Original Article

Cardiovascular Magnetic Resonance Imaging-Derived Mitral Valve Geometry in Determining Mitral Regurgitation Severity

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Abstract

Background: Mitral regurgitation is the most common valvular heart disease worldwide. Magnetic resonance may be a useful tool to analyze mitral valve parameters.

Objective: To distinguish mitral valve geometric patterns in patients with different severities of mitral regurgitation (MR) based on cardiovascular magnetic resonance imaging.

Methods: Sixty-three patients underwent cardiovascular magnetic resonance imaging. Mitral valve parameters analyzed were: tenting area (mm2) and angle (degrees), ventricle height (mm), tenting height (mm), anterior leaflet, posterior leaflet length and annulus diameter (mm). Patients were divided into two groups, one including patients who required mitral valve surgery and another which did not.

Results: Thirty-six patients had trace to mild (1-2+) MR and 27 had moderate to severe MR (3-4+). Ten (15.9%) out of 63 patients underwent surgery. Patients with more severe MR had a larger left ventricle end systolic diameter (38.6 ± 10.2 vs 45.4 ± 16.8, $p < 0.05$) and left end diastolic diameter (52.9 ± 6.8 vs 60.1 ± 12.3, p= 0.005). On multivariate analysis, the tenting area was the strongest determinant of MR severity (r= 0.62, p=0.035). Annulus length (36.1 ± 4.7 vs 41 ± 6.7, $p < 0.001$), tenting area (190.7 ± 149.7 vs 130 ± 71.3, p= 0.048) and posterior leaflet length (15.1 ± 4.1 vs 12.2 ± 3.5, p = 0.023) were larger on patients requiring mitral valve surgery.

Conclusions: Tenting area, annulus and posterior leaflet length are possible determinants of MR severity. These geometric parameters could be used to determine severity and could, in the future, direct specific patient care based on individual mitral apparatus anatomy (Arq Bras Cardiol. 2013;100(6):571-578).

Keywords: Mitral Valve Insufficiency / physiopathology; Magnetic Resonance; Mitral Valve Prolapse.

Abbreviations

AL- anterior leaflet length
PL - posterior leaflet length
TA - tenting angle
TAR - tenting area
TH - tenting height

Introduction

Mitral regurgitation is the most common valvular heart disease worldwide. The most common causes of mitral regurgitation include mitral valve prolapse, ischemic heart disease, rheumatic heart disease, endocarditis, drug-induced valvulopathy and collagen vascular disorders[1]. While rheumatic heart disease is the leading cause of mitral regurgitation in developing countries, ischemic disease plays the major role in the western world and developed countries[2].

The development of mitral regurgitation is a common complication of ischemic heart disease with a negative impact on survival[3,4]. Mitral tenting, in combination with regional left ventricular myocardial scarring leading to segmental alterations, are important mechanisms in the pathophysiology of ischemic mitral regurgitation.

Structural abnormalities of the valve leaflets themselves generally occur secondary to rheumatic heart disease and connective tissue disorders, including Marfan Syndrome, Ehlers – Danlos syndrome and osteogenesis imperfecta[5].

Mitral valve prolapse is another important cause, characterized by systolic billowing of one or both valve leaflets into the left atrium. This condition has a unique appearance on echocardiography and cardiac magnetic resonance imaging.

Echocardiography is well suited to describing valve features in accordance with the cause of regurgitation. Transthoracic echocardiography has been indicated as

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a class I-C recommendation by the American College of Cardiology (ACC) for baseline evaluation of left ventricular size and function, right ventricle and left atrial size, pulmonary pressure and severity of mitral valve disease; it is indicated as class I-B for delineation of the mechanism[1] and determination of the etiology as well as the severity of mitral regurgitation[6].

Data from literature has shown that cardiac magnetic resonance imaging provides excellent correlation with clinical echocardiography[7]. It also has been recognized as an appropriate method for evaluation of native or prosthetic valves, mainly in those patients with limited images from transthoracic or transesophageal echocardiograms. The superior spatial resolution of magnetic resonance imaging is especially helpful in this regard[8]. Furthermore, cardiac magnetic resonance imaging facilitates accurate quantification of regurgitation volumes and regurgitation fraction[8,9]. Therefore, cardiac magnetic resonance imaging may be a useful tool to analyze parameters that could help clinicians to determine the etiology, as well as determine prognosis and the best treatment approach.

