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ORIGINAL ARTICLE

Utility of Noninvasive Testing Before Invasive Coronary Angiography in the Assessment for Revascularization

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Abstract

Objective: To examine the role of noninvasive testing (NIT) before invasive coronary angiography (ICA) by evaluating the association between a positive myocardial perfusion imaging (MPI) or computed tomography angiography (CTA) result and the decision to perform coronary revascularization.

Patients and Methods: We screened all patients who received ICA between August 1, 2015, and July 31, 2019, and identified those who received MPI or CTA within the preceding 12 months. We considered MPI to be a positive result if it found moderate or severe ischemia in a specific coronary territory and CTA to be a positive result if it identified a stenosis greater than 50% in any major coronary artery.

Results: Of the 17,181 individual procedures, 2183 were included. Positive CTA had an odds ratio (OR) of 2.68 (95% CI, 1.82-3.94) for revascularization and positive MPI an OR of 1.29 (95% CI, 1.07-1.56). Overall sensitivity for CTA in the prediction of revascularization was 80.4% (95% CI, 75.7%-84.6%), with vessel-level sensitivity ranging from 57.3% (95% CI, 47.5%-66.7%) to 71.8% (95% CI, 65.8%-77.4%). Overall sensitivity of MPI was 48.2% (95% CI, 44.7%-51.7%), with territory-specific sensitivity ranging from 33.7% (95% CI, 29.9%-37.7%) to 36.5% (95% CI, 32.6%-40.6%). Overall specificity for CTA was low, at 39.5% (32.9%-46.3%), but higher when evaluating at the vessel level, ranging from 60.3% (95% CI, 54.5%-66.0%) to 83.5% (95% CI, 79.6%-86.9%). Overall specificity for MPI was 58.1% (95% CI, 54.9%-61.3%), with territory-specific specificity ranging from 78.6% (95% CI, 76.1%-80.9%) to 78.9% (95% CI, 76.5%-81.3%).

Conclusion: In this population of patients referred for ICA, positive CTA was more closely associated with revascularization than MPI. Further studies are necessary to determine the role of NIT before ICA.

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Despite ongoing improvements in diagnostic and treatment modalities, coronary artery disease (CAD) is a major cause of death in the United States.[1] Invasive coronary angiography (ICA) is the gold standard diagnostic test for CAD, enabling anatomic and physiologic evaluation with fractional flow reserve and other hemodynamic techniques,[2] as well as intervention on stenotic lesions. Guidelines encourage the use of noninvasive testing (NIT) before ICA in certain patient populations to identify high-risk patients who may benefit from revascularization and avoid unnecessary invasive procedures in those who will not.[3-7] Despite this, the influence of NIT on the decision of whether to proceed to ICA and revascularize specific epicardial arteries remains unclear in contemporary practice.

Two of the most commonly used NIT methods include computed tomography angiography (CTA) and myocardial perfusion imaging

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(MPI); the latter of which is performed using either single-photon emission computed tomography or positron emission tomography. CTA allows both visualization of coronary artery anatomy and the evaluation of arterial stenosis and calcification and is thought to be helpful in the exclusion of low-risk patients from unnecessary ICA owing to its relatively high sensitivity and associated negative predictive value (NPV)[8-11] in the prediction of significant CAD. Moreover, MPI has been shown to have decreased sensitivity when compared with CTA, and its utility to identify territories in need of revascularization remains unclear.[12,13] Ischemia-driven revascularization may improve cardiovascular outcomes when compared with revascularization without knowledge of myocardial perfusion[14-16] although this benefit is not seen in all patient populations.[17] The role of ischemia-driven revascularization is further challenged by new evidence suggesting that revascularization of stable CAD does not improve long-term outcomes when compared with medical treatment alone despite the presence of ischemia identified on functional NIT.[18] In light of this conflicting evidence, we sought to examine the role of NIT before ICA by determining the association of a positive CTA or MPI result with the decision of whether to perform coronary revascularization.

