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

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BACKGROUND: Over the past few decades, advanced imaging modalities with excellent diagnostic capabilities have emerged. The aim of the present position statement was to systematically review existing literature to define Canadian recommendations for their clinical use.

METHODS: A systematic literature review to 2005 was conducted for positron emission tomography (PET), multidetector computed tomographic angiography and magnetic resonance imaging (MRI) in ischemic heart disease. Papers that met the criteria were reviewed for accuracy, prognosis data and study quality. Recommendations were presented to primary and secondary panels of experts, and consensus was achieved.

RESULTS: Indications for PET include detection of coronary artery disease (CAD) with perfusion imaging, and defining viability using fluorodeoxyglucose to determine left ventricular function recovery and/or prognosis after revascularization (class I). Detection of CAD in patients, vessel segments and grafts using computed tomographic angiography was considered class IIa at the time of the literature review. Dobutamine MRI is class I for CAD detection and, along with late gadolinium enhancement MRI, class I for viability detection to predict left ventricular function recovery. Imaging must be performed at institutions and interpreted by physicians with adequate experience and training.

CONCLUSIONS: Cardiac imaging using advanced modalities (PET, multidetector computed tomographic angiography and MRI) is useful for CAD detection, viability definition and, in some cases, prognosis. These modalities complement the more widespread single photon emission computed tomography and echocardiography. Given the rapid evolution of technology, initial guidelines for clinical use will require regular updates. Evaluation of their integration in clinical practice should be ongoing; optimal use will require proper training. A joint effort among specialties is recommended to achieve these goals.

Key Words: Coronary artery disease detection and prognosis; Computed tomographic angiography; Magnetic resonance imaging; Positron emission tomography; Viability detection and prognosis

Déclaration commune : SCC/ACR/ACMN/SCCN/CanSCMR sur le rôle de l'imagerie cardiaque non effractive évoluée, soit la tomographie par émission de positrons, l'imagerie par résonance magnétique et l'angiographie par tomodensitométrie multicoupe, dans le diagnostic et l'évaluation des cardiopathies ischémiques – sommaire

CONTEXTE : Au cours des dernières décennies, la technologie a vu naître plusieurs techniques d'imagerie évoluée, dotées d'une excellente capacité diagnostique. La présente déclaration avait pour but un examen systématique de la documentation existante en vue de recommandations canadiennes sur l'utilisation clinique.

MÉTHODE : Un examen systématique de la documentation a été entrepris jusqu'en 2005 quant au rôle de la tomographie par émission de positrons (TEP), de l'angiographie par tomodensitométrie (ATDM) multicoupe et de l'imagerie par résonance magnétique (IRM) dans l'exploration des cardiopathies ischémiques. Les publications qui satisfaisaient aux critères établis ont fait l'objet d'examen quant à la fiabilité et à la valeur pronostique des techniques et à la qualité des études. Les recommandations ont été présentées à deux groupes d'experts, puis il y a eu établissement d'un consensus.

RÉSULTATS : Les indications de la TEP comprennent la détection des coronaropathies (CP) par l'imagerie de perfusion et l'évaluation de la viabilité myocardique à l'aide du fluorodésoxyglucose pour déterminer le degré de récupération fonctionnelle du ventricule gauche ou pour établir le pronostic après une revascularisation (classe I). La détection des CP chez les patients, le repérage des segments vasculaires atteints et l'examen des greffons par ATDM étaient considérés comme de niveau IIa au moment de l'examen de la documentation. L'IRM à la dobutamine est de classe I dans la détection des CP et, au même titre que l'IRM avec rehaussement tardif de contraste par le gadolinium, également de classe I dans l'évaluation de la viabilité myocardique pour déterminer le degré de

Suite à la page suivante

Affiliations are noted in Appendix 1

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récupération fonctionnelle du ventricule gauche. L'imagerie doit être réalisée dans des établissements bien pourvus et interprétée par des médecins bien formés et expérimentés.

