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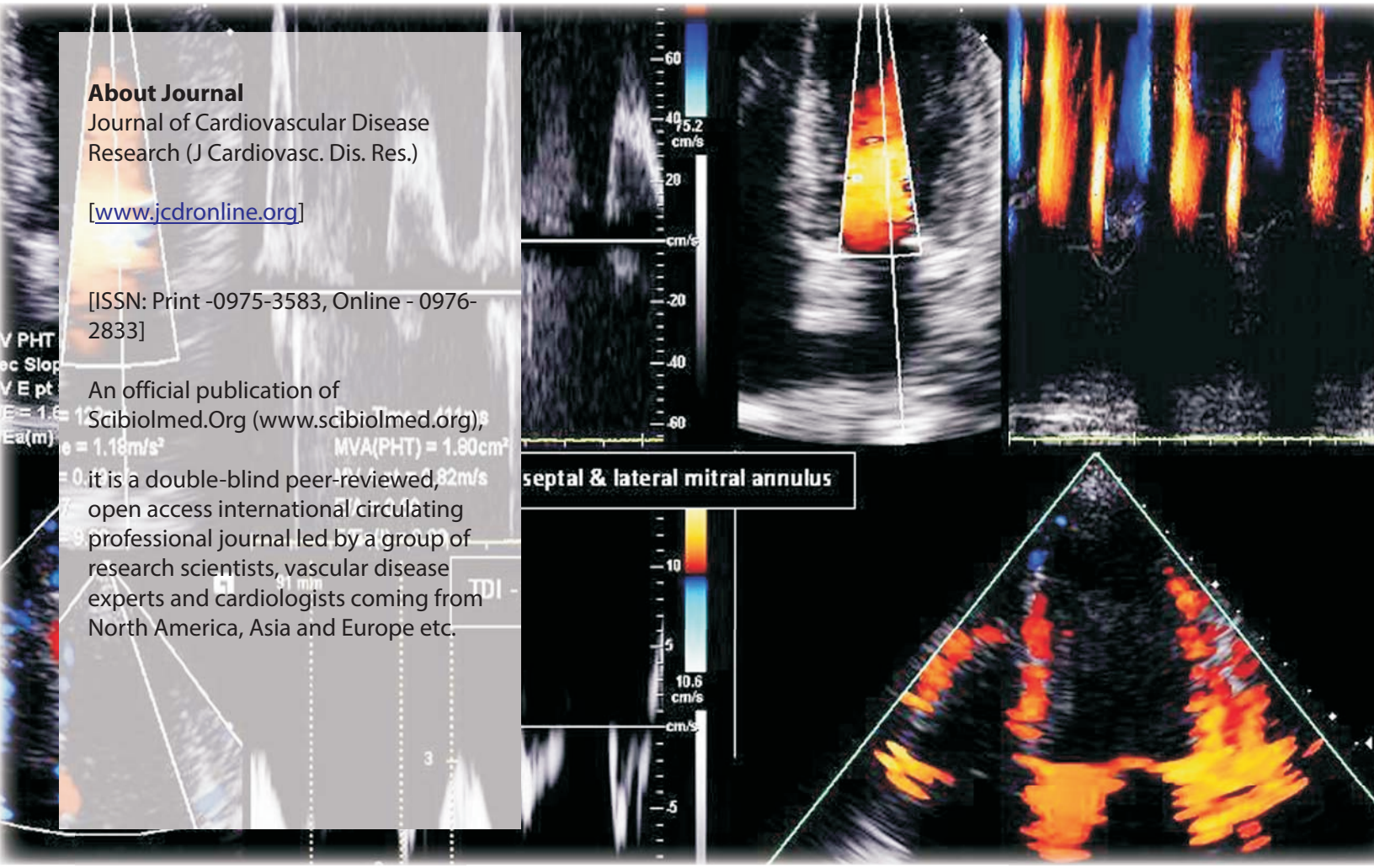

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Original Article

Imaging for Chest Pain Assessment: An Algorithmic Approach Using Non-invasive Modalities to Define Medical vs. Interventional Treatment

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ABSTRACT

Background: To analyze the roles of CCTA, MPI, and CC to formulate a sequential clinical algorithm to use in patients with chest pain, risk factors for CAD, and an abnormal EKG. The goals of the study are to streamline and refine workup, to decrease radiation exposure to patients, and to contain costs.
Materials and Methods: 39 patients underwent CCTA, MPI, and CC within 30 months of each other. CCTA was defined by mild, moderate, or severe CAD. MPI used SSS, SDS, TID, and formal reading to define mild, moderate, or severe physiologic ischemia. CC and coronary intervention cine films were analyzed to define and treat anatomical CAD medically or by intervention.
Results: There was strong correlation between CCTA, CC, and treatment type ($p < 0.0001$). CCTA was able to stratify all patients with mild or severe ischemia to appropriate treatment groups, and to reduce the need for MPI. With moderate ischemia from CCTA, the additional use of MPI could have reduced the need for 16/18 (89%) patients who underwent CC to undergo further testing. No patients with mild or moderate CAD by CCTA, followed by mild to moderate physiologic ischemia by MPI, needed CC or intervention. 37/39 patients (95%) could have avoided one or more tests using our algorithm.
Conclusion: CCTA followed by MPI may be used in symptomatic patients with risk factors for CAD and an abnormal EKG to stratify mild and moderate CAD, and to thereby avoid cardiac catheterization. Our algorithm could lead to savings in healthcare expenditures, save patients from unnecessary invasive procedures, decrease radiation exposure, and reduce total cost.