PATIENTS AND METHODS

The University of Ottawa Heart Institute is a tertiary care center that serves as the primary coronary revascularization site for a catchment area of greater than 1.2 million people.[19] We prospectively enrolled patients undergoing ICA with or without percutaneous coronary intervention (PCI) at University of Ottawa Heart Institute between August 1, 2015, and July 31, 2019, in the CAPITAL (Cardiovascular And Percutaneous Clinical Trials) revascularization registry.[20,21] We screened all patients who received ICA during this 4-year period to identify patients aged 18 years or older who received CTA or MPI within the 12-month period before their ICA. We excluded patients with a history of coronary artery bypass grafting (CABG) occurring before the date of the ICA. We collected data including baseline patient demographic characteristics, NIT protocol and results, coronary anatomy and lesion severity on the basis of ICA, the need for PCI, the number of percutaneous interventions performed (both at the time of the initial ICA and thereafter in staged fashion), whether a patient was revascularized using CABG, and which native vessels were bypassed by CABG. These data were derived from a registry approved by Ottawa Health Science Network Research Ethics Board (OHSN-REB #20190224-01H) to evaluate clinical outcomes after revascularization.

We defined acute coronary syndrome according to either the third or fourth universal definition of myocardial infarction (whichever was standard of care at the time of the ICA).[22,23] We defined diabetes mellitus (DM) using either a hemoglobin A1c of more than or equal to 6.5% on presentation or a previous DM diagnosis including the presence of medical therapy for DM. We divided tobacco use into active smokers (active smoking or cessation of smoking within 1 month before ICA), previous smoker (cessation >1 month before ICA), or nonsmokers (no history of tobacco use). We defined a positive family history as CAD in a first-degree relative aged younger than 55 years for men and younger than 65 for women. We defined dyslipidemia and hypertension as a previous diagnosis of either condition or the use of relevant pharmacotherapy.

We considered CTA to be a positive result if it identified a stenosis greater than 50% in a major coronary artery. We considered MPI to be a positive result if it found moderate or greater ischemia in a specific coronary territory. The presence of resting perfusion defect (scar) was not included in our analysis. We stratified MPI territories into left anterior descending artery (LAD) territory and non-LAD territory (a combined territory of right coronary artery [RCA], circumflex artery [Cx], and the indeterminate territory between RCA and Cx). When 2 or more ICA procedures were performed for the same patient, we considered them to be part of the same event as long as they fulfilled the following criteria: (1) all ICA tests were done within a 12-month period and (2) a single NIT was used before all ICAs as the basis for the decision to proceed with ICA. We considered them to be separate events if separate NITs were used to guide the decision to perform each procedure. We defined revascularization as PCI or CABG within 12 months after ICA.

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Finally, we performed a sensitivity analysis evaluating accuracy of CTA and MPI in predicting revascularization after excluding patients with previous PCI.

We reported data as mean ± SD, median and interquartile range, or number and percentage (%) where appropriate. To compare sets of continuous variables, we used a 2-sided Student *t* test and, for categorical variables, a χ^2 analysis. All reported *P* values are 2-sided, and we considered a value less than .05 to be statistically significant. We also described and compared the accuracy of each imaging modality to predict revascularization using sensitivity, specificity, positive predictive value (PPV), and NPV, as well as odds ratio (OR), all with 95% CIs.

RESULTS

Figure 1 displays patient identification and inclusion. Over the 4-year period between August 1, 2015, and July 31, 2019, there were 17,181 individual procedures in the registry. From this, we identified 2823 separate ICA procedures in patients who had undergone CTA or MPI for the evaluation of CAD before the ICA. After removing duplicate procedures, as well as those who did not receive CTA or MPI within the 12-month period before the ICA and those with a history of CABG, we included 2183 procedures for analysis, encompassing 2162 unique patients. Patient characteristics are summarized in Table 1. Most patients were male (70.5%), and most had a history of hypertension and dyslipidemia (68.3% and 71.2%, respectively). The median age was 65.5±10.4 years. In this cohort, patients who received CTA were younger and less likely to have a history of hypertension, dyslipidemia, type II diabetes, previous MI, previous PCI, peripheral arterial disease, and congestive heart failure. They were more likely to have a family history of CAD and to have stable CAD as the listed indication for ICA.