CONCLUSIONS : Les techniques d'imagerie cardiaque évoluée (TEP, ATDM multicoupe, IRM) se montrent utiles dans la détection des CP, l'évaluation de la viabilité myocardique et, dans certains cas, le pronostic. Ces nouvelles techniques complètent la tomographie d'émission

monophotonique et l'échocardiographie, techniques plus courantes. Compte tenu de l'évolution rapide de la technologie, les premières lignes directrices sur l'application clinique nécessiteront des mises à jour périodiques. L'évaluation de l'intégration des nouvelles techniques dans la pratique clinique devrait se faire de façon continue, et leur utilisation optimale exigera une formation appropriée. Aussi un effort concerté des spécialités est-il recommandé pour permettre l'atteinte des objectifs précédents.

Noninvasive methods for diagnosis and risk stratification remain the cornerstone in the management of patients with heart disease. Over the past few decades, advanced imaging modalities with excellent diagnostic capabilities have emerged; however, these techniques are costly and require specific advanced training. While several professional organizations and governments have established recommendations for advanced imaging technologies (1-3), Canadian recommendations had not previously been developed. Therefore, the aim of the present position statement was to systematically review the existing literature, recommend indications for the clinical use of these modalities, and define areas requiring further research and investigation.

The Canadian Cardiovascular Society, the Canadian Association of Radiologists, the Canadian Association of Nuclear Medicine, the Canadian Nuclear Cardiology Society and the Canadian Society of Cardiac Magnetic Resonance had identified advanced cardiac imaging as a priority for assessment. Primary and secondary panels of experts and practitioners were assembled (Appendix 1). Given the scope and timelines, it was agreed that the present position paper would focus on ischemic heart disease (IHD) (detection, prognosis and viability), with future position statements and/or guidelines focusing on ventricular function and non-IHD. A summary of the findings and recommendations is found herein; the full text may be found at <www.ccs.ca>.

METHODS FOR STUDY IDENTIFICATION

A systematic literature review was conducted for the three imaging modalities: positron emission tomography (PET), magnetic resonance imaging (MRI) and multidetector computed tomography (MDCT) angiography. Searches for each modality were divided into four categories: coronary artery disease (CAD), and/or ischemia detection and diagnosis; CAD prognostication; myocardial viability detection; and viability prognostication. Further details of the systematic review are noted in the full text at <www.ccs.ca>. Databases searched include Medline (1966 to June 2005), Embase (1980 to June 2005), Cochrane, Issue 3, 2005 and other evidence-based medicine Web sites, such as that of the Agency for Healthcare Research and Quality. When a published meta-analysis existed, searches were started from this point forward. Literature was updated by the imaging subgroups beyond the primary search strategy time period when key references were identified that met inclusion criteria.

All members of the subgroup reviewed the papers for their specific modality, and sensitivity and specificity tables were completed. The study quality of each paper reviewed was also assessed using the quality information questionnaire from the University of Alberta Evidence Based Medicine Working Group: <www.med.ualberta.ca/ebm/diagworksheet.htm> and <www.med.ualberta.ca/ebm/prognosisworksheet.htm>.

Based on the data review, preliminary draft recommendations were prepared and presented to the primary and secondary panels using the standard scoring methods adapted from previous guidelines on imaging from the American College of Cardiology, the American Heart Association and the American Society of

Nuclear Cardiology (Appendix 2). Consensus was then achieved. The recommendations are presented.

PET

Given the large number of studies using PET, additional restrictions on search material were applied. For CAD detection, studies were excluded if they involved tracers other than rubidium-82 and N-13 ammonia, applied flow quantification as the only method for defining disease or involved fewer than 20 patients. For prognosis, only studies that considered PET findings in the prediction of outcomes were considered.

Detection and prognosis of CAD: Myocardial perfusion imaging (MPI), using rubidium-82 or N-13 ammonia PET, is a widely accepted technique (1,2). Images are acquired at rest and during pharmacological stress. PET MPI has often been considered the most accurate noninvasive means for detecting functionally significant CAD (1,2). It is considered to be at least as accurate as single photon emission computed tomography (SPECT) MPI. One advantage of PET MPI is its use of accurate and reliable attenuation correction, which improves specificity and probably also sensitivity. This feature may be particularly relevant in patients with obesity or a body habitus prone to attenuation artifact. PET also provides high spatial resolution among nuclear imaging techniques.