Key words: CAD, Stable Angina, Treatment, CCTA, MPI, CC, Algorithm.

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INTRODUCTION

It has been both well-established and well-documented that cardiac catherization (CC) is the gold standard to determine stenosis in symptomatic patients with typical angina.[1] However, it is an invasive test that increases health expenditures and complications, in contrast to less invasive testing.[2] Less invasive testing for typical angina exists in the form of stress EKG, single photon emission computerized tomography myocardial perfusion imaging (SPECT MPI), and cardiac computerized tomography angiography (CCTA). CCTA is an advance in cardiac imaging, capable of noninvasively characterizing patency and compromise of the coronary arteries. SPECT MPI is another well-established method to determine levels of functional ischemia and physiologic perfusion defects. If determined to be effective, these less invasive, less expensive imaging modalities would be preferable to CC as first line diagnostic maneuvers, with CC remaining the gold standard for final diagnosis, and therapy, if necessary.

We sought to demonstrate the interrelationship between these three studies (CC, CCTA, MPI) and their ability to determine the appropriate treatment (medical therapy[3] vs. revascularization), by clarifying clear indications for their sequential use. We set out to devise a streamlined approach and algorithm for cardiac imaging and risk assessment in symptomatic patients with stable angina and an abnormal EKG. Additionally, we sought to further demonstrate how CCTA, MPI, and CC correlate or differ, and relate their results to the course of treatment. Using this information, we have devised a novel imaging algorithm that can be used clinically to optimize effectiveness of these imaging modalities, while simultaneously reducing those that are unnecessary and invasive.

MATERIALS AND METHODS

Study Population

We retrospectively screened the database of patients to identify those who received MPI, CCTA, and CC from February 2009–June 2014 within a 30 month period. The study population includes patients who underwent all three imaging studies within the aforementioned time period, with the MPI exam less than 30 months before CC. In total, 56 patients were identified who met the initial criteria. 12 patients were excluded due to the MPI taking place after CC intervention, 3 were excluded due to the MPI taking place >30 months before CC, and 2 were excluded due to a congenital anomaly being the reason for imaging. 3 patients who had MPI after CC were included in the study since no intervention was performed. All patients who underwent revascularization were subsequently medically managed according to national guidelines.[3] Approval from the Institutional Review Board at both institutions was obtained prior to initiation of the study. Table 1 further describes patient demographics.

MPI Imaging and Analysis

SPECT MPI studies were performed based on American Society of Nuclear Cardiology guidelines.[4] Exercise stress was obtained by

treadmill exercise using the standard Bruce protocol.[5] SPECT images were acquired using dual-head gamma cameras (Vertex EPIC, ADAC Laboratories, Milpitas, CA, USA). Short- and long-axis images were reconstructed using a Butterworth filter. Image interpretation was performed by two experienced nuclear cardiologists based on semi-quantitative polar maps of perfusion, using a 17-segment model.[6,7]

The following results were obtained from each MPI study: normal/abnormal result, gated wall motion, area of myocardium affected by ischemia, left ventricular ejection fraction, summed stress score (SSS), summed rest score (SRS), summed difference score (SDS), and transient ischemic dilation (TID). The SRS and the SSS were calculated by adding the segmental perfusion scores during rest and stress, respectively, and the SDS was calculated by subtracting the SRS from the SSS. Two different board certified nuclear cardiologists (who were blinded to the results of the CCTA and CC studies) graded the severity of ischemia classified by SSS: normal (0–3),mildly abnormal (>3.0–8.0), moderately to severely abnormal (>8.0),[8] and by SDS: no ischemia (0– <2.0), mild ischemia (>2.0–4.0), moderate to severe ischemia (>4.0).[9] If a patient had a SSS< 8.0 or SDS< 4.0 but a TID >1.25, then a grade of severe ischemia was given.[10–13] The final statistic was an average of the individual grades.

CCTA Imaging and Analysis

All CCTAs were obtained using 64-slice CT scanners (Somatom Definition; Siemens Medical Solutions, Forchheim, Germany; and Brilliance 64; Philips, Best, the Netherlands). Before CCTA, all patients with an average heart rate of 65 beats per minute or greater received oral metoprolol 50–100 mg in the absence of contraindications, and were administered sublingual nitroglycerin 0.2–0.6 mg immediately before scanning. During image acquisition, 60–80 mL of contrast were injected, followed by a saline flush. Helical scan data were obtained using the retrospective ECG-gating protocol. Image acquisition included the coronary arteries, left ventricle, and proximal ascending aorta. All CCTA results were transferred to an external three-dimensional workstation, and were analyzed independently by two experienced CCTA radiologists who were blinded to the results of the MPI and CC. The radiologists graded the severity of luminal stenosis of the coronary artery, classified as mild (0–49%), moderate (50–69%), or severe (≥70%).[14] The final statistic was determined as an average of these scores.

