Dobutamine Stress Cardiac MRI is Safe and Feasible in Pediatric Patients with Anomalous Aortic Origin of a Coronary Artery (AAOCA)

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Abstract

Background: Risk stratification in anomalous aortic origin of a coronary artery (AAOCA) is challenged by the lack of a reliable method to detect myocardial ischemia. We prospectively studied the safety and feasibility of Dobutamine stress-cardiac magnetic resonance (DSCMR), a test with excellent performance in adults, in pediatric patients with AAOCA.

Methods: Consecutive DSCMR from 06/2014-12/2019 in patients 20 years old with AAOCA were included. Hemodynamic response and major/minor events were recorded. Image quality and spatial/temporal resolution were evaluated. Rest and stress first-pass perfusion and wall motion abnormalities (WMA) were assessed. Inter-observer agreement was assessed using kappa coefficient.

Results: A total of 224 DSCMR were performed in 182 patients with AAOCA at a median age of 14 years (IQR 12, 16) and median weight of 58.0 kg (IQR 43.3, 73.0). Examinations were completed in 221/224 (98.9%), all studies were diagnostic. Heart rate and blood pressure increased significantly from baseline ($p<0.001$). No patient had major events and 28 (12.5%) had minor events. Inducible hypoperfusion was noted in 31/221 (14%), associated with WMA in 13/31 (42%). Inter-observer agreement for inducible hypoperfusion was very good (K= 0.87). Asymptomatic patients with inducible hypoperfusion are considered high-risk and those with a negative test are of standard risk.

Conclusions: DSCMR is feasible in pediatric patients with AAOCA to assess for inducible hypoperfusion and WMA. It can be performed safely with low incidence of major/minor events. Thus, DSCMR is potentially a valuable test for detection of myocardial ischemia and helpful in the management of this patient population.

Introduction

Current practice guidelines attest to the lack of a reliable tool to risk stratify young athletes with anomalous aortic origin of a coronary artery (AAOCA) anomalies because the recommended tests (exercise stress test, stress echocardiography, and nuclear perfusion imaging) have low negative predictive value in detecting myocardial ischemia [1,2]. Dobutamine stress-cardiac magnetic resonance imaging (DSCMR) has excellent performance in adults with suspected or known ischemic heart disease, and shown to be predictive of major cardiovascular events [3,4]. DSCMR has been reported in pediatric patients, but data are sparse in AAOCA [5]. Pathophysiologic events in a demand ischemia cascade demonstrated that reversible ischemia precedes changes in wall motion abnormalities (WMA) [6,7]. Hence, the addition of first-pass perfusion (FPP) to wall motion assessment improves the sensitivity of DSCMR [8,9]. We aimed to prospectively determine the feasibility and safety of DSCMR in detecting inducible ischemia and WMA in pediatric patients with AAOCA and describe the utility of the test results in the decision-making process in a multidisciplinary approach.

Methods

Study Population

All patients 20 years old with AAOCA were prospectively enrolled in the Coronary Artery Anomalies Program and managed following a standardized clinical algorithm (Fig.S1). Patients with consecutive DSCMR examinations from June 2014 to December 2019 were included in this study. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution's human research committee and informed consent was obtained from each patient/guardian. All patients ³8 years old and younger patients with concern for myocardial ischemia underwent DSCMR at baseline and 3 months after surgery. DSCMR was repeated if there was a concern for myocardial ischemia [10,11]. Patients with other congenital heart diseases and those with isolated hypoplastic coronary artery (CA) were not included in this study. Contraindications for DSCMR included severe ventricular dysfunction, hypertrophic cardiomyopathy, severe hypertension (³200/120 mmHg), non-compatible metallic implants, unstable angina, and following sudden cardiac arrest upon presentation.

DSCMR Protocol

A pediatric cardiovascular anesthesiologist assessed the necessity of sedation and was present for all sedated examinations. DSCMR and the use of dobutamine, atropine, gadolinium, and potential adverse events were discussed with the families by a pediatric cardiologist before the test. All patients were prepared by a pediatric nurse who monitored the patients until discharge. A pediatric cardiologist was at the scanner throughout the examination to supervise the test, monitor the patient, and evaluate the images.

DSCMR was performed on 3 CMR scanners (initially, 1.5T Ingenia and 3T Achieva, Philips Medical System, Best, the Netherlands, and recently a 1.5T Magnetom Aera, Siemens Heathineers, Erlangen, Germany). Depending on patient size, 5, 16, or 28-element phase array coils were used on 1.5T scanners, and a 32-element cardiac coil was used on the 3T scanner. Heart rate was monitored continuously, and blood pressures were cycled every 3 minutes during dobutamine infusion. Patients were monitored until all symptoms resolved and vital signs returned to baseline. Major events considered were ventricular arrhythmia, myocardial infarction, and cardiac arrest. Minor events considered were severe hypertension (³200/120 mmHg), chest pain, nausea/vomiting, paradoxical bradycardia to atropine, rash, anxiety, dizziness, and dyspnea.