The mean sensitivity and specificity of PET MPI for detection of CAD are 89% and 89% (Table 1), with ranges from 83% to 100% and 73% to 100%, respectively. A recent study by Bateman et al (4) demonstrated superior diagnostic accuracy and normalcy rates for gated PET MPI compared with gated SPECT MPI ($P=0.02$). Recent advances in PET, including PET/computed tomography (PET/CT), are currently being evaluated in multicentre studies such as the Study of Perfusion and Anatomy's Role in CAD (SPARC [5]).

A normal PET MPI result indicates an excellent prognosis. Hard cardiac event rates range from 0.09% to 0.9%, depending on the population and the definition of normal (6-8). These rates are comparable with those of SPECT MPI. Patients with abnormal PET MPI have a worse prognosis, with a death rate of 4.3% per year or a hard event rate of 7.0% per year (for moderate to severe defects) (7). PET MPI also appears to have prognostic value in specific subpopulations with obesity or those referred after nondiagnostic SPECT MPI (Table 2) (7).

Exercise PET, quantification of myocardial blood flow (2) and preoperative assessment are discussed in greater detail in the full position statement at <www.ccs.ca>.

MPI USING PET FOR DIAGNOSIS AND/OR RISK STRATIFICATION OF CAD

Recommendations

Cardiac PET MPI interpretation should be carried out only by physicians and institutions with adequate training and experience.

Class I indications

1. Pharmacological MPI using PET for the diagnosis of CAD (diagnosis is intended for patients with

TABLE 1
Positron emission tomography coronary artery disease (CAD) diagnosis

Author	Year	Patients, n	Stress	Tracer	Reference coronary angiogram	Sensitivity			Specificity		
						Positive test	Patients with CAD	%	Negative test	Patients without CAD	%
Schelbert HR	1982	45	Dipyridamole	¹³ NH ₃	>50%	31	32	97	13	13	100
Tamaki N	1985	25	Exercise	¹³ NH ₃	Not reported	18	19	95	6	6	100
Yonekura Y	1987	50	Exercise	¹³ NH ₃	>75%	37	38	97	12	12	100
Tamaki N	1988	51	Exercise	¹³ NH ₃	>50%	47	48	98	3	3	100
Gould L*	1986	50	Dipyridamole	⁸² Rb/ ¹³ NH ₃	QCA SFR <3	21	22	95	9	9	100
Demer L*	1989	193	Dipyridamole	⁸² Rb/ ¹³ NH ₃	QCA SFR <4	126	152	83	39	41	95
Go RT	1990	202	Dipyridamole	⁸² Rb	>50%	142	152	93	39	50	78
Stewart RE	1991	81	Dipyridamole	⁸² Rb	QCA >50%†	50	60	83	18	21	86
Marwick T	1992	74	Dipyridamole	⁸² Rb	>50%	63	70	90	4	4	100
Grover McKay	1992	31	Dipyridamole	⁸² Rb	>50%	16	16	100	11	15	73
Laubenbacher	1993	34	Dipyridamole/adenosine	¹³ NH ₃	QCA >50%†	14	16	88	15	18	83
Bateman TM‡	2006	112	Dipyridamole	⁸² Rb	>50%†	64	74	86	38	38	100
Williams BR§	1994	287	Dipyridamole	⁸² Rb	>67%	88	101	87	99	112	88
Simone GL§	1992	225	Dipyridamole	⁸² Rb	>67%	§	§	83	§	§	91
Totals + weighted mean		1460				696	778	89	297	333	89
Weighted mean, excluding retrospective studies						544	603	90	160	183	87
Nonweighted mean								91			91

For complete reference list, see the full text at <www.ccs.ca>. *Demer reported that 50 patients in Gould et al 1986 were included, thus the study by Gould et al was not included in mean calculations; †Other cut-offs reported; >50% noted here; ‡Electronic database, matched cohort design; values derived from reported population, sensitivity and specificity; §Retrospective study; myocardial perfusion imaging influenced coronary angiogram decision; mixed patient and region method for sensitivity and specificity; patients with disease could not be easily determined in one study. ¹³NH₃ N-13 ammonia; ⁸²Rb Rubidium-82; SFR Stenosis flow reserve based on quantitative coronary angiography (QCA) data