CC Imaging and Analysis

Coronary interventions were performed using the Judkins Technique with 5– or 6–F (femoral artery access) or 4– or 5–F (radial artery access) guiding catheters according to current standard methods. Anticoagulants administered were heparin, Angiomax, or Glycoprotein IIb/IIIa inhibitors, per the cardiologist's discretion. An intravenous (IV) bolus of heparin at 70 units/kg was given with frequent activated clotting times (ACT) to adjust heparin by further IV bolus dosing to maintain ACT between 250–300 seconds.[15] An IV bolus of Angiomax at 0.75 mg/kg was given with a maintenance dose of 1.75 mg/kg/hr during the procedure, and then up to 4 hours post procedure.[16] Coronary angiograms were obtained in multiple projections. Anterograde flow of the infarct-related artery was graded according to the classification of the thrombolysis in myocardial infarction (TIMI) trial.[17] Balloon angioplasty and stenting were performed to achieve an optimal angiographic result until defined as success by ACC (American College of Cardiology).[18] All angiograms had a frame rate of 15 frames per second, and were stored digitally on a compact disc. GE cardiac catheterization camera and systems including software were utilized for imaging using standard cine films and fluoroscopy. Standard views were obtained and were operator dependent. Each CC imaging study was analyzed for the following information: ejection fraction, location of stenosis, and percentage occlusion. Two different board certified interventional cardiologists, blinded to the results of MPI and CCTA, graded each patient to a category of stenosis: mild (<50%), moderate (50–69%), and severe (≥70%). The final statistic was an average of these grades.

Statistical Analysis

Patient demographic characteristics were ascertained using means and standard deviations for continuous variables; frequencies and proportions for categorical variables. Furthermore, frequencies and proportions were ascertained for each of the assigned categorical grades for the three different tests (MPI, CCTA, CC). The Kruskal-Wallis test was used to determine the ability of each test to predict the level of therapy (medical vs. interventional). Spearman's rank correlation was used to determine the association between any pair of MPI, CCTA, and CC. Unless stated otherwise, p-values <0.05 are deemed significant. The Stata software package was used for both graphs and analysis (StataCorp 2013. Stata Statistical Software: Release 13. College Station TX: StataCorp LP).

RESULTS

39 patients were included in the current analysis. 19 patients received medical therapy, while 7 patients and 13 patients received CABG and angioplasty respectively (Table 1). 11 patients (57.9%) and 5 patients (26.3%) within in the medical therapy treatment group presented with moderate to severe ischemia after undergoing the MPI SSS and MPI SDS imaging modalities respectively. The CCTA and CC imaging modalities rendered 16 (84.2%) patients and 9 (47.4%) patients with moderate stenosis respectively (Table 1).

Among the 7 patients within the CABG treatment group, the MPI SSS showed 4 (57.1%) patients with moderate to severe ischemia, while the MPI SDS showed 2 (28.6%) patients with moderate to severe ischemia. All 7 patients within this treatment group showed severe stenosis after undergoing the CCTA and CC imaging modalities.

The MPI SSS and SDS showed that 6 (46.2%) patients presented with moderate to severe ischemia and thus received angioplasty. 11 (84.6%) patients and 13 (100%) patients within the angioplasty treatment group showed severe stenosis with the CCTA and CC imaging modalities, respectively.

Of the four imaging modalities, CCTA and CC were correlated to the treatment distributions among the patients (p = <0.001 for both).

Figures 1–3 showed correlations between imaging modalities by assessing the distribution of treatment modalities across specified categories.

18/18 patients (100%) with severe stenosis (>70%) on CCTA were treated with interventional therapy through either surgical intervention or angioplasty, regardless of the result from MPI. When CCTA showed mild stenosis (<50%), 3/3 (100%) patients were treated with medical therapy, and none needed interventional therapy (as defined by Hulten *et al.*)[19] regardless of the result from MPI. When CCTA revealed moderate stenosis (50–70%) and MPI SSS was < 8, 8/8 patients (100%) were treated with medical therapy. Conversely, with MPI SSS >8, 8/10 (80%) were treated with medical therapy and 2/10 (20%) were treated with interventional therapy (Figure 1).

18/18 patients (100%) with severe stenosis from CCTA were treated with interventional therapy, and with mild stenosis 3/3 patients (100%) were treated with medical therapy. With moderate stenosis and an MPI SDS score of < 4.0, 12/12 patients (100%) were treated with medical therapy. With an SDS score of > 4.0, 4/6 patients (67%) were treated with medical therapy and 2/6 patients (33%) were treated with interventional therapy (Figure 2).

Figure 3 shows that with severe stenosis on CCTA, all 18/18 patients had severe stenosis on CC, and all underwent interventional therapy.

Table 1: Patient Data

	Medical Therapy N = 19	CABG N = 7	Angioplasty N = 13	P-Value[1]	Spearman's Rho (P - Value)
Variables					
Age at First Test (years, SD)	72.7 (9.5)	74.6 (7.2)	68.9 (8.5)	0.34	–0.19 (0.25)
Time Between Test (years, SD)	0.65 (0.99)	0.27 (0.83)	1.0 (0.82)	0.23	0.08 (0.62)
Gender (Males, %)	8 (42.1)	6 (85.7)	10 (76.9)	0.06	–0.34 (0.03)
MPI SSS Results (n, %)				0.59	–0.16 (0.32)
Normal	2 (10.5)	3 (42.9)	4 (30.8)		
Mild	6 (31.6)	0 (0)	3 (23.1)		
Moderate to Severe	11 (57.9)	4 (57.1)	6 (46.2)		
MPI SDS Results (n, %)				0.54	0.15 (0.35)
No Ischemia	10 (52.6)	4 (57.1)	5 (38.5)		
Mild Ischemia	4 (21.1)	1 (14.3)	2 (15.4)		
Moderate to Severe	5 (26.3)	2 (28.6)	6 (46.2)		
CCTA Results (n, %)				<0.001	0.80 (<0.001)
Mild	3 (15.8)	0 (0)	0 (0)		
Moderate	16 (84.2)	0 (0)	2 (15.4)		
Severe	0 (0)	7 (100)	11 (84.6)		
CC Results (n, %)				<0.001	0.82 (<0.001)
Mild	8 (42.1)	0 (0)	0 (0)		
Moderate	9 (47.4)	0 (0)	0 (0)		
Severe	2 (10.5)	7 (100)	13 (100)		

[1]P-Values Calculated Using Kruskal Wallis Test for ordinal variables and Fisher's Exact for nominal variables.

