LV segmental contraction changes, moderate or more severe valvular heart disease, aortic stenosis, hypertrophic cardiomyopathy, biological or metallic aortic prosthesis, a pacemaker rhythm, or an irregular rhythm (frequent extrasystole or atrial fibrillation or flutter). As it is a pilot study, we arbitrated the sample in 30 patients.

The patients signed an Informed Consent Form upon arriving at the hemodynamics laboratory for elective CAG and subsequently underwent transthoracic echocardiography with electrocardiographic monitoring. The tests were performed using a Vivid E95 cardiovascular ultrasound device (GE Medical Systems, Horten, Norway) equipped with 3.5-MHz MS5 phased-array sector probes.

Echocardiographic measurements and assessments were obtained according to American Society of Echocardiography recommendations.[9] Two-dimensional standard images were obtained with three cycles trigged by the QRS complex and digitally recorded for offline analysis using EchoPAC software version 202 (GE Vingmed Ultrasound). LVEF was calculated using the three-dimensional method.

The myocardial global work index (GWI) was quantified by calculating the rate of regional shortening by the differentiation of the global longitudinal tracing and multiplying by the instantaneous LV pressure. This instantaneous measurement was integrated over time to measure myocardial work as a function of time during systole (time interval from mitral valve closure to mitral valve opening). The segments were analyzed during LV ejection for myocardial global wasted work (GWW) and/or myocardial global constructive work (GCW), with global values determined as the means of all segmental values and displayed on the pressure-LV deformation circuit diagram. The following parameters were generated by the software: GWI (mmHg%), area within the LV global pressure curve; GCW (mmHg%), estimated work performed by the LV segments consisting of shortening during systole plus stretching in isovolumetric relaxation; GWW (mmHg%), estimated negative work done by the LV segments consisting of myocardial stretching during systole plus any shortening during isovolumetric relaxation; myocardial global work efficiency (GWE; %), GCW divided by the sum of GCW and GWW expressed as a percentage (not affected by peak LV pressure).[1,10,11]

Functional ischemia area (FIA) was defined as established by Boe *et al.*,[7] who considered adjacent segments as ischemic when the absolute GLS value was < 14% and the GWI was < 1,700 mmHg%. According to these values, we defined and correlated the FIA with the significantly obstructed coronary artery.

### Cineangiography assessment

CAG was performed using a Philips FD10 catheterization device according to Brazilian Society of Hemodynamics and Interventional Cardiology techniques.[12] Significant CAD was defined as luminal narrowing ≥ 50% in the left main coronary artery (LMCA) and/or ≥70% in the anterior descending (AD), diagonal (DG), circumflex (CX), marginal (MG), or right coronary (RC) arteries through visual assessment by the hemodynamic cardiologist.

### Statistical analysis

The data were tabulated and analyzed using Stata® Intercooled software version 12.0.

Categorical variables are presented as absolute (n) and relative (%) frequency. Continuous variables are presented as mean and SD or as median and interquartile range according to the skewness and kurtosis normality tests.

The significance of any intergroup differences was assessed using Student's t-test for normally distributed data. The Mann-Whitney U or Kruskal-Wallis test was used to examine non-normally distributed variables.

The chi-square or the Fisher's exact test was used to examine categorical variables when appropriate.

Receiver operating characteristic analysis was used to identify the optimal cutoff point for each parameter.

A logistic regression model was performed to determine independent variables capable of identifying patients with significant coronary disease. The FIA determined by strain and myocardial work was analyzed in separate models.

P values < 0.05 indicated statistical significance.

## Results

### Clinical characteristics

A total of 30 patients with a mean age of 64.2 ± 12.8 years were included in the study; most were men (63.3%), of whom 68.4% had significant obstructive coronary lesions (SOCL) (Table 1).

Most patients were hypertensive and dyslipidemic (19 [63.3%] in each group), 36.6% were diabetic, 30% were obese, and none had a previous history of stroke. Significant lesions were present on CAG in 63.2% of hypertensive, 73.7% of dyslipidemic, 63.6% of diabetic, and 77.8% of obese patients.