TABLE 2
Positron emission tomography coronary artery disease prognosis

Author	Year	Patient number	Stress	Tracer	Outcomes	Follow-up, years	Normal scan – annual event rate/year, %		Abnormal scan – annual event rate/year, %	
							Hard events	Total events	Hard events	Total events
Yoshinaga	2006	367	Dipyridamole	⁸² Rb	Death, MI, revascularization, hospitalization	3.1	0.4	1.7	Mild: 2.3; moderate and severe: 7.0	Mild: 12.9; moderate and severe: 13.2
Chow	2005	629	Dipyridamole	⁸² Rb	Death, MI, revascularization, coronary angiogram	2.3	0.09	0.98	ECG positive, normal MP: 0.6	ECG positive, normal MP: 1.9
Marwick T	1997	581	Dipyridamole	⁸² Rb	Death, MI, revascularization, unstable angina	3.4	0.9	4	4	7
Marwick T	1995	Prediction of perioperative and late cardiac events before vascular surgery*								
MacIntyre	1993	Outcomes in patients with false-negative thallium-201 single photon emission computed tomography*								

For complete reference list, see the full text at <www.ccs.ca>.*See full text for details. ECG Electrocardiogram; MI Myocardial infarction; MP Myocardial perfusion; ⁸²Rb Rubidium-82

intermediate pretest likelihood of disease) and/or risk stratification of patients who:

- have nondiagnostic, noninvasive imaging tests, or when such a test does not agree with clinical diagnosis (Level B evidence);
- may be prone to artifact that could lead to an equivocal result on another test, such as obese patients (Level B evidence);
- are unable to exercise, or have left bundle branch block or ventricular pacing (Level B evidence).

Class IIa indications

- Pharmacological MPI using PET for the diagnosis of CAD (diagnosis is intended for patients with intermediate pretest likelihood of disease) and/or risk stratification of patients who are able to exercise (Level B evidence);
- For diagnosis and risk stratification of patients being considered for high-risk noncardiac surgery who have intermediate clinical risk predictors or mild clinical risk predictors with poor functional capacity (less than four metabolic equivalents) (Level B/C evidence).

TABLE 3
Positron emission tomography viability diagnosis (ejection fraction [EF] less than 40%)

Author	Year	Patients, n	EF, %	Tracer	Reference method	Sensitivity			Specificity		
						Positive test	Patients/ segments with recovery	%	Negative test	Patients/ segments without recovery	%
Bax (meta-analysis) 20 studies	2001	598	36±8	¹⁸ FDG	WM/EF, 4.1 m FU	751	807	93	417	725	58
Barrington*	2004	25	36	¹³ NH ₃ / ¹⁸ FDG uptake + MM	WM, 8 m FU	6	6	100	23	25	92
Bax, Visser†	2001	47	30	²⁰¹ Tl/ ¹⁸ FDG SPECT MM	WM + EF, 3 m – 6 m FU	18	21	86	24	26	92
Bax, Fath-Ordoubadi†	2002	34	32	¹³ NH ₃ / ¹⁸ FDG MRGR >60%	WM + EF, 4 m – 6 m FU	10	10	100	17	24	71
Bax, Maddahi†	2003	47	30	¹⁸ FDG SPECT uptake	EF, 6 m FU	17	19	89	24	28	86
Gerber**†	2001	178	38	¹⁸ FDG-MGU % uptake	EF, 4 m – 6 m FU	65	82	79	49	89	55
Kosoroglou	2004	41	31	MIBI/ ¹⁸ FDG uptake	WM, 3 m – 6 m FU	‡	‡	90	‡	‡	44
Nowak	2003	42	38	TF/ ¹⁸ FDG MM ¹⁵ O-H ₂ O	WM, 6 m – 17 m FU	32	40	80	23	32	72
Wiggers†	2001	35	35	¹³ NH ₃ / ¹⁸ FDG uptake + MM	Patient WM, 6.1 m FU	14	14	100	14	21	67
Totals + weighted mean		1047	33.8			913	999	91	591	970	61
Mean weighted by number of patients								90			61