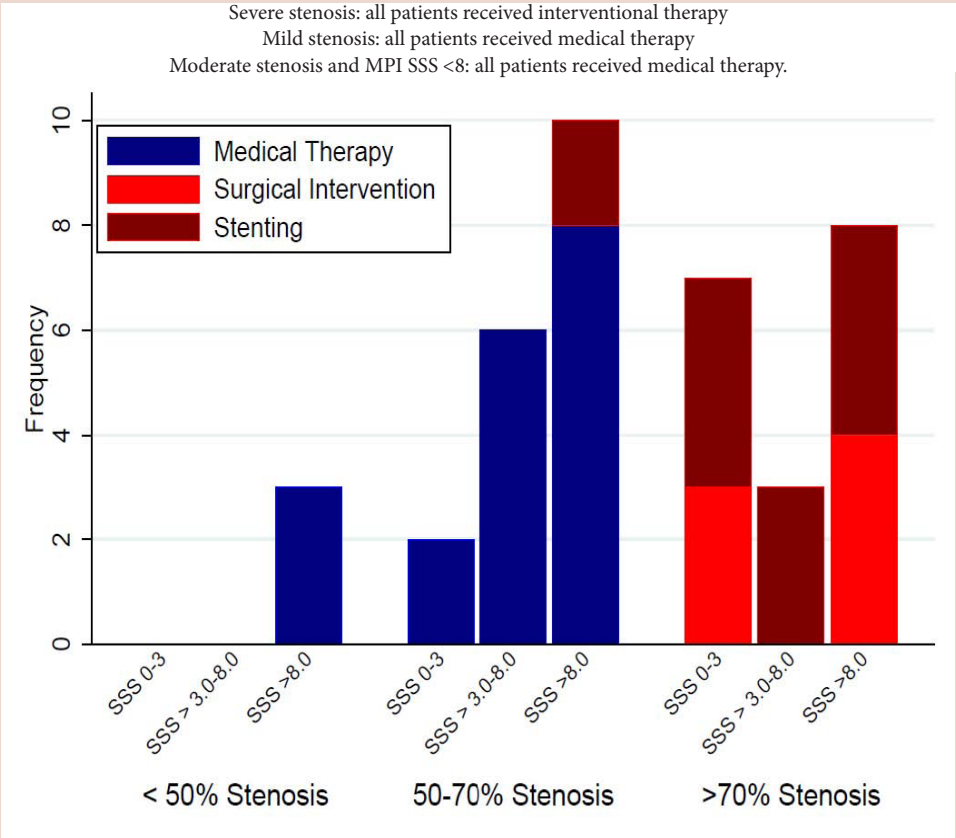

Figure 1: Demonstrates type of therapy related to stenosis on CCTA and ischemia on MPI SSS:

*Histogram showing the correlation between CCTA (major grouping on x-axis) vs. MPI by SSS (subgrouping on x-axis) with the corresponding type of prescribed medical treatment (medical therapy, surgical intervention, stenting) in color coding.

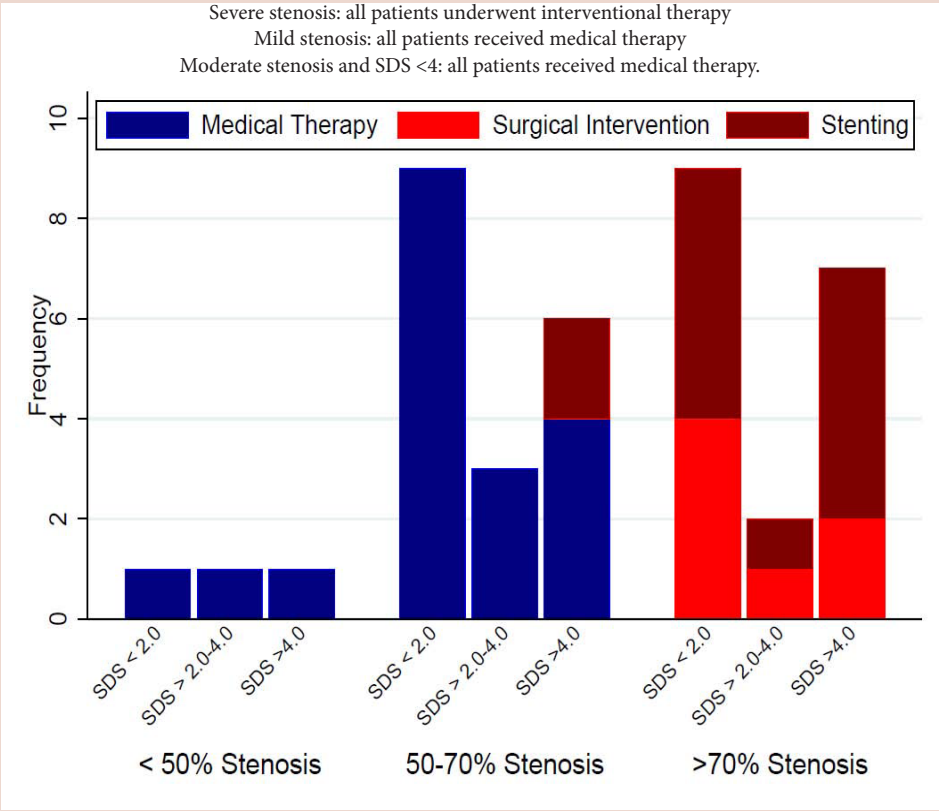

Figure 2: Depicts type of therapy related to stenosis on CCTA and ischemia on MPI SDS.