The imaging protocol was consistent during the study period (Figure1). Multiplanar survey imaging was followed by cine sequences in the ventricular long axis, 4-chamber, and short axis orientations. Myocardial perfusion was assessed at rest following administering 0.1 mmol/kg of gadolinium-based contrast agent (Gadavist, Bayer Healthcare Pharmaceuticals, Ontario, Canada) intravenously at 2.5 ml/s. A single-shot, T_1-weighted saturation recovery gradient echo sequence was acquired at 3 ventricular levels (basal, mid, and apical) within the same cardiac cycle to assess for first pass perfusion (FPP) in 16 segments as defined in the American Heart Association (AHA) model [12]. A parallel imaging

(SENSE/GRAPPA) acceleration factor of 2, repetition time/echo time/flip angle of 2.6 ms/1.3 ms/17^{o}, voxel size 1.1-2.1x1.1-2.1x8-10 mm^{3} (field of view 200-320 mm to cover all 16-segment AHA model), and a saturation delay of 120 ms were used. The FPP was conducted for about 60 seconds. A late gadolinium enhancement (LGE) sequence in short axis and 4-chamber orientation was performed around 5 minutes after contrast administration to assess myocardial viability.

Dobutamine was started at 10 µg/kg/minute and increased every 4 minutes to a maximum of 40 µg/kg/minute unless the patient developed severe hypertension (³200/120 mmHg). Additional atropine 0.01 mg/kg was given intravenously if target heart rate was not attained. A heart rate of at least 150 was used as minimal target hemodynamic response based on our observation of patients' maximal response to dobutamine and atropine protocol. In this study, a calculated peak combined rate-pressure product (RPP = heart rate x systolic blood pressure) ³20x10^{3} bpm·mmHg was considered an indirect estimate of high intermediate myocardial oxygen consumption [13]. Cine sequences in the short axis and 4-chamber orientation were performed without breath-hold at the each dobutamine dose to assess for WMA. A repeat FPP sequence was performed with a second dose of gadolinium. The study was aborted if major events occurred, or patients developed minor events and requested to stop the examination. We aimed for a temporal resolution of the cine sequences £40 msec/frame, and spatial resolution of the FPP £2.2x2.2 mm.

Image analysis

The image quality of stress cine and FPP was graded by the interpreting cardiologists as good, adequate, or non-diagnostic based on signal uniformity and artifacts induced by motion or parallel imaging in the myocardium. Good image quality included sharply defined myocardial borders, adequate when there is blurring but FPP and WMA can be definitively evaluated, and non-diagnostic if structures are significantly blurred. In this study, a post-hoc analysis of DSCMR image quality was performed to assess its dependence on heart rate. Myocardial FPP and WMA were assessed visually. A myocardial hypoperfusion was determined based on persistent regional hypointensity in the subendocardial or transmural myocardium in the coronary territory of interest. WMA was assessed as normal, hypokinetic, akinetic, or dyskinetic. A hypoperfusion identified at stress and not at rest was considered inducible or reversible. A fixed hypoperfusion was characterized by a defect seen both at rest and stress, corresponding with the presence of WMA and LGE [14].

Utility of DSCMR results

All cases were discussed in our biweekly institutional multidisciplinary discussion and recommendations were then shared with the patients and families. In addition to other conventional markers concerning for myocardial ischemia, an inducible hypoperfusion is considered as a sign of reversible myocardial ischemia and discussed among team members and with the families. These patients were counseled of the unknown but potential risk of having an event near peak exertion. Unknown risk was discussed for those with a negative DSCMR. Surgery or medical intervention would be considered based on individual

patient discussion and recommended for patients with a positive DSCMR. If a patient is undergoing surgical repair of AAOCA, a similar approach would be used routinely at 3 months after surgery and help inform return to activities [15–19].

Statistical analysis

Variables were expressed as mean and standard deviations or median and interquartile ranges, and count and percentages, where appropriate. Normality of continuous variables was assessed both visually using frequency distribution (histogram) and by Shapiro-Wilk test. We compared the response in heart rate, blood pressures, and RPP using a paired Student's t-test or Wilcoxson signed rank sum test, where appropriate. A Student t-test or Wilcoxon rank sum test was used to compare continuous variables and χ^2 or Fisher's exact test for categorical variables between groups. A kappa coefficient as well as overall, positive and negative percent agreements were calculated as measures of interobserver agreement of myocardial perfusion interpretation between two observers in 45 DSCMR examinations. A p-value < 0.05 was considered as statistically significant.

Results

The data underlying this article will be shared on reasonable request to the corresponding authors.

From June 2014 to December 2019, 224 consecutive DSCMR examinations were performed in 182 patients (112 males, 61.5%) with AAOCA at a median age of 14 years (IQR 12, 16) and median weight of 58.0 kg (IQR 43.3, 73.0). The study was performed in 31 (14%) pediatric patients with anomalous aortic origin of a left coronary artery (AAOLCA), 20 (9%) intraseptal AAOLCA, and 173 (77%) anomalous aortic origin of a right coronary artery (AAORCA). Maximum dobutamine dose of 40 μg/kg/minute was administered in 210 (94%) and atropine was given in 140 (63%) examinations.