For complete reference list, see the full text at <www.ccs.ca>. *Values derived from sensitivity, specificity and other values provided; †EF recovery used or patient-based recovery; ‡Not reported and cannot be easily determined from data presented. ¹⁸FDG F-18 fluorodeoxyglucose; FU Follow-up; m Month; MIBI Methoxyisobutyl isonitrile; MM Mismatch; MGU Myocardial glucose uptake; MRGR Metabolic rate of glucose (relative); ¹³NH₃ N-13 ammonia; ¹⁵O-H₂O ¹⁵O-labelled water; SPECT Single photon emission computed tomography; TF Tetrofosmin; ²⁰¹Tl Thallium-201; WM Wall motion

Class IIb indications

1. Exercise PET using MPI for the diagnosis of CAD and/or risk stratification (Level B evidence);
2. Quantification of myocardial flow to determine the hemodynamic significance of a given coronary stenosis or to diagnose balanced multivessel disease (Level B/C evidence);
3. Quantification of myocardial flow to define impaired microvascular function (eg, syndrome X) (Level B/C evidence).

Class III (no benefit or harmful)

1. Contraindications to all pharmacological agents (dipyridamole, adenosine, dobutamine);
2. Unstable pattern of ischemic chest pain;
3. Contraindications to radiation exposure.

Myocardial viability diagnosis: In addition to the restrictions noted above, additional exclusion criteria were applied to ¹⁸F fluorodeoxyglucose (FDG) viability imaging studies. Excluded were studies with a sample size 20 or less, mean ejection fraction (EF) 40% or greater, early postmyocardial infarction (10 days or less), left ventricular (LV) recovery evaluation eight weeks or less, or lack of LV recovery or outcome evaluation.

FDG PET imaging has long been regarded as the best standard for detection of viable recoverable myocardium (2). In a comprehensive review of all prior published viability studies, Bax et al (9) identified that FDG PET was the most sensitive

method for predicting wall motion recovery, while dobutamine echocardiography was the most specific. These methods provide accurate means for predicting recovery of function after revascularization (2,9). PET-defined scar tissue and hibernating myocardium may be combined with clinical parameters to predict LV function recovery. This approach is currently being evaluated in a randomized controlled trial (RCT).

The sensitivity and specificity of FDG PET for LV function recovery are 91% and 61% (Table 3) (9), with ranges from 80% to 100% and 44% to 92%, respectively. Lower specificity likely relates to incomplete revascularization or failure to account for prolonged LV function recovery. With higher sensitivity than other methods, FDG PET has the potential to more definitively rule out viable myocardium. This is often helpful in selecting patients with LV dysfunction for revascularization.

Myocardial viability and prognosis: Outcome data have consistently demonstrated that FDG PET can define viable myocardium in patients with LV dysfunction, and that these patients are at high risk for death and subsequent cardiac events if they do not undergo timely revascularization (Table 4) (10-13). There is one small published RCT (14) that compared FDG PET with technetium-99m methoxyisobutyl isonitrile SPECT. Trends, but no significant differences in outcomes, were identified. In this study, however, two-thirds of patients had mild to moderate LV dysfunction and were thus not representative of the population most likely to benefit from defining viable myocardium, namely, those with severe LV dysfunction. Ongoing RCTs are evaluating the use of FDG PET in directing therapy in patients with severe LV dysfunction and IHD.

TABLE 4
Positron emission tomography (PET) viability prognosis (ejection fraction [EF] less than 40%)