*Histogram showing the correlation between CT coronary angiography (CCTA – major grouping on x-axis) vs. myocardial perfusion imaging (MPI) by summed difference score (SDS) (subgrouping on x-axis) with the corresponding type of prescribed medical treatment (medical therapy, surgical intervention, stenting) in color coding.

With mild stenosis on CCTA, 3/3 patients had mild stenosis on CC and all had medical therapy. With moderate stenosis from CCTA, 5/18 (28%) patients had mild stenosis on CC and underwent medical therapy; 9/18 (50%) patients had moderate stenosis on CC and underwent medical therapy; 4/18 patients (22%) had severe stenosis on CC with 2 receiving medical therapy and 2 interventional treatment.

Figure 4 shows that using MPI by SDS as a first line diagnostic test with CCTA as a follow-up did not effectively stratify patients into categories that are predictive of treatment type.

Using our algorithm (Figure 5), 3/39 patients (8%) could have avoided testing with MPI and CC, 21/39 patients (54%) could have avoided MPI, and 16/39 patients (41%) could have avoided CC, with only 2/39 patients (5%) needing all three imaging studies. Thus, in our cohort, 37/39 patients (95%) could have avoided one or more tests.

DISCUSSION

Our data show that using CCTA as a first line imaging study could be used to effectively reduce non-essential imaging and can direct subsequent therapy (medical vs. interventional). CCTA showed a statistically significant correlation to the severity of stenosis on CC ($p < 0.0001$) and type of treatment therapy prescribed ($p < 0.0001$). All patients who showed mild stenosis from CCTA also had mild stenosis from CC and received medical therapy. In this group, the additional testing from either MPI or CC was not needed, as CCTA was able to effectively rule out severe disease and eliminate the need for interventional therapy.

In certain situations in our study when CCTA showed 50–70% stenosis, the additional use of MPI added clinically useful information. When SDS was <4.0, all patients received medical therapy. When SDS was >4.0, 4/6 patients underwent medical therapy, while 2/6 patients underwent interventional treatment. The 2 patients who received interventional treatment also had limiting symptoms at the time of treatment (severe chest pain on exercise stress test that also limited daily activity), while the 4 who received medical therapy did not. When combined with the results from CCTA and MPI, the presence of limiting symptoms could be used to help stratify the patients for revascularization or medical therapy.

In our study, CCTA showed a strong ability to correlate to CC with severe stenosis, indicating a high true positive rate (100%). All patients who had severe stenosis from CCTA also had severe stenosis from CC and subsequently underwent interventional treatment. In this group, the additional use of CC was warranted as it helped to direct angioplasty or revascularization. It has been well-established that severe levels of coronary stenosis (>70%) as detected by CC are the gold standard to determine treatment through revascularization, either through angioplasty or bypass surgery.[20] Severe obstructions have been linked to a 40x increased relative risk for a major adverse coronary event, so with a severe stenosis result on CCTA (or multiple proximal vessel involvement), a follow up with CC and aggressive treatment would be indicated.[14,19,21] CC remains the gold standard to determine coronary stenosis diagnostically, but CCTA is a reliable, less invasive, and more cost effective tool.[2]

Our data prompted us to develop a new imaging algorithm (Figure 5). A symptomatic patient with stable angina and an abnormal EKG should

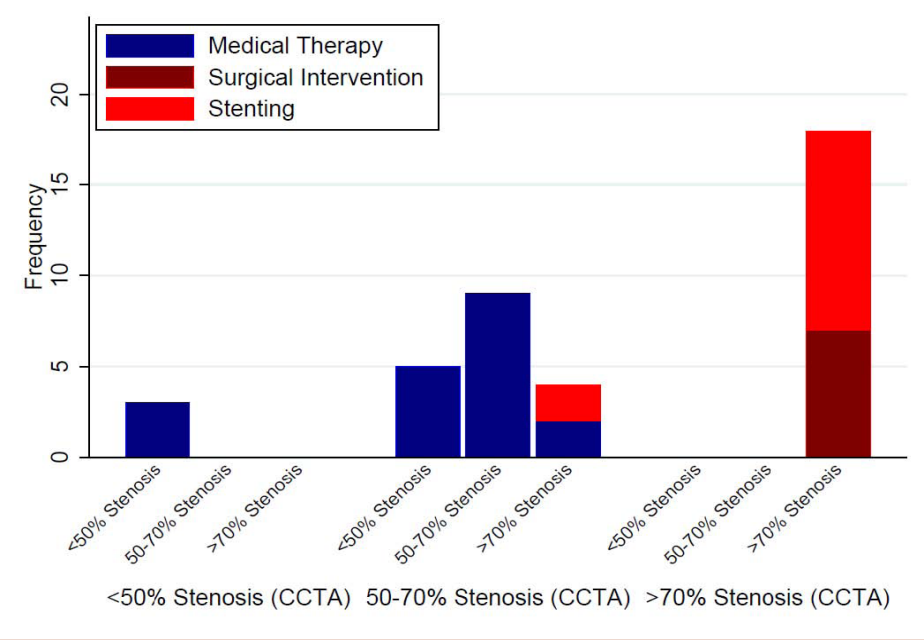

Figure 3: Illustrates the interrelationship between severity of stenosis on CC and CCTA correlating to therapy type.