Supplemental Tables 1 and 2 (available online at http://www.mcpiqojournal.org) summarize NIT data for included patients. Within the 12 months before ICA, 540 patients in our cohort underwent CTA and 1746 underwent MPI, with 103 undergoing both CTA and MPI. By CTA, 391 patients (72.4%) were found to have significant stenosis, with 293 (54.3%) having significant stenosis in the LAD, 163 (30.2%) in the RCA, and 134 (24.8%) in the Cx. Of the MPI tests, 1068 (61.2%) were single-photon emission computed tomography. The most commonly used stress agent was dipyridamole (82.7%). Of the 1746 patients who underwent MPI, 783 (44.8%) found positive results for ischemia, with 442 (25.3%) in the LAD territory and 462 (26.5%) in the non-LAD territory.

Figure 2 and Table 2 summarize the ability of CTA and MPI to predict lesion revascularization. Of the 391 patients with positive-result CTA, 259 (66.2%) were revascularized, and of the 149 patients with negative-result CTA, 63 (42.3%) were revascularized (OR for revascularization, 2.68; 95% CI, 1.82-3.94). Significant stenosis of the LAD by CTA had an OR of 3.88 (95% CI, 2.70-5.58) for revascularization; for the RCA, an OR of 10.85 (95% CI, 6.96-16.93); and for the Cx, an OR of 6.78 (95% CI, 4.30-10.69).

Of the 783 patients with positive-result MPI, 396 were revascularized (50.6%). Of the 963 patients with a negative-result MPI, 426 (44.2%) were revascularized (OR, 1.29; 95% CI, 1.07-1.56). For the LAD territory, positive-result MPI had an OR of 1.90 (95% CI, 1.52-2.37) for revascularization of the LAD and, for the non-LAD territory, an OR

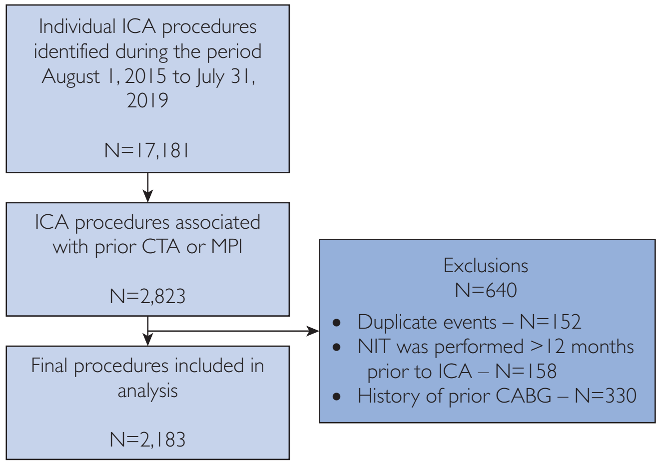

FIGURE 1. Flow chart of included patients. We identified 17,181 individual ICA procedures during the 4-year study period; 2183 were included in our final analysis. CABG, coronary artery bypass grafting; CTA, computed tomography angiography; ICA, invasive coronary angiography; MPI, myocardial perfusion imaging; NIT, noninvasive testing.