Author	Year	Patient population			Test method (tracer)	Mortality rates, %			
		Patients, n	EF, %	Mean FU, months		Viability positive, revascularization positive	Viability positive, revascularization negative	Viability negative, revascularization positive	Viability negative, revascularization negative
Allman	2002	3088	32	25	²⁰¹ Tl/DE/ ¹⁸ FDG	3.2	16.0	7.7	6.2
(meta-analysis)*									
Allman (PET)*		1029	35	24	Perfusion/ ¹⁸ FDG	6.0	21.0	7.0	8.0
Eitzman	1993	82	33	12	⁸² Rb- ¹³ NH ₃ / ¹⁸ FDG	3.8	33.3 [†]	0.0	8.3
Di Carli	1994	93	25	14	¹³ NH ₃ / ¹⁸ FDG	11.5	23.5 [†]	5.9	18.2
Lee	1994	129	37	17	⁸² Rb/ ¹⁸ FDG	8.2	14.3 [†]	5.3	12.5
Beanlands	1998	85	26	17	MIBI/ ¹⁸ FDG	3.2	28.6 [‡]	—	18.8
Zhang	2001	123	35	37	MIBI/ ¹⁸ FDG	0.0	26.7 [§]	8.0	3.8
Rohatgi	2001	99	22	25	¹³ NH ₃ / ¹⁸ FDG	0.0	34.5 [§]	0.0	15.2
Santana	2004	90	26	22	G- ⁸² Rb/ ¹⁸ FDG	NR	NR [¶]	NR	NR
Dessideri**	2005	261	29	34	¹³ NH ₃ / ¹⁸ FDG	14.5	28.3 [§]	10.3	21.5
Sawada††	2005	61	29	48	¹³ NH ₃ / ¹⁸ FDG	47.4	83.3 [§]	57.1	43.8
Totals/mean††		933	30	26		9.4	30.9^{§§}	11.8	17.7

For complete reference list, see the full text at <www.ccs.ca>. *Meta-analysis of 24 viability studies; rates reported are for all studies in line 1; line 2 is data for 11 F-18 fluorodeoxyglucose (¹⁸FDG) PET studies, seven of which reported outcomes and four of which compared event rates in subgroups and had EF<40%; table data derived from reported values and estimated for a one-year follow-up based on rates and mean follow-up reported; [†]P<0.05 viability positive, revascularization negative versus revascularization positive for total cardiac event rates; [‡]P<0.05 delayed versus early revascularization; [§]P<0.05 viability positive, revascularization negative versus revascularization positive (also versus other groups [Allman 2002; Zhang 2002]); [¶]Values not reported (NR): 11% survival benefit with revascularization in patients with viability and left ventricular remodelling (end diastolic volume of more than 260 mL); **Values determined from reported percentages; ^{††}Patients with diabetes, left ventricular dysfunction and coronary artery disease; ^{‡‡}Totals/mean include eight studies with reported values; does not include meta-analysis; ^{§§}P<0.05 versus other groups using Fisher's exact test. DE Dobutamine echocardiography; G G-gated FDG; MIBI Methoxyisobutyl isonitrile; ¹³NH₃ N-13 ammonia; ²⁰¹Tl Thallium-201

Knowing the extent of scar tissue and hibernating myocardium, which may be defined using FDG PET, is often important in decision making for revascularization, particularly in the setting of severe LV dysfunction (2). Fusion imaging of FDG PET with MRI or CT may provide even greater accuracy for detecting viable myocardium by combining the advantages of each technique.

MYOCARDIAL FDG PET VIABILITY IMAGING

Recommendations

FDG PET viability imaging interpretation should be carried out only by physicians and institutions with adequate training and experience.

Class I indications

- To define myocardial viability in patients with:
 - IHD and severe LV dysfunction to identify extent of recoverable myocardium and prognosis in patients being considered for revascularization or cardiac transplantation (Level B evidence);
 - moderate to large fixed perfusion defects, or with equivocal results on another viability test (Level B evidence).

Class IIa indication

- Moderate systolic LV dysfunction and IHD to identify the extent of recoverable viable myocardium and prognosis in patients being considered for revascularization or cardiac transplantation (Level B evidence).

Class III (no benefit or harmful)

- Contraindications to insulin;
- Severe untreated hypokalemia;
- Contraindications to radiation exposure.

CT ANGIOGRAPHY

Detection of CAD

With recent advances in the spatial and temporal resolution of MDCT scanners, cardiac CT angiography (CTA) is feasible and becoming increasingly accurate. CTA has the benefit of being a noninvasive modality with the potential of providing anatomical information with a very short imaging sequence (5 s to 25 s). CTA may avoid many of the risks associated with conventional invasive coronary angiography.