This study aims to distinguish mitral valve geometric patterns in patients with different severity and treatment for mitral valve regurgitation by cardiovascular magnetic resonance imaging.

Methods

Study population

Patients were referred for cardiac magnetic resonance imaging for standard clinical indications and all study data were obtained by clinical image dataset. Over a 24-month time period, 63 patients with mitral regurgitation were enrolled in the current cross sectional study. At the time of the study patients had clinically stable New York Heart Association class I, II or III symptoms of congestive heart failure. We used the Carpentier's functional classification to classify mechanisms of primary valvular regurgitation[10]. All data were obtained by electronic software analysis, without violation of ethical research principles. A local IRB approved the research protocol (R4977).

Magnetic Resonance Imaging Protocol

Images were obtained using a 1.5T General Electric whole body scanner (HD Excite version 12 GE – Milwaukee – WI). Subjects were imaged in the supine position and signal reception was accomplished using a 4 channel phased array cardiac coil. Sequences of interest included single shot Echo Planar Imaging, using a cardiac-triggered system with 40mT maximum gradient strength and 150 mT/m/ms maximum slew rate. The following parameters were used: repetition time (TR) = 9ms, echo time (TE) = 4ms, flip angle (FA) = 40 degrees, slice thickness = 8mm, , number of excitations (NEX) = 2 – 4, field of view = 380 - 420mm, and matrix 128 x 128. Sagital scout images were used to plan multiplanar steady state free-precession sequences (SSFP), without contrast administration. Mitral valve and ventricular geometry were analyzed using cine sequences.

Mitral and ventricular measurements

Contours of the mitral valve and parameters such as leaflet length, height and areas were manually traced at end-systolic frames.

The following mitral valve parameters were measured in the three-chamber view: tenting area (TAR), tenting angle (TA), tenting height (TH) and anterior (AL) and posterior leaflet (PL) lengths. The annular diameter and ventricular height (VH) were measured in the two-chamber view. (Figure 1, 2, and 3). Study patients were divided into two groups based on regurgitant jet areas within the left atrium (trace to mild: 1 to 2+ and moderate to severe: 3 to 4+). Patients were also divided into two groups based on outcomes: one group included patients who underwent mitral valve surgery and the other included patients who did not.

Mitral annular dimensions were obtained by measuring the distance between the attachment points of the anterior mitral leaflet to the aorta and the posterior mitral leaflet to the left ventricular posterior wall. Tenting area was obtained by calculating the area between the mitral annulus plane and the leaflets at end systole. If there was evidence of mitral valve prolapse, the tenting area was not calculated; instead, the prolapse area and height were calculated. Tenting angle was calculated at the cooptation of the anterior and posterior leaflets. Ventricular height was obtained by the distance between the annulus to the apex in the long axis view.

Statistics

The goal of our statistical analysis was to compare geometric parameters between groups of patients with different mitral regurgitation severities, and between patient groups requiring surgical versus non-surgical management. We did not calculate ideal sample size because a non-probability sample was used. The Statistical Package for Social Science (SPSS) v 16.0 was used for all statistical analysis[11]. Continous variables were recorded as mean +/- standard deviation and categorical variables as proportions. Variables were tested for their normality using the Kolmogorov Smirnov test. Variables were compared using a paired t-test and dichotomous data was compared by the X^2 statistical test. Due to the variety of geometrical variables that could influence mitral regurgitation severity, we performed multiple regression. Major determinants of mitral regurgitation severity were analysed based on enter exploratory multiple regression. The dependent variable was the severity of mitral regurgitation. A p value of < 0.05 was considered significant.

Results

Demographics

The mean age was 58.1 ± 14.8 years. Thirty-three patients were men and 30 were women. Out of 63 patients (pts), 46 patients had restricted leaflet motion during diastole or systole (class III), eight had leaflet prolapse