*Histogram showing the correlation between CT coronary angiography (CCTA – major grouping on x-axis) vs. cardiac catherization (CC-subgrouping on x-axis) with the corresponding type of prescribed medical treatment (medical therapy, surgical intervention, stenting) in color coding.

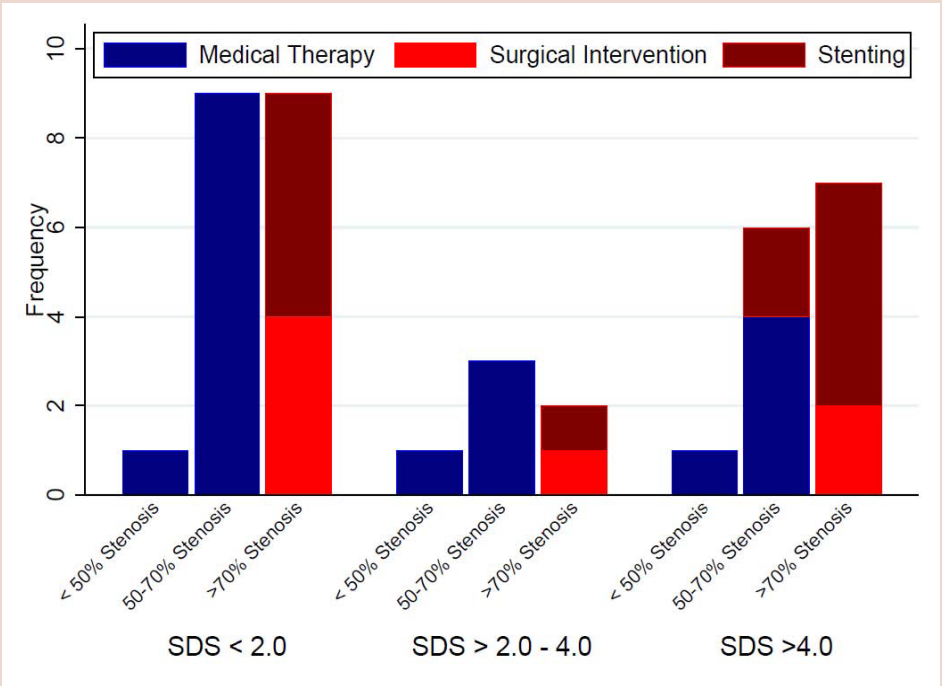

Figure 4: Shows that using MPI SDS as a first-line imaging test did not place patients in predictive categories that could be used to predict treatment modality.

*Histogram showing the correlation between myocardial perfusion imaging (MPI) by summed difference score (SDS). (major grouping on x-axis) vs. cardiac catherization (CC-subgrouping on x-axis) with the corresponding type of prescribed medical treatment (medical therapy, surgical intervention, stenting) in color coding.

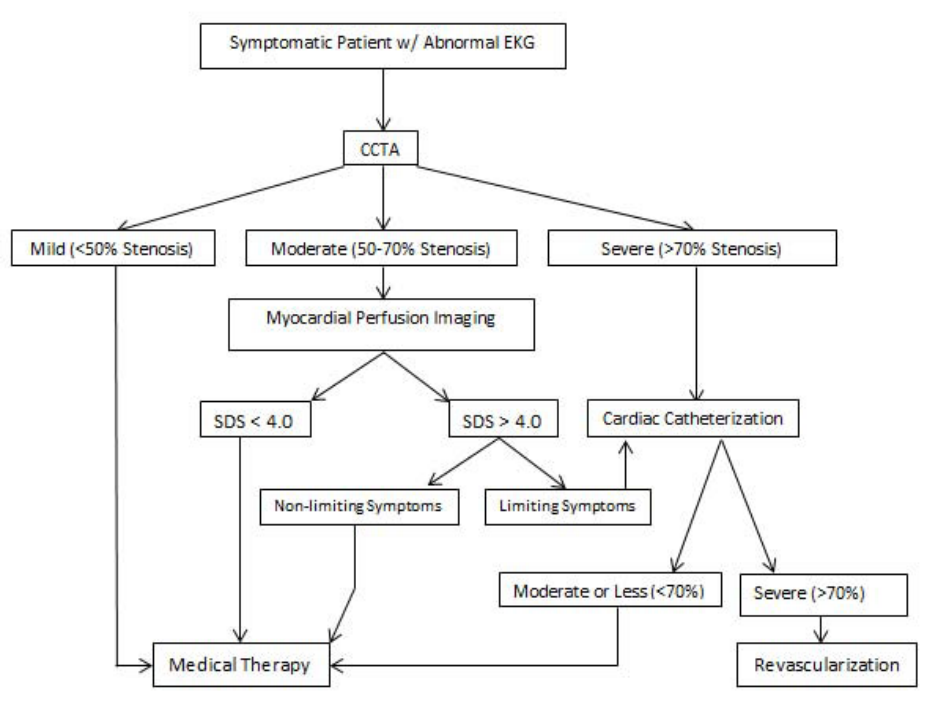

Figure 5: Proposed imaging algorithm explaining when to use CCTA, MPI, and CC.
*Revascularization in Figure 5 includes angioplasty, stents, CABG.

first be referred for CCTA. CCTA will then be able to determine whether severe CAD (>70% stenosis) is present. If so, the patient should be referred to CC for confirmatory diagnosis and revascularization. If severe CAD is absent, and the level of stenosis is <50%, medical treatment according to national guidelines[3] is the appropriate therapy. When the results of CCTA show moderate CAD (50–70% stenosis), additional imaging by MPI is warranted to determine the course of therapy. If the results from MPI show anything less than moderate ischemia (with a large area of ischemia, SDS >4.0, or a TID >1.25), the patient should undergo medical therapy and subsequently be monitored for progression of disease. If the results show severe ischemia, and the patient has symptoms on maximal anti-anginal medication, the patient should be referred to CC for confirmatory diagnosis and possible revascularization.