TABLE 1. Patient Demographic Characteristics

	Total cohort (n=2183); n (%)	CTA (n=540); n (%)	MPI (n=1746); n (%)	*P*
Age (mean ± SD)	65.5±10.4	61.9±9.3	66.4±10.4	<.01
Female sex	643 (29.5)	163 (30.1)	509 (29.2)	.65
Hypertension	1490 (68.3)	329 (60.9)	1235 (70.7)	<.01
Dyslipidemia	1554 (71.2)	364 (67.4)	1265 (72.5)	.024
Diabetes				
Type I	10 (0.458)	2 (0.370)	9 (0.515)	.67
Type II	707 (32.4)	128 (23.7)	608 (34.8)	<.01
Smoking				
Never	1317 (60.3)	331 (61.3)	1051 (60.2)	.65
Previous	592 (27.1)	136 (25.2)	486 (27.8)	.23
Current	274 (12.6)	73 (13.5)	209 (12.0)	.34
Previous PCI	465 (21.3)	25 (4.63)	449 (25.7)	<.01
Previous MI	344 (15.8)	21 (3.89)	330 (18.9)	<.01
History of CVA	113 (5.17)	22 (4.07)	94 (5.38)	.23
Peripheral arterial disease	137 (6.28)	17 (3.15)	127 (7.27)	<.01
Family history of CAD	346 (15.8)	118 (21.9)	249 (14.3)	<.01
Atrial fibrillation	180 (8.25)	43 (7.96)	149 (8.53)	.68
Congestive heart failure	140 (6.41)	20 (3.70)	124 (7.10)	<.01
Indications for ICA				
Stable CAD	1489 (68.2)	405 (75.0)	1163 (66.7)	<.01
Acute coronary syndrome	313 (14.3)	54 (10.0)	264 (15.1)	<.01
Staged PCI	132 (6.05)	29 (5.37)	107 (6.13)	.52
Other	249 (11.4)	52 (9.63)	212 (12.1)	.11

Abbreviations: ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; CAD, coronary artery disease; CVA, cerebrovascular accident; ICA, invasive coronary angiography; MI, myocardial infarction; PCI, percutaneous coronary intervention.

of 2.11 (95% CI, 1.70-2.63) for revascularization of either the Cx or the RCA.

Overall sensitivity for CTA in the prediction of revascularization was 80.4% (95% CI, 75.7%-84.6%), with territory-specific sensitivity ranging from 57.3% (95% CI, 47.5%-66.7%) for the Cx to 71.8% (95% CI, 65.8%-77.4%) for the LAD. Sensitivity was much lower for MPI, with an overall sensitivity of 48.2% (95% CI, 44.7%-51.7%) and a sensitivity of 33.7% (95% CI, 29.9%-37.7%) for the LAD territory and 36.5% (95% CI, 32.6%-40.6%) for the non-LAD territory. Specificity was low overall for CTA at 39.5% (95% CI, 32.9%-46.3%) but higher when evaluating at the vessel level, ranging from 60.3% (95% CI, 54.5%-66.0%) for the LAD to 83.5% (95% CI, 79.6%-86.9%) for the Cx. Overall specificity for MPI was 58.1% (95% CI, 54.9%-61.3%), with a value of 78.9% (95% CI, 76.5%-81.3%) for the LAD territory and 78.6% (95% CI, 76.1%-80.9%) for the non-LAD territory. The PPV and diagnostic accuracy was greater for CTA than MPI. NPV was similar between both modalities. When the analysis was repeated after excluding patients who had received PCI previously (Supplemental Table 3, available online at http://www.mcpiqojournal.org), similar trends in sensitivity, specificity, PPV, NPV, and diagnostic accuracy were observed.

DISCUSSION

This analysis evaluated the association between a positive NIT result and revascularization in patients undergoing ICA. Notably, even in the context of a positive-result MPI, only approximately 50% of patients underwent revascularization. Further, CTA was more accurate than MPI in the prediction of revascularization, both overall and when analyzing each vascular territory. Sensitivity was fair for CTA but very low for MPI, whereas specificity was low for both modalities.

Our findings complement other reports in the literature, suggesting that CTA may have