Feasibility of DSCMR and Hemodynamic Response

Sedation was required in 39 DSCMR (17%) performed in younger patients (Table 1). DSCMR was completed in all but 3 (1.34%) non-sedated, first time examinations due to patients' discomfort. Twenty-three patients had both baseline and post-operative DSCMR and 22 had other types of stress imaging tests done prior to surgery and had post-operative DSCMR (Figure 2). Heart rate, blood pressure, and RPP increased significantly at peak pharmacologic stress (Table S1). An RPP $\geq 20x10^3$ bpm·mmHg was achieved in 193/224 (86%). Peak heart rates and percent RPP increase were similar in sedated and non-sedated patients, while peak systolic blood pressure was lower in the sedated group resulting in a lower RPP. All hemodynamic parameters both at rest and at peak pharmacologic stress were similar between patients with and without inducible hypoperfusion (Table 2). The peak heart rates in complete and incomplete examinations were summarized in Table S2. Heart rate did not affect FPP image quality and only heart rates >85% of age-predicted maximum reduced the cine image quality (Table S3). Images at 3-ventricular levels were achieved in all DSCMR. The spatial resolution of perfusion images was <2.2x2.2x8-10 mm^3 and temporal resolution of the cine sequences <40 msec/frame (Table S4). LGE and

cine were non-diagnostic in 3 (1.34%) and 1 (0.45%), respectively, due to motion artifact while FPP images were diagnostic in all completed examinations.

Safety of DSCMR

There were no major events in our study. Minor events occurred in 28 examinations (12.5%) and were not associated with sedation (Table 1). Minor events were observed in 5/8 (62.5%) cases with peak heart rate <130 bpm, of whom 4 had severe hypertension. There were no complications from general anesthesia. Patients' symptoms resolved once dobutamine was discontinued, vital signs returned to baseline, and all patients were discharged the same day.

DSCMR Findings and Utility

Inducible myocardial hypoperfusion were detected in 31/221 (14%) with associated WMA in 13/31 (42%) examinations. Fixed hypoperfusion with WMA occurred in 1/221. LGE was present in 3 examinations (Figure 3). The segmental distribution of inducible hypoperfusion was described in Figure 4.

Of 161/164 first time, completed DSCMR in patients with unrepaired AAOCA, including AAORCA (128/161, 80%), AAOLCA (17/161, 10%), and intraseptal AAOLCA (16/161, 10%), exertional syncope or syncope associated with exertional chest pain were associated with inducible hypoperfusion. The rate of inducible hypoperfusion in AAORCA, AAOLCA, and intraseptal AAOLCA were 17/128 (13%), 3/17 (18%), and 7/16 (44%), respectively (Table 2). Of 27/161 (17%) patients with inducible hypoperfusion, 19 (70%) underwent successful surgical interventions, 4 awaited multi-disciplinary discussion/scheduling surgeries, and medical management was recommended in 4 patients with intraseptal AAOLCA. Additionally, fixed hypoperfusion with corresponding hypokinesis of the inferior wall .

Of the 45 post-operative DSCMR examinations, inducible hypoperfusion was detected on 1 study after unroofing for AAORCA, which subsequently resolved on a follow-up DSCMR. None of the patients with a negative DSCMR has had any concerning symptoms or events thereafter during the time of the study.

Dark rim artifact lasted a couple of cycles on the rest perfusion sequence (Video 1) compared to a true hypoperfusion (Video 2, Figure S2) in a 14-year-old male with AAORCA who did not have WMA (Video 3 & Video 4).

Interobserver Agreement

There was very good agreement (k = 0.87) between the two readers on 45 DSCMR, including 37 negative tests and 7 with inducible hypoperfusion. In one examination, there was disagreement on the stress FPP sequence, however, both readers agreed on a normal rest FPP, wall motion, and LGE. The overall percent agreement between the two observers was 97.8% with 87.5% positive percent agreement and 100% negative percent agreement.

Discussion

To the best of our knowledge, this is the first study to describe the use of DSCMR in the assessment of myocardial perfusion, wall motion, and myocardial viability in a large cohort of pediatric patients with AAOCA. We demonstrated feasibility and safety with DSCMR and this strategy has been helpful at our institution in risk stratification and decision-making of these challenging patients at presentation, follow-up, and post-intervention assessment [16–20]. Inducible hypoperfusion resolved in the majority of patients after surgery.

Adequate hemodynamic response with RPP ³20x10 was achieved in the majority of the cases and all hemodynamics parameters were not different between patients with and without inducible hypoperfusion. Sedation did not affect peak heart rate, although systolic blood pressure and RPP were lower in the sedated group, likely secondary to general anesthesia and younger age. All completed DSCMR had diagnostic FPP image quality. Dark rim artifact was generally distinctly transient compared to a more persistent pathologic hypoperfusion [14,21]. Good image quality allowed for an excellent interobserver agreement on regional myocardial hypoperfusion, which were reliably detected in the territory of interest based on the type of AAOCA.