### Characteristics of cineangiography

Of the total number of patients in the sample, six (20%) had no lesions on CAG and 24 (80%) had coronary obstructions greater than 50%. Of the patients with coronary lesions, 19 (63.3%) had SOCL. In this group, 68.4% were men, with a mean age of 65.4 ± 10.6 years.

Regarding coronary lesion location, 18 patients (60%) had lesions in the AD, one (3.3%) in the LMCA, seven (23.3%) in the DG, five (16.7%) in the CX, four (13.3%) in the MG, and six (20%) in the RC artery.

### Echocardiographic characteristics

The echocardiographic characteristics of the sample are described in Table 2. Grade 1 diastolic dysfunction was present in 50% of the sample. No patients had grade 3 diastolic dysfunction, while all had preserved systolic function. The mean LVEF calculated using the three-dimensional method was 65.2 ± 3.3% in patients with SOCL versus 63.6 ± 4.6% in those without SOCL.

According to Table 2, the mean GLS was 18.3 ± 2% in the sample with SOCL and 19.1 ± 2.9% without SOCL on CAG (p = 0.313).

Mean MGWI was 1,876 ± 253.8 mmHg% in patients with SOCL versus 2,054.2 ± 417.3 mmHg% in those without SOCL (p = 0.089).

The GCW was higher in patients without versus with SOCL on CAG, being 2,329.3 ± 462.9 mmHg% and 2,109.5 ± 332.3 mmHg%, respectively (p = 0.064).

The mean GWW values were higher in patients with versus without SOCL (103.7 ± 47.1 mmHg% vs. 68.3 ± 33.8 mmHg%, p = 0.038).

Figure 1 shows an image from a sample patient with an AD lesion in which the wasted myocardial work of the basal segment of the anterior septum is greater than the GWW. There was no difference in GWE between patients with or without significant lesions (95.6 ± 2.0 vs. 94.7 ± 2.2, p = 0.296).

GLS presented no statistically significant difference between patients with or without SOCL, the same occurring when analyzed by arterial territory (Table 3).

**Table 1 – Clinical characteristics.**

| Variables | Total (n=30) |
|---|---|
| Age (years) | 64.2 ± 12.8* |
| Weight (kg) | 69.2 ± 16.9* |
| SBP (mmHg) | 127.4 ± 16.6* |
| DBP (mmHg) | 73 ± 9.1* |
| HR (bpm) | 69.4 ± 11.8* |
| Comorbidities | |
| Hypertension | 19 (63.3%) |
| DM 2 | 11 (36.7%) |
| Previous CAD | 15 (50%) |
| Stroke | 0 (0%) |
| Dyslipidemia | 19 (63.3%) |
| Obesity | 9 (30%) |
| Smoking | 2 (6.7%) |

*CAD: coronary artery disease; DBP: diastolic; blood pressure; DM 2: type 2 diabetes mellitus; HR: heart rate; SBP: systolic blood pressure; *mean ± standard deviation;*

**Table 2 – Echocardiographic characteristics.**

| Variables | Total (n=30) | SOCL on CAG (=11) | No SOCL on CAG (=19) | P value |
|---|---|---|---|---|
| Diastolic dysfunction | | | | 0,167 |
| Absent | 7 (23.3) | 2 (28.6) | 5 (71.4) | |
| Grade 1 | 15 (50) | 4 (26.7) | 11 (73.3) | |
| Inconclusive | 7 (23.3) | 5 (71.4) | 2 (28.6) | |
| Grade 2 | 1 (3.3) | 0 (0) | 1 (100) | |
| 3D LVEF (%) | 64.6 ± 3.8 | 63.3 ± 4.6 | 65.2 ± 3.3 | 0.313 |
| GLS,% | 18.3 ± 2.7 | 18.3 ± 2.4 | 19.1 ± 2.9 | 0.377 |
| GWI (mmHg%) | 1989 ± 371.2 | 1876 ± 253.8 | 2054.2 ± 417.3 | 0.089 |
| GWE (%) | 95 ± 2.2 | 95.6 ± 2.0 | 94.7 ± 2.2 | 0.296 |
| GCW (mmHg%) | 2248 ± 427.4 | 2109.5 ± 332.3 | 2329.3 ± 462.9 | 0.064 |
| GWW (mmHg%) | 90.7 ± 427.4 | 68.3 ± 33.8 | 103.7 ± 47.1 | 0.039 |