CTA has been used to assess native coronary arteries, arterial and saphenous vein bypass grafts, coronary stents and anomalous coronary arteries (15-20). Table 5 shows the numerous studies that have evaluated the accuracy of 16-slice MDCT compared with that of invasive coronary angiography. In coronary segments that can be evaluated (those greater than 1.5 mm in diameter), the overall sensitivity and specificity for defining angiographic disease are 87% and 96%, respectively. For detection of disease in patients, the sensitivity and specificity are 91% and 95%, respectively. More recently, studies using 64-slice MDCT have also demonstrated very good accuracy, with a larger number of segments that may be evaluated, compared with 16-slice MDCT (Table 6).

Patients referred for coronary angiography are generally suspected of having obstructive CAD, based on previous non-invasive investigations. This unavoidable bias in patient selection may result in the overestimation of CTA specificity (ie, the underestimation of the false-positive rate of CTA studies). However, the use of normal reference segments suggests that any overestimation of specificity is probably small. The negative predictive value of CTA has consistently been excellent. CTA may therefore be most beneficial in patients for whom the diagnosis of obstructive CAD needs to be ruled out. A recent meta-analysis (20) of MDCT and MRI confirms the use of CTA, and also suggests that it has a significantly

TABLE 5
16-slice multidetector computed tomography

Author	Year	Number of segments	Segments	Segment analysis		Patient analysis		Accuracy, %
				Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %	
Nieman	2002	58	≥2 mm	95 (82/86)	86 (125/145)	100 (50/50)	88 (7/8)	98 (57/58)
Mollet	2004	128	≥2 mm	92 (216/234)	95 (1092/1150)	100 (106/106)	86 (18/21)	98 (124/127)
Kuettner	2004	58	All	72 (54/75)	97 (679/700)		97 (58/60)	
Martuscelli	2004	61	>1.5 mm	89 (83/93)	98 (511/520)			
Hoffmann U	2004	33	All	70 (30/43)	94 (371/393)	86 (19/22)	82 (9/11)	85 (28/33)
Cademartini	2005	40	≥2 mm	96 (88/92)	96 (322/336)			
Cademartini	2005	60	≥2 mm	93 (93/100)	97 (557/572)			
Doregelo	2005	22	≥2 mm	94 (30/32)	96 (216/225)			
Morgan-Hughes	2005	57	All	83 (75/90)	97 (566/585)	100 (32/32)	96 (24/25)	98 (56/57)
Heuschmid	2005	37	All	59 (22/37)	96 (329/343)			97 (36/37)
Hoffman M	2005	103	≥1.5 mm	95 (149/157)	98 (1117/1139)	96 (55/58)	84 (38/45)	90 (93/103)
Kefer	2005	52	≥1.5 mm	82 (64/78)	79 (293/369)	92	67	
Schuijff	2005	31	≥2 mm	93 (53/57)	96 (179/186)	95 (20/21)	80 (8/10)	90 (28/31)
Mollet	2005	51	≥2 mm	95 (61/64)	98 (537/546)	100 (31/31)	85 (17/20)	94 (48/51)
Kuettner	2005	72	All	82 (96/117)	98 (804/819)			90 (65/72)
Achenbach	2005	50	≥1.5 mm	94 (50/53)	96 (559/582)	100 (25/25)	83 (19/23)	92 (44/48)
Aviram	2005	22	>1.5 mm	86 (24/28)	98 (255/260)			
Burgstahler	2005	117	All	84 (294/348)	97 (1105/1134)			
Kuettner	2005	124	All	85 (304/359)	98 (1172/1201)	85	98	92 (110/120)
Weighted mean				87 (1868/2143)	96 (10789/11205)	98 (352/359)	86 (140/163)	

For complete reference list, see the full text at <www.ccs.ca>

TABLE 6
64-slice multidetector computed tomography

Author	Year	Number of segments	Segments	Segment analysis		Patient analysis		Accuracy, %
				Sensitivity, %	Specificity, %	Sensitivity, %	Specificity, %	
Raff	2005	70	All	86 (79/92)	95 (802/843)	95 (38/40)	90 (27/30)	93 (65/70)
Leber	2005	55	All	79 (52/66)	73 (29/40)	88 (22/25)		
Leshcka	2005	67	≥1.5 mm	94 (165/176)	97 (805/829)	100 (47/47)	100 (20/20)	100 (67/67)
Mollet	2005	52	All	99 (93/94)	95 (601/631)	100 (38/38)	92 (12/13)	98 (51/52)
Weighted mean				91 (389/428)	95 (2237/2343)	97 (145/150)	94 (59/63)	

For complete reference list, see the full text at <www.ccs.ca>

higher diagnostic accuracy than MRI for detection of obstructive CAD. At this time, there are no data supporting the use of CTA in determining patient prognosis. The use of this diagnostic technique is the focus of current research studies such as the SPARC study (5), and it will continue to be an important subject of future investigation.