Dobutamine increases heart rate and myocardial contractility, decreases systemic vascular resistance [22,23], and provides maximal coronary vasodilation with potential CA flow maldistribution [24]. Therefore, it was believed to serve as an advantageous pharmacologic agent to produce a state of increased oxygen consumption associated with increase in contractility and aortic volume and decrease in regional CA filling, all of which may play a role in the complex pathophysiology of AAOCA [6,22,25]. Advances in CMR imaging have allowed the addition of FPP kinetics of gadolinium to WMA to assess myocardial perfusion reliably [26]. Inducible hypoperfusion is independently predictive of adverse cardiovascular outcomes in adults with ischemic heart disease [3,27]. DSCMR was previously reported in small series of pediatric patients with AAOCA and had good correlation with surgical inspection [5,25]. Pharmacologic stress was achieved not only through increase in heart rate, but also by notable increase in inotropy and blood pressures. Achieving RPP ³20x10^3 and the significant increase from resting RPP captures this effect outside of heart rate alone. The peak heart rate and RPP achieved in our patients were in fact higher than those reported in adults (158 vs 135-138 and 24.1 vs 19.5-21.2x10^3, respectively) and comparable to those reported in pediatric patients (158 vs 168 and 24.1 vs 25.4x10^3, respectively) [5,26,27].

High dose dobutamine was found to be safe and overall, well tolerated with no major events and transient minor events. Chest pain was reported by 2 patients during peak pharmacologic stress and resolved as soon as dobutamine was discontinued. Our safety profile is different from data reported in adults with reduced ventricular function who had a higher incidence of severe complications [26,27]. This is likely because our study subjects had no significant underlying cardiac defects or ventricular dysfunction. Similar to the report by Strigl et al, our study subjects did not have any complications from general anesthesia [5]. In non-sedated patients, explaining the test in detail, including the expected side effects, and communicating well with them during the tests allowed the patients to anticipate, participate,

cooperate and tolerate the study. Close monitoring during and after the examination was important for the successful performance of a DSCMR.

Inclusion of 3 ventricular levels on FPP and cine sequences were possible in all completed cases. The image quality was diagnostic with good image quality in the majority at all heart rate ranges. In one examination, significant motion artifacts were observed in the cine sequence precluding an adequate WMA interpretation. The perfusion image quality did not seem to be affected by peak heart rate. Only at heart rates >85% of age-predicted maximum, there was a slight shift of the cine sequences' quality from good to adequate; however, both temporal and in-plane resolution were of diagnostic quality for interpretation. About half of the cases with inducible hypoperfusion had associated WMA. It is conceivable that these patients may have a more severe coronary flow during dynamic conditions, though this remains speculative at this time.

DSCMR has consistently demonstrated both high positive and negative predictive values in risk prognostication of adults with suspected or known CA disease [3,27,28]. Although it might be precocious to extrapolate these results in pediatric patients, our data are encouraging, and findings are helpful in studying CA perfusion in this young population with AAOCA. In a series of patients with AAOCA, DSCMR results concurred with fractional flow reserve measured invasively, particularly if performed with close proximity in time [29]. The mechanism leading to myocardial ischemia and sudden death in patients with AAOCA remains incompletely understood, although ostial stenosis, acute angulation, and dynamic compression of the CA are hypothesized as contributors [2]. Higher rate of reversible hypoperfusion in intraseptal AAOLCA suggests that an intramyocardial course of a CA may be an important contributor to the presence of inducible hypoperfusion. We consider this finding as a sign of reversible ischemia which is an indication for intervention [1,2]. Most of the postoperative DSCMR demonstrated no inducible hypoperfusion and the test has been used in the standardized assessment both before and after interventions with most patients returning to normal activities [16–19]. We are cautiously optimistic that DSCMR may be an important tool in detecting myocardial ischemia in risk stratification of patients with AAOCA , though longitudinal studies unquestionably are essential to fully assess its implication on clinical outcomes.

Study Limitations

DSCMR's role to detect myocardial ischemia in pediatric patients with AAOCA needs to be validated, as does its clinical impact and long-term outcome data. The high rate of abnormal DSCMR in our study could be subjected to referral bias. Despite a heart rate ≥150 bpm and RPP ≥$20x10^3$ bpm·mmHg were observed in many patients at maximal dobutamine dose, the study was limited by the lack of an evidence-based target hemodynamic response in the assessment of FPP on DSCMR in this population. Although image quality was assessed at the time of the DSCMR, post-hoc assessment of image quality at varying heart rate ranges did not provide direct guidance at the time of DSCMR interpretation.

Conclusions

Our study demonstrates that DSCMR is feasible in pediatric patients with AAOCA, given the high completion rate, significant hemodynamic response, and good interobserver agreement. It can be performed safely with a low incidence of major or minor events and informed our management of this challenging population. DSCMR may be a valuable test for assessment of myocardial perfusion in this patient population. Further longitudinal studies are necessary to determine the implications of these findings on risk stratification and clinical outcomes.