*3D: three-dimensional; CAG: cineangiography; GCW: global constructive work; GLS: global longitudinal strain; GWE: global work efficiency; GWI: global work index; GWW: global wasted work; LVEF: left ventricular ejection fraction; SOCL: significant obstructive coronary lesions.*
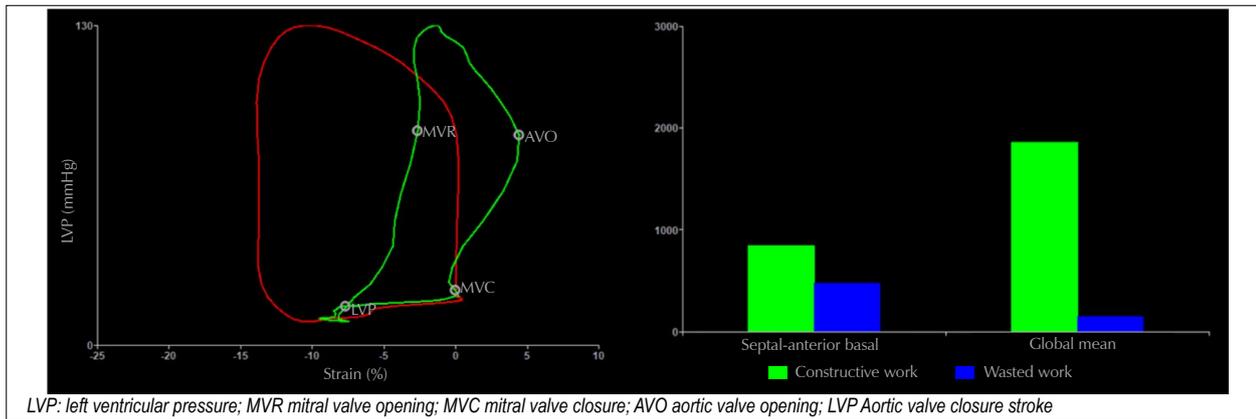
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LVP: left ventricular pressure; MVR mitral valve opening; MVC mitral valve closure; AVO aortic valve opening; LVP Aortic valve closure stroke

**Figure 1 –** *Left ventricular pressure-strain curve diagram. (A) The global myocardial work is represented in red and the regional work of the basal segment of the anterior septum is represented in green. (B) There is decreased constructive work and increased wasted work of the septal-anterior basal segment in relation to the global mean.*

**Table 3 – Relationship between coronary lesions and global longitudinal strain for each coronary territory.**

|  | SOCL on CAG (=11) | No SOCL on CAG (=19) | P value |
|---|---|---|---|
| GLS (%) | 18.3 ± 2.4 | 19.1 ± 2.9 | 0.377 |
| AD strain (%) | 19.5 ± 2.6 | 19.4 ± 3.2 | 0.900 |
| CX strain (%) | 17.8 ± 3.1 | 19.4 ± 3.5 | 0.359 |
| RC strain (%) | 18.2 ± 3.1 | 21.5 ± 3.0 | 0.103 |

*AD: anterior descending artery; CX: circumflex artery; GLS: global longitudinal strain; RC: right coronary artery.*

The presence of a GWW lower than 115 mmHg% demonstrated a sensitivity of 83.3% and a specificity of 41.7% for identifying patients with SOCL, with an area under the curve (AUC) of 0.625 (Table 4).