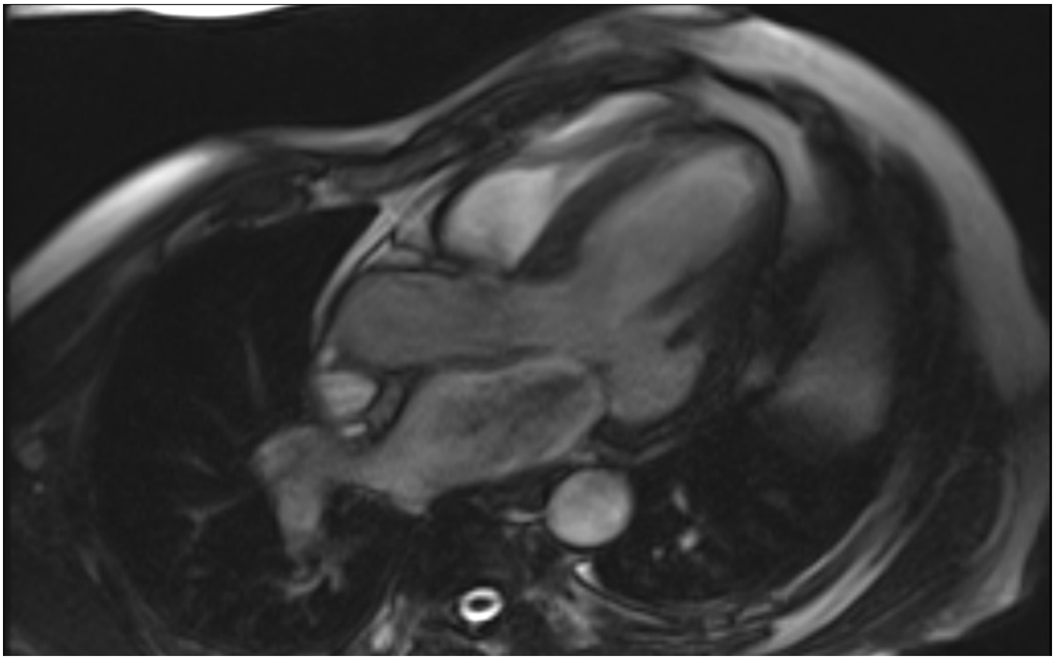

Figure 1 - *A three-chamber view. Mild to moderate mitral regurgitation. CMR can easily calculate regurgitation fraction and volume. At the end systolic frame mitral geometrical features such as tenting area, tenting angle, tenting height and posterior and anterior leaflet lengths were measured.*

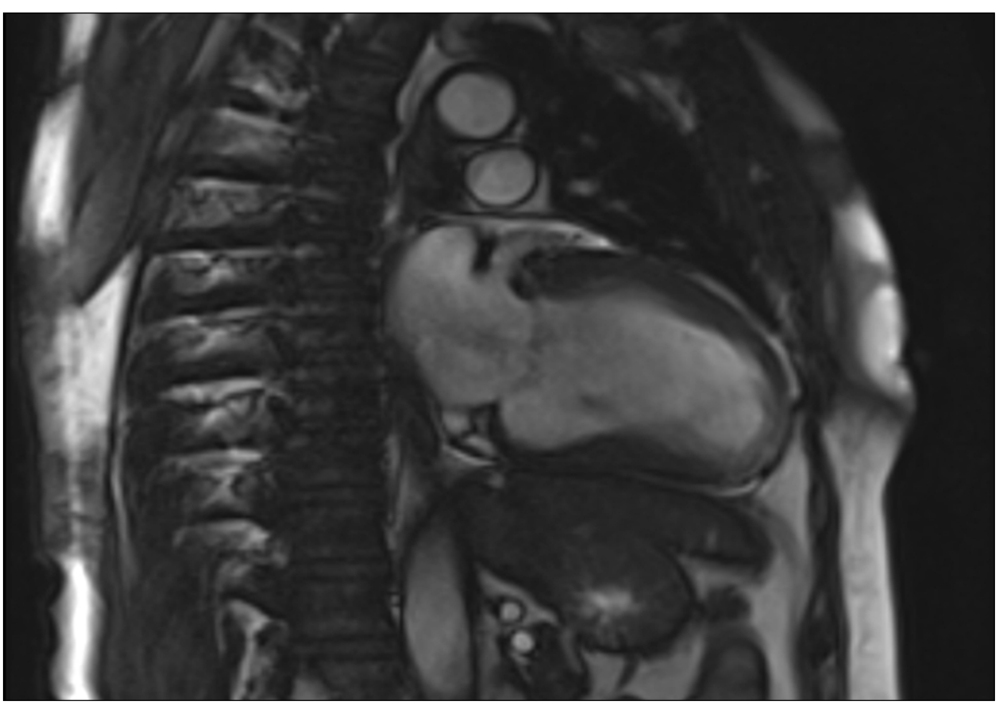

Figure 2 - *A two-chamber view. This view was used to measure the mitral annulus and ventricle height.*