List Of Abbreviations

DSCMR	Dobutamine stress cardiac magnetic resonance imaging
AAOCA	Anomalous aortic origin of a coronary artery
AAOLCA	Anomalous aortic origin of a left coronary artery
AAORCA	Anomalous aortic origin of a right coronary artery
AHA	American Heart Association
CA	Coronary artery
FFP	First-pass perfusion
LGE	Late gadolinium enhancement
RPP	Rate-pressure product
WMA	Wall motion abnormality

Declarations

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Tables

Table 1. Patient demographics and features of sedated and non-sedated DSCMR examinations

	Sedated N = 39	Non-sedated N = 185	P value
Age (years)	9.1 (7.3, 10.8)	14.9 (13.2, 16.6)	<0.001
Weight (kg)	32.4 (25.4, 46.8)	62.2 (50, 75)	<0.001
Resting hemodynamics			
HR (bpm)	81 ± 14	70 ± 11	<0.001
SBP (mmHg)	93 ± 9	113 ± 10	<0.001
DBP (mmHg)	40 (38, 45)	58 (51, 66)	<0.001
RPP (x 10^3 bpm·mmHg)	7.2 (6.6, 8.5)	7.8 (6.8, 8.8)	0.07
Inducible FPP defects (n = 220)	4 (10.3)	27 (14.9)	0.61
Inducible WMA (n = 218)	0	13 (7.3)	0.13
Stress hemodynamics			
HR (bpm)	155 (146, 169)	157 (148, 170)	0.36
%HR increase (%)	99 ± 36	130 ± 43	<0.001
SBP (mmHg)	134 (125, 150)	155 (145, 167)	<0.001
DBP (mmHg)	71 (60, 80)	79 (69, 89)	<0.001
RPP (x 10^3 bpm·mmHg)	21.0 (18.6, 23.3)	23.9 (21.9, 27.0)	<0.001
³20 x 10^3, N (%)	24 (61.5)	169 (91.4)	<0.001
%RPP increase (%)	184 (135, 257)	207 (166, 260)	0.13
Major events			
Cardiac arrest	0	0	
Myocardial infarction	0	0	
Ventricular arrhythmia	0	0	
Minor events	2 (5.1)	26 (14.1)	0.18
HTN ³200/120 mmHg	0	7 (3.4)	
Paradoxical bradycardia	0	2 (1)	
Chest pain	0	2 (1)	
Nausea/vomiting	2 (5.1)	10 (5.7)	0.99
Skin rash	0	2 (1)	

Anxiety	0	2 (1)
Dizziness	0	1 (0.5)
Dyspnea	0	1 (0.5)

DBP = diastolic blood pressure; HR = heart rate; HTN = hypertension; NS = non-significant; LVEF = left ventricular ejection fraction; PHR = age-predicted maximum heart rate; SBP = systolic blood pressure

(%) Percentage of the value in the column

Table 2. Patient characteristics and hemodynamic responses in patients with and without inducible hypoperfusion

	Inducible FPP defects N = 31	No inducible defect N = 189	P value
Age, years	14.4 (12.9, 17.8)	14.3 (12.2, 16.5)	0.73
Weight, kg	59 (41.5, 74)	58 (44.7, 73.0)	0.76
Type of scanner			
Philips 1.5 T Ingenia	13 (42)	96 (51)	0.61
Philips 3 T Achieva	11 (35)	61 (32)	
Siemens 1.5 T Aera	7 (23)	32 (17)	
Presenting symptoms (N = 161)†	N = 27	N = 134	
Non-exertional, N (%)	7 (26)	43 (32)	0.52
Exertional chest pain/syncope, N (%)	15 (56)	41 (31)	**0.01**
Exertional chest pain, N (%)	12 (44)	35 (26)	0.06
Exertional syncope, N (%)	7 (26)	11 (8)	**0.008**
Exertional and non-exertional, N (%)	5 (19)	20 (15)	0.64
Asymptomatic, N (%)	5 (19)	48 (36)	0.08
Type of anomalies (N = 161)†	N = 27	N = 134	
AAORCA, N (%)	17 (63)	111 (83)	0.02
AAOLCA, N (%)	3 (11)	14 (10)	0.99
Intraseptal AAOLCA, N (%)	7 (26)	9 (7)	0.002
CA dominance, N (%)	N = 31	N =189	
Left	4 (12.9)	16 (8.5)	0.62
Right	22 (71.0)	142 (75.1)	
Co-dominant	0	4 (2.0)	
Super right (diminutive/absent LCX)	4 (12.9)	14 (7.4)	
Unknown	1 (3.2)	13 (6.9)	
Baseline LVEF, %	60 (57, 63)	58 (56, 61)	0.15
LVEF <55%, N (%)	2 (6.5)	9 (4.8)	0.66
Sedated DSCMR, N (%)	4 (12.9)	35 (18.5)	0.61
Resting hemodynamics			