The separations of patients by arterial territory showed that the GWW presented a better AUC for identifying significant lesions in the AD (0.643) than in the RC (0.432) and CX (0.405) arteries (Figure 2).

The GLS was ≤16.5% in eight patients, of whom five had SOCL on catheterization with a sensitivity of 62.5% for obstructive CAD on CAG (Table 4).

## Discussion

This study showed that GWW was higher in patients with SOCL on CAG than in those without SOCL.

Noninvasive myocardial work is a new tool for assessing LV systolic function as demonstrated in several studies, being superior to isolated LVEF and LV GLS.[8,13] Myocardial work parameters can assess LV performance and segmental function.

Wasted work is energy expenditure measured as work consumed during segmental lengthening (negative work) as a percentage of work during segmental shortening (positive work)[14]. Therefore, wasted work measurement can quantify the work done by the ventricle that does not contribute to ejecting blood from the LV.[15]

In the present study, a GWW > 115 mmHg% showed a sensitivity of 83.3% for identifying significant coronary obstructions, suggesting that it can be used to identify anatomically important lesions. Edwards *et al.* stated that a cutoff point of 80 mmHg% for GWW was associated with a sensitivity of 89.3% for SOCL detection similar to our study but with a lower cutoff point.[1]

A structurally normal heart presents few differences between the contraction times of the different LV segments.[16] All segments contract almost simultaneously against similar LV pressure, with only small physiological differences in segmental contraction timing.[15,14] When segmental contraction changes, some segments initiate relaxation at the end of systole under high ventricular pressure. This shows that some of the work done by the contracting segments is wasted during stretching of the relaxing segments.[15]

This study showed that the GWW in patients with significant AD artery lesions was greater than that in those without significant lesions in this artery compared to the global value when separated by arterial territory affected. Conversely, GCW was higher in patients without versus with significant lesions on CAG.

GWI can be defined as the total work accounted for by the LV strain curve pressure area from mitral valve closing to opening.[17] GWI can aid misinterpretations of reduced LV systolic function based only on decreased LV strain in patients with high afterload but no coronary obstruction.[7] In this study, the GWI was constant with the GLS. We also observed that GWI was lower in patients with SOCL on CAG, although the difference was not statistically significant.

A decreased LV GLS has been demonstrated as a predictor of CAD even in cases without significant obstruction[18] in addition to being superior to LVEF and LV segmental dysfunction as a predictor of cardiovascular events.[19] In our study, the assessment of LV GLS demonstrated a sensitivity of 62.5% for SOCL.

If confirmed by other studies, due to the good sensitivity

**Table 4 – Echocardiographic parameters and detection of significant coronary artery obstruction.**

|  | GLS | GWI | GWE | GCW | GWW |
|---|---|---|---|---|---|
| AUC | 0,494 | 0,444 | 0,625 | 0,444 | 0,625 |
| AUC CI95% | 0,312-0,687 | 0,254-0,625 | 0,438-0,801 | 0,255-0,626 | 0,438-0,801 |
| Cutoff value | <16,5% | <1700mmHg% | <95% | <2000mmHg% | >115mmHg% |
| Sensitivity (%) | 62,5 | 55,6 | 75 | 55,5 | 83,3 |
| Specificity (%) | 36,4 | 33,3 | 50 | 33,3 | 41,7 |