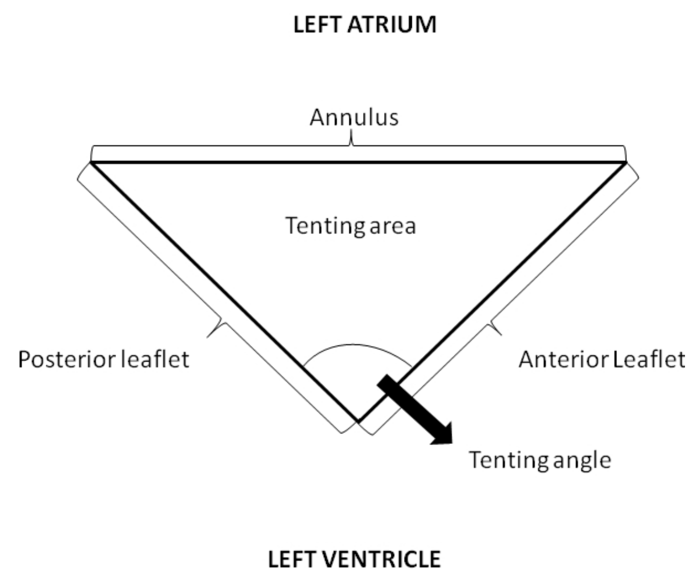

Figure 3 - *Schematic view showing how the measurements were performed in the three- chamber view.*

(class II), and nine had mitral regurgitation due to annular dilatation. We specified the etiology for secondary mitral regurgitation as follows: nineteen had ischemic etiology for MR (including cases of myocardial infarction and inoperable ischemic heart disease); 27 had functional regurgitation, eight had mitral valve prolapse and nine were classified as having other causes such as cardiomyopathies. Thirty-six patients had trace to mild (1-2+) and 27 pts had moderate to severe mitral regurgitation (3-4+). Sample characteristics are listed in table 1. Ten (15.9%) out of 63 patients underwent surgery (six underwent mitral valve repair and four underwent valve replacement).

Mitral regurgitation etiology, severity and mitral geometry

Patients with more severe mitral regurgitation showed a larger left ventricular end systolic diameter (38.6 ± 10.2 vs. 45.4 ± 16.8, $p < 0.05$) and left end diastolic diameter (52.9 ± 6.8 vs 60.1 ± 12.3, $p = 0.005$) compared to those with milder severity of regurgitation. Otherwise, there were no significant differences in geometric variables and ventricle volumes between the two groups (Table 2).

In regards to geometric valve variables, on multivariate analysis the tenting area was the strongest determinant of mitral regurgitation severity ($r = 0.62$, $p = 0.035$). No other variable was identified as an independent determinant of mitral regurgitation severity.

There was a significant effect regarding Carpentier's group classification on left ventricle end systolic diameter ($F = 3.49$, $p < 0.05$), ejection fraction ($F = 4.15$, $p < 0.05$), TAR ($F = 3.49$, $p < 0.05$) and TA ($F = 4.12$, $p< 0.05$).

Surgery and mitral geometry

Ten (15.9%) out of 63 patients underwent surgery because of symptoms, left ventricle ejection fraction or ventricle diameters measured by echocardiography. As expected, mitral regurgitation severity was a determinant for surgical treatment.

Left ventricle end diastolic diameter was significantly increased (61.7 ± 8.9 vs. 54.9 ± 10, $p= 0.05$) in patients who underwent mitral valve surgery. In regards to mitral geometry, annulus length measurement was significantly higher in patients subjected to mitral valve repair or replacement (36.1 ± 4.7 vs. 41 ± 6.7, $p < 0.001$). In addition, tenting area (190.7 ± 149.7 vs. 130 ± 71.3, $p = 0.048$) and posterior leaflet length (15.1 ± 4.1 vs. 12.2 ± 3.5, $p = 0.023$) were larger in surgically treated patients. This comparison between the surgical and nonsurgical groups is available in table 3.

Discussion

The aim of this study was to demonstrate that cardiac magnetic resonance imaging with its accurate spacial resolution can be used to determine mitral valve geometry and analyze its impact on the severity of regurgitation.