HR rest, bpm	70 (65, 80)	70 (63, 80)	0.60
SBP rest, mmHg	110 (103, 118)	110 (100, 118)	0.96
DBP rest, mmHg	56 (49, 66)	55 (47, 63)	0.64
RPP rest, (x 10^3 bpm·mmHg)	7.8 (6.8, 8.9)	7.7 (6.7, 8.7)	0.66
Stress hemodynamics			
HR stress, bpm	160 (148, 173)	156 (147, 169)	0.48
³150, N (%)	23 (74))	136 (72)	0.80
%HR increase, %	125 ± 48	124 ± 43	0.89
SBP stress, mmHg	154 (144, 174)	151 (138, 163)	0.15
%SBP increase, %	41 (31, 60)	38 (29, 49)	0.16
DBP stress, mmHg	81 ± 15	77 ± 13	0.15
%DBP increase, %	38 (22, 61)	38 (18, 61)	0.66
RPP stress, (x 10^3 bpm·mmHg)	24.2 (21.7, 27.8)	23.3 (21.4, 26.4)	0.12
³20 x 10^3, N (%)	28 (90)	162 (86)	0.78
%RPP increase, %	210 (166, 246)	205 (161, 260)	0.59

AAOLCA = anomalous aortic origin of a left coronary artery; AAORCA = anomalous aortic origin of a right coronary artery; LCX = left circumflex artery; HR = heart rate; DBP = diastolic blood pressure; SBP = systolic blood pressure; bpm = beats per minute; RPP = rate-pressure product

(%) Percentage of the value in the column

* Excluded incomplete DSCMR (3) and fixed hypoperfusion (1)

† Included only the first baseline DSCMR (n = 161)

Figures

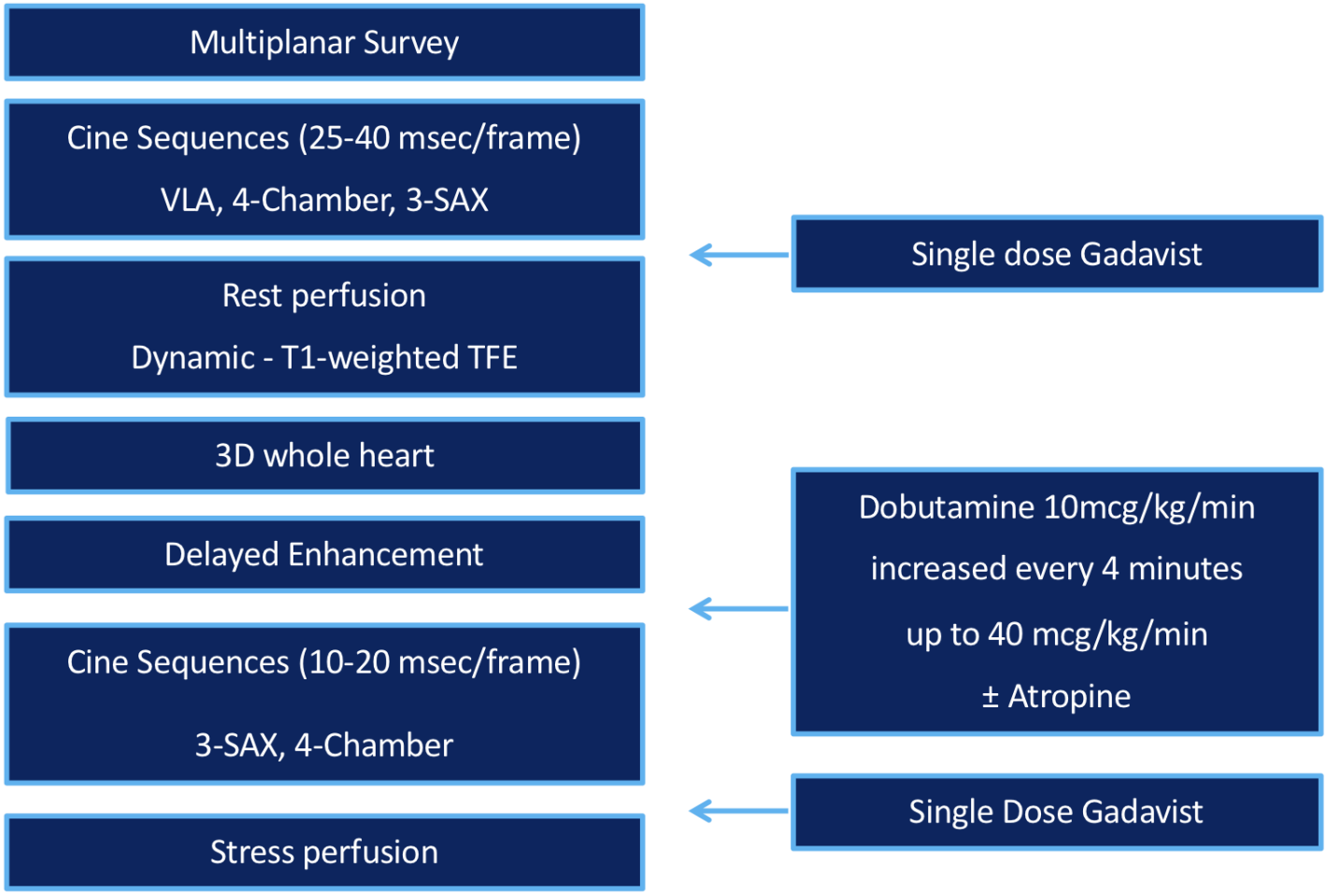

Figure 1

DSCMR acquisition protocol 3-SAX = short axis at 3 levels; TFE = turbo field echo; VLA = ventricular long axis.