*AUC: area under the curve; CI: confidence interval; GLS: global longitudinal strain; GCW: global constructive work; GWE: global work efficiency; GWI: global work index; GWW: global wasted work.*
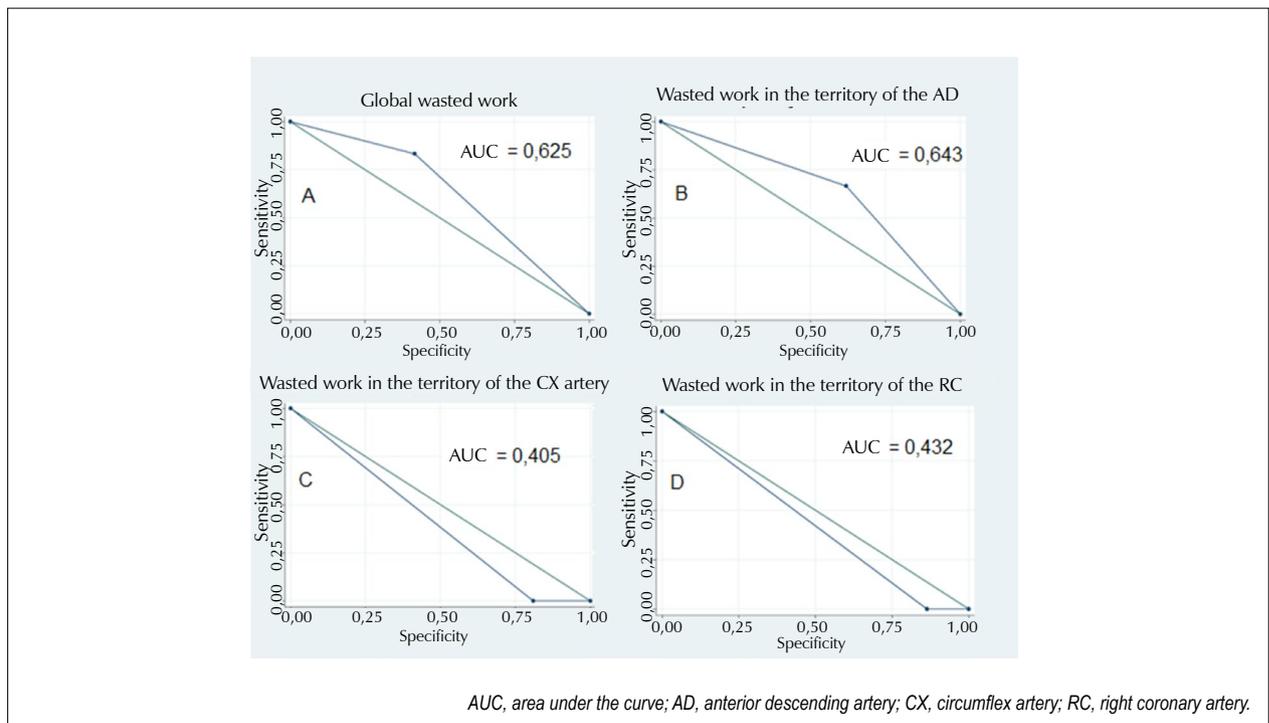


*AUC, area under the curve; AD, anterior descending artery; CX, circumflex artery; RC, right coronary artery.*

**Figure 2 –** *Area under the curve of the global wasted work and each arterial territory. (A) Global wasted work. (B) Work wasted in the territory of the anterior descending artery. (C) Wasted work in the circumflex artery territory. (D) Work wasted in the territory of the right coronary artery.*

of GWW, this method may be a screening tool for CAD with significant lesion (stenosis > 70%), selecting patients for further investigation.

### Study limitations

The small sample of patients in this study may have contributed to its lack of statistical significance. In addition, an invasive stratification was performed in patients with a high probability of CAD, as coronary lesions were previously diagnosed by coronary computed tomography angiography or an ischemic functional test, thus restricting the number of patients who were young or lacking risk factors in our sample.

### Conclusion

GWW correlated with the identification of significant coronary obstructions with a sensitivity of 83.3%.

This myocardial work information can be used to detect significant obstructive lesions. Further studies are necessary to confirm the value of these promising data.

### Authors' contributions

Research conception and design, manuscript writing, data analysis and interpretation, statistical analysis: Pereira MM; manuscript writing, data analysis and interpretation: Barroso AC; critical review of the manuscript for important intellectual content: Juliano MTH, Melo RJL, Gama CAV, Barbosa JB, and de Melo Filho JX; data collection: Barbosa MM, Araujo AC, and Gama GT.

### Conflict of interest

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

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