It has been well established that ventricular dimensions strongly impact prognosis in patients with mitral regurgitation[1].

In accordance with previous studies[12], our patients with severe mitral regurgitation showed a larger left ventricle end systolic diameter (38.6 ± 10.2 vs 45.4 ± 16.8, $p < 0.05$) and left ventricular end diastolic diameter

Table 1 - Geometrical ventricle and mitral features measured in sixty-three patients

	Mean	Std Deviation
LVEDD (mm)[a]	56.0	10.2
LVESD (mm)[b]	41.5	13.7
Ejection fraction (%)	47.3	19.4
EDV (ml)[c]	219.9	89.0
ESV (ml)[d]	135.0	96.1
Systolic volume (ml)	84.9	19.5
Septum (mm)	11.3	3.1
Posterior wall (mm)	8.9	2.6
Annulus length(mm)	36.9	5.3
Ventricle height (mm)	94.2	11.1
Tenting angle (°)	133.5	21.3
Tenting area (mm)	139.7	89.5
Anterior leaflet (mm)	21.8	6.3
Posterior leaflet (mm)	12.6	3.7
Tenting height (mm)	7.2	2.7

LVEDD: left ventricle end diastolic diameter; LVESD: left ventricle end systolic diameter; EDV: end diastolic volume; ESV: end systolic volume.

Table 2 - Differences between patients with trace to mild and moderate to severe mitral regurgitation

	MR Degree 3 and 4+ (n=27)		MR degree 1 and 2+ (n=36)		
	Mean	Std. deviation	Mean	Std deviation	p value
Age (years)	57.4	15.8	58.7	14.2	0.733
LVEDD (mm)[a]	60.1	12.3	52.9	6.8	0.005
LVESD (mm)[b]	45.4	16.8	38.6	10.2	0.05
EDV (ml)[c]	241.0	110.1	202.1	63.6	0.132
ESV (ml)[d]	147.1	118.9	124.1	72.4	0.430
Ejection fraction (%)	45.8	20.4	48.5	19.0	0.578
Systolic volume (ml)	11.0	3.7	11.5	2.6	0.537
Posterior wall (mm)	8.6	3.2	9.2	2.0	0.455
Annulus length (mm)	38.0	5.8	36.0	4.7	0.137
Ventricle height (mm)	95.3	13.2	93.4	9.4	0.501
Tenting angle (°)	134.3	26.8	132.8	16.5	0.785
Tenting area (mm)	162.4	119.1	122.6	54.4	0.081
Anterior leaflet length (mm)	23.1	7.3	20.9	5.3	0.166
Posterior leaflet length (mm)	13.2	3.8	12.2	3.7	0.305
Tenting height (mm)	7.7	3.5	6.8	1.9	0.198

LVEDD: left ventricle end diastolic diameter; LVESD: left ventricle end systolic diameter; EDV: end diastolic volume, ESV. end systolic volume.

Table 3 - Comparison between groups of patients that underwent mitral valve surgery and those that did not undergo surgery

	Group who underwent surgery (n = 10)		Group who did not undergo surgery (n = 53)		
	Mean	Std deviation	Mean	Std deviation	p value
Age (years)	60.6	14.9	57.6	14.8	0.566
LVEDD (mm)†	61.7	8.9	54.9	10.0	0.05
LVESD (mm)‡	44.1	13.8	41.0	13.8	0.513
Ejection fraction (%)	52.0	15.6	46.5	20.2	0.413
Systolic volume (ml)	9.9	2.4	11.6	3.2	0.122
EDV (ml)[c]	227.0	95.0	218.0	89.0	0.79
ESV (ml)[d]	118.0	80.0	140.0	100.0	0.53
Posterior wall thickness (mm)	8.1	3.9	9.1	2.2	0.283
Annulus length (mm)	41.0	6.7	36.1	4.7	0.006
Ventricle height (mm)	91.0	13.8	94.8	10.6	0.327
Tenting angle (°)	139.6	22.3	132.32	21.2	0.327
Tenting area (mm)	190.7	149.7	130.0	71.3	0.048
Anterior leaflet length (mm)	25.1	8.6	21.2	5.6	0.074
Posterior leaflet length (mm)	15.1	4.1	12.2	3.5	0.023
Tenting height (mm)	6.9	4.7	7.2	2.2	0.682

LVEDD: left ventricle end diastolic diameter; LVESD: left ventricle end systolic diameter; EDV: end diastolic volume; ESV: end systolic volume.