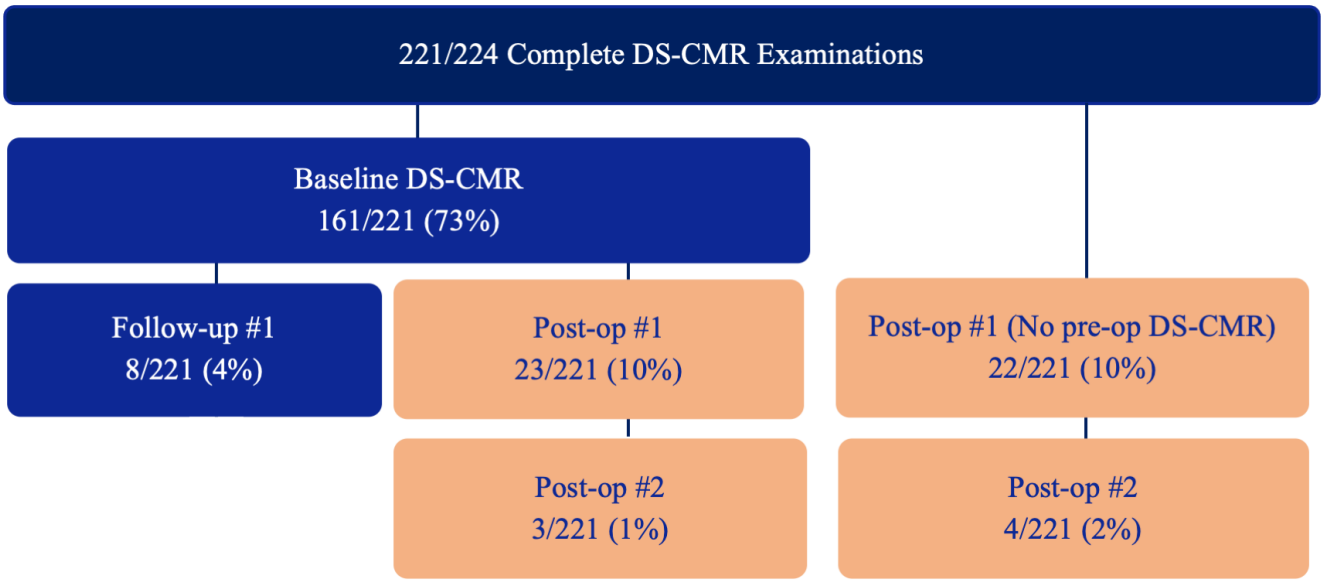

Figure 2

Distribution of 221 completed DSCMR in the initial assessment and follow-up

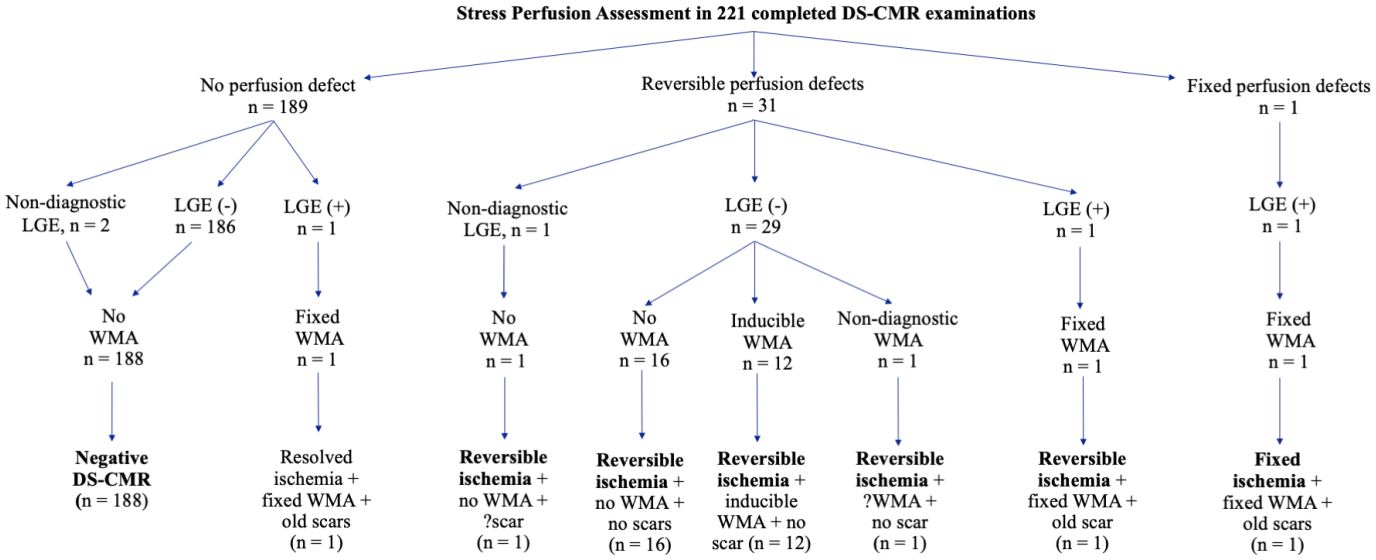

Figure 3

Flowchart demonstrating the findings in 221 completed DSCMR examinations LGE = late gadolinium enhancement; WMA = wall motion abnormalities