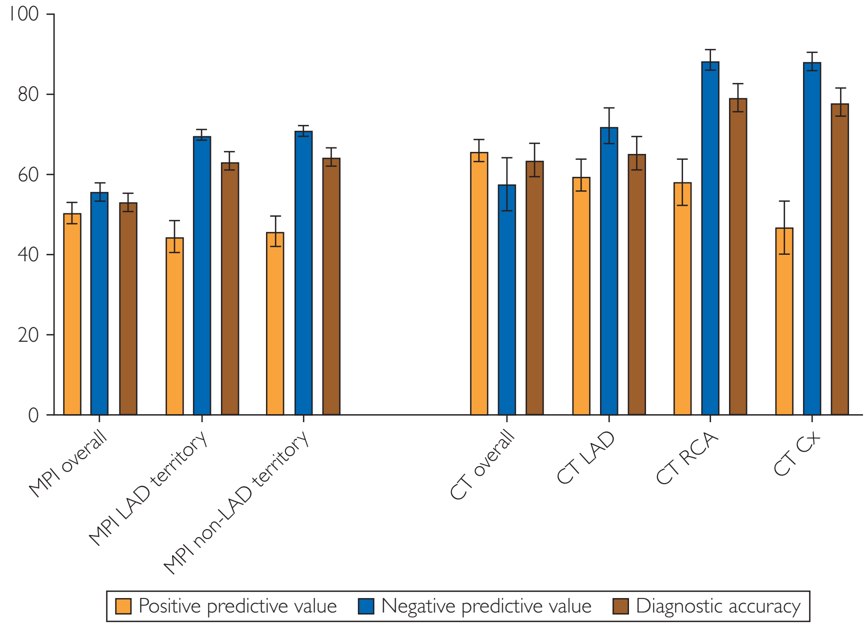

FIGURE 2. Diagnostic accuracy of NIT. Positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy of myocardial perfusion imaging (MPI) and computed tomography (CT) in the prediction of revascularization. CT was seen to have superior PPV and diagnostic accuracy, and similar NPV when compared with MPI. CT, computed tomography; Cx, circumflex artery; LAD, left anterior descending artery; MPI, myocardial perfusion imaging; RCA, right coronary artery.

better performance in the prediction of revascularization. Large cohort studies comparing CTA with MPI in the diagnosis of CAD consistently demonstrate superior sensitivity with CTA, with most showing similar specificity between the 2 modalities.[12,13,24,25] However, our study design is unique from these cohorts in that it is a population of patients referred for ICA. Furthermore, we assessed accuracy in the prediction of revascularization rather than of obstructive CAD in general. Nonetheless, our findings recapitulate studies that only evaluated anatomic correlation, suggesting that CTA remains superior in this regard.

Our findings further question the utility of MPI before ICA. The 2019 European Society of Cardiology guidelines on diagnosis of chronic coronary syndromes recommends CTA over MPI as the preferred first-line NIT in the workup for CAD,[26] primarily owing to its superior sensitivity and greater ability to rule out CAD across a wide range of pretest probabilities when compared with functional imaging such as MPI.[27] Furthermore, the role of ischemia testing in the revascularization decision has been challenged by the recent ISCHEMIA trial,[18] which found no difference in outcomes when revascularization was compared with medical therapy alone in patients with stable CAD and moderate or greater ischemia seen on functional testing. Importantly, all patients received CTA before randomization, and those with left main coronary stenosis were excluded from the trial—encouraging the continued use of anatomical assessments of coronary arteries to rule out high-risk disease.

Overall, although diagnostic accuracy was higher for CTA than MPI in our cohort, both modalities performed poorly overall when predicting need for revascularization. The role of both functional and anatomical imaging in contemporary cardiology remain poorly defined, and there is ongoing debate on how NIT should be used to optimize health care resource utilization and improve care quality and patient outcomes. For example, care pathways often capitalize on the high specificity and NPV observed with