(52.9 ± 6.8 vs 60.1 ± 12.3, p= 0.005) as compared to those with lesser degrees of regurgitation. The role of left ventricular ejection fraction (LVEF) as an important prognosticator has already been demonstrated by prior studies. Furthermore, it is one of the parameters used to indicate the need for surgery in asymptomatic patients (usually abnormal LVEF with LV dilatation)[1].

The role of mitral valve geometry has been emphasized in the last few years. It is becoming clearer that valve measurements can provide further information about the etiology, physiology and treatment[7].

Previous studies have shown that the anterior leaflet length does not correlate with the degree of mitral regurgitation in patients with ischemic mitral regurgitation[6]. Otherwise, it can be used as a reference measurement to quantify annulus dilatation in functional mitral regurgitation[13], probably playing a role as a non-direct determinant of severity. In this study, AL was not associated with mitral regurgitation severity, nor did it indicate the need for surgical treatment.

In regards to the mitral annulus, it has been shown to be related to the severity of mitral regurgitation in prior studies[14-17]. Furthermore, it has been previously described as a parameter predictive of surgical success after mitral valve repair. In one series, it was used to successfully predict a 50% failure of simple annuloplasty[16]. In accordance with previous studies, this study demonstrated that larger annular diameter is associated with the need for mitral valve surgery.

To date, many studies have been published regarding tenting measurements, highlighting their importance in determining the severity of mitral regurgitation and prognosis. The TAR is well related to severity in animal models[18]. Furthermore, it has been demonstrated as a measurement able to predict failure in annuloplasty. In intraoperative echocardiograms, a tenting area greater than 1.6 cm^2 has been shown to predict mitral annulosplasty failure[19].

In our study, tenting area was greater in those patients with more severe valve lesions, and also in those who underwent mitral valve procedures.

The tenting height has been described as a major determinant in ischemic patients[20] and has been repeatedly found to have a correlation with mitral regurgitation severity[17,21,22]. Interestingly, our data did not point out TH as a determinant of severity in patients with mitral regurgitation.

Therefore, the mitral valve features that play a role in predicting surgical treatment are: annular diameter, TAR and PL. In line with published literature, our study suggests the consistent role of TAR in determining mitral regurgitation severity[23].

Studies with humans are usually invasive or involve echocardiographic studies. There have been many non-echocardiographic methods described to define mitral valve anatomy. This is especially important given the limitations of echocardiography[24]. Magnetic resonance imaging can easily detail mitral valve anatomy and geometry without the need for an invasive procedure, with a satisfactory concordance with echocardiography[14]. Furthermore, cardiac magnetic resonance imaging is shown to be concordant with the clinical need for mitral valve surgery and is also a feasible tool to define the etiology of mitral regurgitation confirmed at surgery[23].

There were quite a few limitations to our study. The number of subjects was constrained and few underwent mitral valve surgery. This population underwent cardiac magnetic resonance imaging for other reasons other than the evaluation of the mitral valve, and image quality was not always well-suited to valve evaluation, e.g., not all patients were submitted to phase velocity mapping sequences. Furthermore, a non-probability sample was used, decreasing the ability to make generalizations to the overall population.

In conclusion, in this study left ventricular diameters measured by cardiac magnetic resonance imaging are shown to be concordant with echocardiography and clinical evaluation. Mitral geometrical measurements, such as tenting area, annulus and posterior leaflet length are possible determinants of mitral regurgitation severity. If our results are indeed confirmed by further studies, one may argue that these geometric parameters could be used to judge severity and perhaps, in the future, tailor individualized treatment for patients based on their unique anatomic mitral apparatus geometry.

Author contributions

Conception and design of the research: Fernandes AM, Biederman RW, Aras Jr. R; Acquisition of data: Fernandes AM, Rathi V, Yamrozik JA, Graunt S; Analysis and interpretation of the data: Fernandes AM, Biederman RW, Doyle M, Yamrozik JA, Willians RB, Hedge V, Aras Jr. R; Statistical analysis: Fernandes AM, Doyle M, Willians RB, Hedge V, Graunt S, Aras Jr. R; Writing of the manuscript: Fernandes AM, Rathi V, Biederman RW, Hedge V, Aras Jr. R; Critical revision of the manuscript for intellectual content: Biederman RW, Aras Jr. R.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

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