This algorithm uses the benefits of each imaging modality to effectively rule in or rule out CAD. We recommend CCTA as a first line imaging modality due to its ability to rule out disease. Tamarappoo *et al.*[1,22] and Budoff *et al.*[23] illustrated the strong negative predictive value of CCTA, indicating the ability of CCTA to determine a true negative result and rule out disease. In patients with moderate stenosis, MPI is a valuable adjunctive imaging modality that can provide additional information for symptomatic patients. In symptomatic patients with severe levels of myocardial ischemia, more aggressive treatment through revascularization can be planned. CC remains the confirmatory diagnostic study, due to its accuracy as the gold standard for coronary imaging. Using this algorithm, unnecessary testing (such as using MPI when CCTA shows severe or mild stenosis) can be avoided.

Recently, data from the PROMISE trial have indicated non-inferiority of CCTA compared to functional testing.[24] The authors assigned 10,000 symptomatic patients to two treatment arms (anatomic testing with CCTA, or physiologic testing with stress EKG, MPI, stress echocardiography), and found at a follow-up of 25 months, the primary end point (death, MI, hospitalization for unstable angina, measured procedural complication) was equivalent in both treatment arms (3.3% in CCTA group vs. 3% in functional testing group) with equivalent economic results from the each arm of the study.[24] Comparing CCTA to physiologic testing, cumulative radiation exposure (10.0 mSv vs. 11.3 mSv) and false positive results [non-invasive imaging suggesting stenosis >50% necessitating CC] (3.4% vs. 4.3%) were lower in the CCTA group than functional testing group.[24] The results of this study show non-inferiority among each arm of the study, suggesting that initial cardiac imaging should be chosen that accurately predicts medical vs. interventional treatment.

LIMITATIONS OF CURRENT STUDY

First, this was a single-center study with a limited sample size. Second, the tests were not all performed at the same time (mean time between testing was 0.69 years with standard deviation of 0.91 years). To obtain sufficient patient data for analysis, this criterion for imaging was within 30 months. This could have allowed for increased luminal thrombosis, worsening of CAD, and/or clinically significant changes in this time frame. Third, it would not be ethically permissible to prospectively assign patients to all three imaging studies, and thus a retrospective analysis was utilized. Since the 39 patients were analyzed by all three studies, they were inherently difficult to stratify for medical vs. interventional treatment. Therefore, they may not be completely representative of the population with typical angina. However, even with the limited sample size, our data reinforce the literature for the correlation between the various imaging studies. Additionally, the eventual outcomes of these patients were not followed.

For future study, a multi-center prospective analysis with a large patient population using this imaging and treatment algorithm would

be beneficial to assess patient outcomes. The progress of these patients should be followed over time so that adverse events can be tracked to determine if their prevention could have been predicted, and whether alterations in the imaging algorithm need to be made.

CONCLUSION

This retrospective study has helped establish the relative importance and interrelationships of CCTA, MPI, and CC. CCTA is a noninvasive imaging approach to determine CAD with high levels of sensitivity, specificity, and negative predictive value. Its use as a first line imaging modality in the patient with stable angina and an abnormal EKG is suggested by our study. Following a result from CCTA showing moderate stenosis (50–70%), MPI yields prognostic benefit to determine therapy stratification. The utilization of these imaging studies according to our algorithm should reduce the need for invasive CC, using it only for confirmatory diagnosis and eventual treatment in the setting of severe stenosis, while simultaneously avoiding the unnecessary use of MPI (such as using MPI when CCTA shows mild or severe stenosis). Future prospective analysis using our algorithm is warranted, assessing outcomes at each level of the algorithm, to measure the development of adverse coronary events and the response to the different therapies that were guided by the proposed algorithmic approach.

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CONFLICT OF INTEREST

There are no significant conflicts of interest from the authors of this study.

ABBREVIATIONS USED

CT: Coronary angiography (CCTA); **MPI:** Myocardial perfusion imaging; **CC:** Cardiac catherization, **SSS:** Summed stress score; **SDS:** Summed difference score; **CAD:** Coronary artery disease; **TID:** Transient ischemic dilation.