TABLE 2. Ability of CTA and MPI to Predict Lesion Intervention

	Interventions on vessels classified as abnormal, n (%)	Interventions on vessels classified as normal, n (%)	OR (95% CI)	Sn (95% CI)	Sp (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy (95% CI)
All MPI	396 (50.6)	426 (44.2)	1.29 (1.07-1.56)	48.2 (44.7-51.7)	58.1 (54.9-61.3)	50.6 (48.0-53.2)	55.8 (53.6-57.9)	53.4 (51.1-55.8)
LAD territory	198 (44.8)	390 (29.9)	1.90 (1.52-2.37)	33.7 (29.9-37.7)	78.9 (76.5-81.3)	44.8 (40.9-48.8)	70.1 (68.7-71.4)	63.7 (61.4-66.0)
Non-LAD territory	213 (46.1)	370 (28.8)	2.11 (1.70-2.63)	36.5 (32.6-40.6)	78.6 (76.1-80.9)	46.1 (42.3-49.9)	71.2 (69.8-72.6)	64.6 (62.3-66.8)
All CTA	259 (66.2)	63 (42.3)	2.68 (1.82-3.94)	80.4 (75.7-84.6)	39.5 (32.9-46.3)	66.2 (63.5-68.9)	57.7 (50.9-64.3)	63.9 (59.7-68.0)
LAD	176 (60.1)	69 (27.9)	3.88 (2.70-5.58)	71.8 (65.8-77.4)	60.3 (54.5-66.0)	60.1 (56.2-63.9)	72.1 (67.4-76.3)	65.6 (61.4-69.6)
RCA	95 (58.3)	43 (11.4)	10.85 (6.96-16.93)	68.8 (60.4-76.5)	83.1 (79.1-86.6)	58.3 (52.3-64.1)	88.6 (85.8-90.9)	79.4 (75.8-82.8)
Cx	63 (47.0)	47 (11.6)	6.78 (4.30-10.69)	57.3 (47.5-66.7)	83.5 (79.6-86.9)	47.0 (40.5-53.7)	88.4 (86.0-90.5)	78.2 (74.4-81.6)

Abbreviations: CTA, computed tomography angiography; Cx, circumflex artery; LAD, left anterior descending artery; MPI, myocardial perfusion imaging; NPV, negative predictive value; PPV, positive predictive value; Sn, sensitivity; Sp, specificity; RCA, right coronary artery.

CTA in the broad CAD population[8-11] by implementing it as a "gatekeeper" test to prevent unnecessary ICAs in low-risk and intermediate-risk patients. With such a low false-negative rate, obstructive CAD is unlikely to be missed with this strategy, and patients who will not benefit from ICA will be spared from an invasive procedure with an associated risk of harm. The utility of MPI for this purpose is less clear given its inferior specificity and NPV.[12] Although ischemia-driven revascularization has been observed to be beneficial in prior studies,[14,15] we did not observe a meaningful association between ischemia and revascularization in our cohort. Future research should focus on identifying which patients benefit from ischemia-drive revascularization, to further clarify the role of functional imaging in the management of stable CAD.

Certainly, our study is not without limitations. First, our cohort included only patients already referred for ICA and, thus, is not representative of the broader CAD population—specifically those medically managed. Second, the indication for revascularization might have been affected by the NIT results, which were not blinded. In addition, given the nonrandomized study design, differences in various patient characteristics were observed between the group that received CTA and the group that received MPI. We were unable to determine the influence that these differences might have had on the decision to test initially with either CTA or MPI, as well as on the decision to refer for ICA. Finally, this study evaluated only MPI and CTA, although other forms of NIT, such as stress echocardiography and treadmill testing, are frequently used in other clinical situations.

CONCLUSION

In this population of patients who underwent ICA, CTA was more accurate than MPI in the prediction of revascularization, but overall diagnostic accuracy was poor for both modalities. Further prospective and randomized studies involving both NIT and ICA are necessary to determine the true predictive capability of each modality and to clarify the role of MPI in contemporary practice.

POTENTIAL COMPETING INTERESTS

The authors report no competing interests.

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ETHICS STATEMENT

The study data were derived from a registry approved by Ottawa Health Science Network Research Ethics Board (OHSN-REB #20190224-01H) to evaluate clinical outcomes after revascularization.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mcpiqojournal.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **CAD,** coronary artery disease; **CABG,** coronary artery bypass grafting; **CTA,** computed tomography angiography; **Cx,** circumflex artery; **DM,** diabetes mellitus; **ICA,** invasive coronary angiography; **LAD,** left anterior descending artery; **MPI,** myocardial perfusion imaging; **NIT,** noninvasive testing; **PCI,** percutaneous coronary intervention; **RCA,** right coronary artery