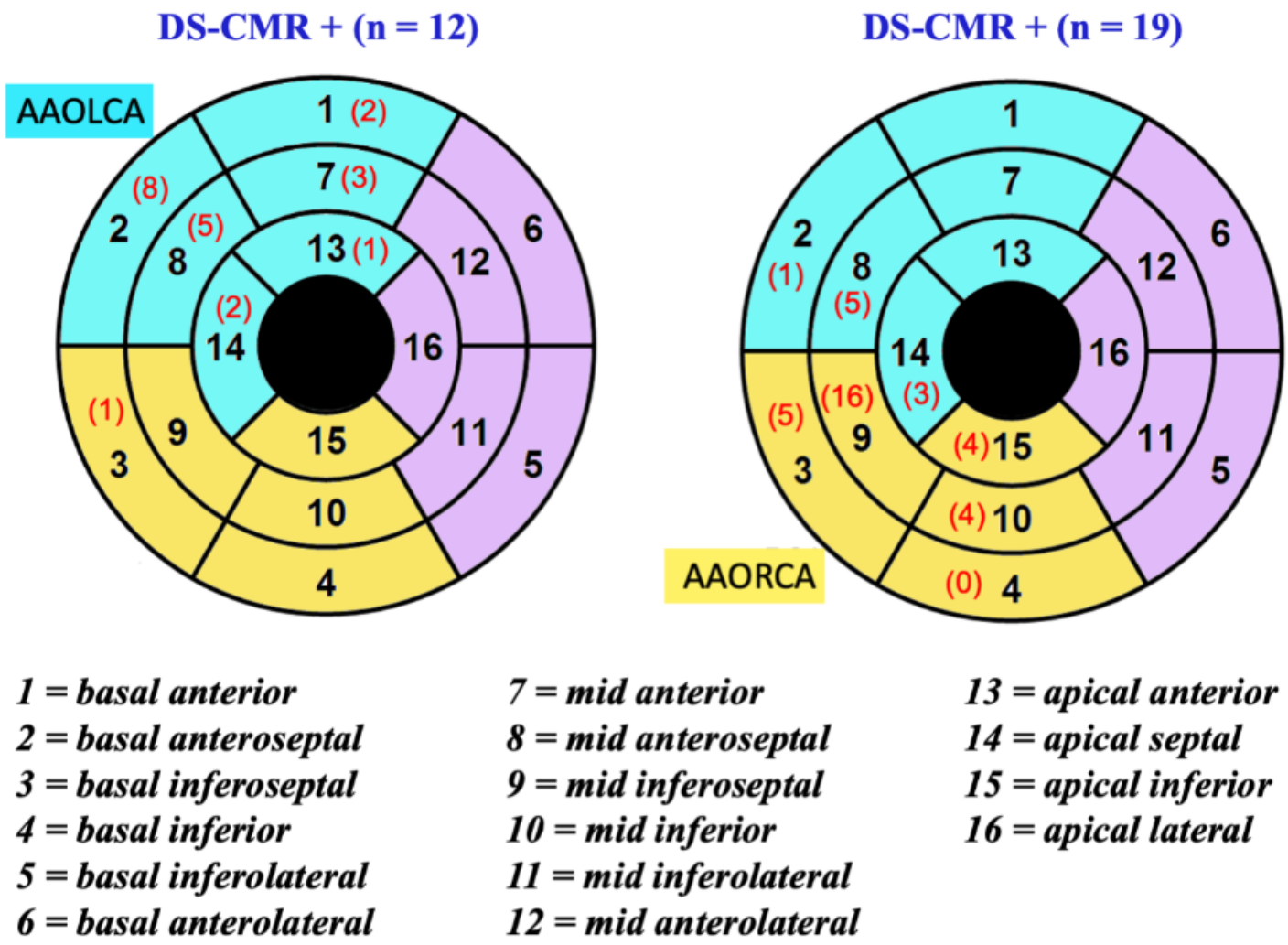

Figure 4

Distribution of regional inducible hypoperfusion in AAOLCA and AAORCA with inducible perfusion defects. The numbers in red (parentheses) represent the number of patients with inducible hypoperfusion in the respective wall segments.

Supplementary Files

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- TableS1.docx
- TableS2.docx
- TableS3.docx

- TableS4.docx
- Video1.RestPerfusionDarkRimArtifact.mp4
- Video2.StressPerfusionwithaDefect.mp4
- Video3.ShortAxisCineatPeakStress.mp4
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