REFERENCES

1. Tamarappoo BK, Hachamovitch R. Myocardial perfusion imaging versus CT coronary angiography: when to use which?. J Nucl Med. 2011;52(7):1079-86.
2. Catalan P, Callejo D, Blasco Ja. Cost-effectiveness analysis of 64–slice computed tomography vs. cardiac catheterization to rule out coronary artery disease before non-coronary cardiovascular surgery. Eur Heart J Cardiovasc Imaging. 2013;14(2):149-57.
3. Qaseem A, Fihn SD, Dallas P, Williams S, Owens DK, Shekelle P. Management of stable ischemic heart disease: summary of a clinical practice guideline from the American College of Physicians/American College of Cardiology Foundation/American Heart Association/American Association for Thoracic Surgery/Preventive Cardiovascular Nurses Association/Society of Thoracic Surgeons. Ann Intern Med. 2012;157(10):735-43.
4. Henzlova M, Cerqueria MD, Hansen CL, Taillefer R, Yao S. ASNC imaging guidelines for nuclear cardiology procedures: stress protocols and tracers. J Nucl Cardiol. 2009;16:331.
5. Bruce RA, Lovejoy FW, Pearson R, Yu PNG, Brothers GB, Velasquez T. Normal respiratory and circulatory pathways of adaptation in exercise. Journal of Clinical Investigation. 1949;28(6 Pt 2):1423-30.
6. Stein PD, Beemath A, Kayali F, Skaf E, Sanchez J, Olson RE. Multidetector computed tomography for the diagnosis of coronary artery disease: a systematic review. Am J Med. 2006;119(3):203-16.
7. Cerqueira MD, Weissman NJ, Dilsizian V, Jacobs AK, Kaul S, Laskey WK, *et al.* Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart. A statement for healthcare professionals from the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association. Int J Cardiovasc Imaging. 2002;8(1):539-42.
8. Hachamovitch R, Berman DS, Shaw LJ. Incremental prognostic value of myocardial perfusion single photon emission computed tomography for the prediction of cardiac death: differential stratification for risk of cardiac death and myocardial infarction. Circulation. 1998;97:535-43.
9. Hachamovitch R, Hayes SW, Friedman JD, Cohen I, Berman BS. Stress myocardial perfusion single-photon emission tomography is clinically effective and cost effective in risk stratification of patients with a high likelihood of coronary artery disease (CAD) but no known CAD. J Am Coll Cardiol. 2004;43:200-8.
10. Kinoshita N, Sugihara H, Adachi Y. Assessment of transient left ventricular dilation on rest and exercise on Tc-99 m tetrofosmin myocardial SPECT. Clin Nucl Med. 2002;27(1):34-9.
11. Abidov A, Bax JJ, Hayes SW. Transient ischemic dilation ratio of the left ventricle is a significant predictor of future cardiac events in patients with otherwise normal myocardial perfusion SPECT. J Am Coll Cardiol. 2003;42(10):1818-25.
12. Mazzanti M, Germano G, Kiat H. Identification of severe and extensive coronary artery disease by automatic measurement of transient ischemic dilation of the left ventricle in dual-isotope myocardial perfusion SPECT. J Am Coll Cardiol. 1996;27(7):1612-20.
13. McClellan JR, Travin MI, Herman SD. Prognostic importance of scintigraphic left ventricular cavity dilation during intravenous dipyridamole technetium-99m sestamibi myocardial tomographic imaging in predicting coronary events. Am J Cardiol. 1997;79(5):600-5.
14. Nakazato R, Arsanjani R, Achenbach S. Age-related risk of major adverse cardiac event risk and coronary artery disease extent and severity by coronary CT angiography: results from 15187 patients from the International Multisite CONFIRM Study. Eur Hear J Cardiovasc Imaging. 2014;15(5):586-94.
15. Niccoli G, Banning, AP.. Heparin dose during percutaneous coronary intervention: how low dare we go?. Heart,.2002;88(4):331-4.
16. Lincoff AM, Bittl JA, Harrington RA, Feit F, Kleiman NS, Jackman JD. REPLACE-2 Investigators. (2003). Bivalirudin and provisional glycoprotein IIb/IIIa blockade compared with heparin and planned glycoprotein IIb/IIIa blockade during percutaneous coronary intervention: REPLACE-2 randomized trial. Jama. 2003;289(7):853-63.
17. Group TTiMITS. The thrombolysis in myocardial infarction (TIMI) trial. Phase I findings. TIMI study group. N Engl J Med. 1985;312(14):932-6.
18. Holmes D, Hirshfeld J, Faxon D, Vlietstra R, Jacobs A, King S, Wolk M. ACC Expert Consensus document on coronary artery stents: document of the American College of Cardiology. Journal of the American College of Cardiology. 1998;32(5):1471-82.
19. Hulten EA, Carbonaro S, Petrillo SP, Mitchell JD, Villines TC. Prognostic value of cardiac computed tomography angiography: a systematic review and meta-analysis. J Am Coll Cardiol. 2011;57(10):1237-47.
20. Management of patients undergoing coronary artery revascularization; American College of Cardiology Foundation; ACCF/AHA Pocket Guideline, November 2011.
21. Min JK, Shaw LJ, Devereux RB. Prognostic value of multidetector coronary computed tomographic angiography for prediction of all-cause mortality. J Am Coll Cardiol. 2007;50(12):1161-70.
22. Shaw L, Narula J. Risk assessment and predictive value of coronary artery disease testing. J Nucl Med. 2009;50(8):1296-306.
23. Budoff MJ, Dowe D, Jollis JG. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. J Am Coll Cardiol. 2008;52(21):1724-32.
24. Douglas PS, Hoffmann U, Patel M, Mark D, Cooper L, Lee K. PROMISE Investigators. A randomized comparison of anatomic versus functional diagnostic testing strategies in symptomatic patients with suspected coronary artery disease: results from the PROMISE trial (PROspective Multicenter Imaging Study for Evaluation of chest pain). Program and abstracts of the American College of Cardiology 64th Annual Scientific Session & Expo; March 14–16, 2015; San Diego, California. Abstract LBA 400-16.

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