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REFERENCES

1. Lloyd-Jones D, Adams R, Carnethon M, et al. Heart disease and stroke statistics—2009 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. *Circulation*. 2009;119(3):e21-e181. https://doi.org/10.1161/CIRCULATIONAHA.108.191261.
2. Berger A, Botman KJ, MacCarthy PA, et al. Long-term clinical outcome after fractional flow reserve-guided percutaneous coronary intervention in patients with multivessel disease. *J Am Coll Cardiol*. 2005;46(3):438-442. https://doi.org/10.1016/j.jacc.2005.04.041.
3. Beanlands RS, Chow BJ, Dick A, et al. CCS/CAR/CANM/CNCS/CanSCMR joint position statement on advanced noninvasive cardiac imaging using positron emission tomography, magnetic resonance imaging and multidetector computed tomographic angiography in the diagnosis and evaluation of ischemic heart disease—executive summary. *Can J Cardiol*. 2007;23(2):107-119. https://doi.org/10.1016/s0828-282x(07)70730-4.
4. Fihn SD, Gardin JM, Abrams J, et al. 2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS guideline for the diagnosis and management of patients with stable ischemic heart disease: executive summary: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, and the American College of Physicians, American Association for Thoracic Surgery, Preventive Cardiovascular Nurses Association, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. *J Am Coll Cardiol*. 2012;60(24):2564-2603. https://doi.org/10.1016/j.jacc.2012.07.012.
5. Mancini GB, Gosselin G, Chow B, et al. Canadian Cardiovascular Society guidelines for the diagnosis and management of stable ischemic heart disease. *Can J Cardiol*. 2014;30(8):837-849. https://doi.org/10.1016/j.cjca.2014.05.013.
6. Klocke FJ, Baird MG, Lorell BH, et al. ACC/AHA/ASNC guidelines for the clinical use of cardiac radionuclide imaging—executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASNC Committee to Revise the 1995 Guidelines for the Clinical Use of Cardiac Radionuclide Imaging). *J Am Coll Cardiol*. 2003;42(7):1318-1333. https://doi.org/10.1016/j.jacc.2003.08.011.
7. Writing Committee M, Gulati M, Levy PD, et al. 2021 AHA/ACC/ASE/CHEST/SAEM/SCCT/SCMR guideline for the evaluation and diagnosis of chest pain: executive summary: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. *J Am Coll Cardiol*. 2021;78(22):2218-2261. https://doi.org/10.1016/j.jacc.2021.07.052.
8. Budoff MJ, Dowe D, Jollis JG, et al. 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):1724-1732. https://doi.org/10.1016/j.jacc.2008.07.031.
9. Budoff MJ, Nakazato R, Mancini GB, et al. CT Angiography for the prediction of hemodynamic significance in intermediate and severe lesions: head-to-head comparison with quantitative coronary angiography using fractional flow reserve as the reference standard. *JACC Cardiovasc Imaging*. 2016;9(5):559-564. https://doi.org/10.1016/j.jcmg.2015.08.021.
10. Janne d'Othée B, Siebert U, Cury R, et al. A systematic review on diagnostic accuracy of CT-based detection of significant coronary artery disease. *Eur J Radiol*. 2008;65(3):449-461. https://doi.org/10.1016/j.ejrad.2007.05.003.
11. Shaw LJ, Hausleiter J, Achenbach S, et al. Coronary computed tomographic angiography as a gatekeeper to invasive diagnostic and surgical procedures: results from the multicenter CONFIRM (Coronary CT Angiography Evaluation for Clinical Outcomes: an International Multicenter) registry. *J Am Coll Cardiol*. 2012;60(20):2103-2114. https://doi.org/10.1016/j.jacc.2012.05.062.
12. Budoff MJ, Li D, Kazerooni EA, et al. Diagnostic accuracy of noninvasive 64-row computed tomographic coronary angiography (CCTA) compared with myocardial perfusion imaging (MPI): the PICTURE study, a prospective multicenter trial. *Acad Radiol*. 2017;24(1):22-29. https://doi.org/10.1016/j.acra.2016.09.008.
13. Neglia D, Rovai D, Caselli C, et al. Detection of significant coronary artery disease by noninvasive anatomical and functional imaging. *Circ Cardiovasc Imaging*. 2015;8(3):e002179. https://doi.org/10.1161/CIRCIMAGING.114.002179.
14. Kim YH, Ahn JM, Park DW, et al. Impact of ischemia-guided revascularization with myocardial perfusion imaging for patients with multivessel coronary disease. *J Am Coll Cardiol*. 2012;60(3):181-190. https://doi.org/10.1016/j.jacc.2012.02.061.

15. Akil S, Hedeer F, Oddstig J, et al. Appropriate coronary revascularization can be accomplished if myocardial perfusion is quantified by positron emission tomography prior to treatment decision. *J Nucl Cardiol*. 2021;28(4):1664-1672. https://doi.org/10.1007/s12350-019-01938-y.
16. Li J, Yang X, Tian Y, et al. Complete revascularization determined by myocardial perfusion imaging could improve the outcomes of patients with stable coronary artery disease, compared with incomplete revascularization and no revascularization. *J Nucl Cardiol*. 2019;26(3):944-953. https://doi.org/10.1007/s12350-017-1145-z.
17. Perera D, Crake T, Lee V. Angiography-guided multivessel percutaneous coronary intervention versus ischemia-guided percutaneous coronary intervention versus medical therapy in the management of significant disease in non-infarct-related arteries in ST-elevation myocardial infarction patients with multivessel coronary disease. *Crit Pathw Cardiol*. 2018;17(2):77-82. https://doi.org/10.1097/HPC.0000000000000144.
18. Maron DJ, Hochman JS, Reynolds HR, et al. Initial invasive or conservative strategy for stable coronary disease. *N Engl J Med*. 2020;382(15):1395-1407. https://doi.org/10.1056/NEJMoa1915922.
19. Le May MR, So DY, Dionne R, et al. A citywide protocol for primary PCI in ST-segment elevation myocardial infarction. *N Engl J Med*. 2008;358(3):231-240. https://doi.org/10.1056/NEJMoa073102.
20. Gillmore T, Jung RG, Moreland R, et al. Impact of intracoronary assessments on revascularization decisions: a contemporary evaluation. *Catheter Cardiovasc Interv*. 2022;100(6):955-963. https://doi.org/10.1002/ccd.30417.
21. Simard T, Jung RG, Di Santo P, et al. Modifiable risk factors and residual risk following coronary revascularization: insights from a regionalized dedicated follow-up clinic. *Mayo Clin Proc Innov Qual Outcomes*. 2021;5(6):1138-1152. https://doi.org/10.1016/j.mayocpiqo.2021.09.001.
22. Thygesen K, Alpert JS, Jaffe AS, et al. Third universal definition of myocardial infarction. *Eur Heart J*. 2012;33(20):2551-2567. https://doi.org/10.1093/eurheartj/ehs184.
23. Thygesen K, Alpert JS, Jaffe AS, et al. Fourth universal definition of myocardial infarction (2018). *J Am Coll Cardiol*. 2018;72(18):2231-2264. https://doi.org/10.1016/j.jacc.2018.08.1038.
24. Li B, Dandan W. A comparative study of 64-slice coronary CT angiography (CCTA) and myocardial perfusion imaging (MPI) in the identification of coronary artery stenosis. *Heart Surg Forum*. 2023;26(6):E722-E727. https://doi.org/10.59958/hsf.6685.
25. Danad I, Raijmakers PG, Driessen RS, et al. Comparison of coronary CT angiography, SPECT, PET, and hybrid imaging for diagnosis of ischemic heart disease determined by fractional flow reserve. *JAMA Cardiol*. 2017;2(10):1100-1107. https://doi.org/10.1001/jamacardio.2017.2471.
26. Knuuti J, Wijns W, Saraste A, et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. *Eur Heart J*. 2020;41(3):407-477. https://doi.org/10.1093/eurheartj/ehz425.
27. Knuuti J, Ballo H, Juarez-Orozco LE, et al. The performance of non-invasive tests to rule-in and rule-out significant coronary artery stenosis in patients with stable angina: a meta-analysis focused on post-test disease probability. *Eur Heart J*. 2018;39(35):3322-3330. https://doi.org/10.1093/eurheartj/ehy267.