Cardiac motion and coronary calcification are two important limiting factors in the use of CTA. Accordingly, certain patients should not routinely undergo CTA, such as those with irregular cardiac rhythms (eg, atrial fibrillation or frequent extrasystoles), severe coronary calcification, an inability to perform sufficient breath-holds, or contraindications to intravenous contrast agents or radiation exposure.

Ionizing radiation exposure with CT remains a concern. The estimated effective radiation dose with 16-slice CTA ranges from 7 mSv to 15 mSv (21-23). The radiation dose of CTA appears to be similar to, or slightly higher than, that for other traditional noninvasive modalities. Clinicians must continue to strive to minimize patient exposure to ionizing radiation. Future technological developments must be

made without additional increases in patient radiation exposure.

Calcium scoring is used to identify calcified plaque. While it may have prognostic value, it is beyond the scope of the present evaluation. CTA also shows promise in the assessment of atherosclerotic plaque, but it remains a research tool.

At the time of the present review, there were limited data on 64-slice CTA. The panel anticipates that recommendations presented here will require amendments as CTA continues to evolve.

CAD DETECTION WITH CTA

Recommendations

The interpretation of cardiac CT and CTA should be carried out only by physicians and institutions with adequate training and experience.

Class I indication

1. Assessment of anomalous coronary arteries (Level C evidence).

Class IIa indications

1. 16- or 64-slice MDCT for patient diagnosis of significant CAD (50% diameter stenosis or more) (Level B evidence);
2. 16- or 64-slice MDCT for identification of coronary artery segments with significant stenosis (50% diameter stenosis or more) in coronary segments 1.5 mm or more in diameter (Level B evidence);
3. 16- and 64-slice MDCT for assessment of graft patency (Level B evidence).

Class IIb indication

1. 64-slice MDCT for the assessment of all coronary segments, including those with vessel diameters less than 1.5 mm (Level B evidence).

Class III (no benefit or harmful)

1. Diagnosis of CAD in patients with
 - a. irregular dysrhythmias (atrial fibrillation, frequent extrasystoles);
 - b. severe coronary calcification;
 - c. inability to perform sufficient breath-holds;
 - d. renal failure or other contraindications to intravenous contrast agents;
 - e. contraindications to radiation exposure.

MRI**Detection of CAD**

Several cardiac magnetic resonance (CMR) approaches are used to detect CAD. These include the direct visualization of the coronary artery lumen, visualization of ischemic myocardial injury (infarction), as well as the detection of the effects of induced ischemia on wall motion, perfusion and coronary blood flow.

Coronary magnetic resonance angiography

Magnetic resonance angiography (MRA) and quantification of vascular flow are a common approach used for almost all vessels in the body except the coronaries. It remains technically challenging to image the coronary arteries with the temporal and spatial resolution necessary to predict greater than 50% stenosis. This is due to the size, tortuosity and, most importantly, complex motion of the coronary arteries during the cardiac cycle. The negative predictive value for coronary MRA to exclude multivessel proximal obstructive CAD reached 81% in a recent multicentre trial (24), but current techniques have not yet been shown to reproducibly predict diameter stenoses. In two recent meta-analyses of 999 patients in 28 MRA studies (20,25), the positive and negative predictive values for detection of greater than 50% stenosis in interpretable segments were 65% and 90%, respectively (Table 7). When uninterpretable segments are included, these values fall to 37% and 85%, respectively. More recent work has been performed at 3 Tesla field strength and yielded a sensitivity of 82% and specificity of 89% (26). Overall, coronary MRA has a good diagnostic performance in all vessels except the circumflex coronary artery; this is likely due to its proximity to the adjacent

blood pools of the left atrium and ventricle, and the lower signal from its location, which is often farthest from the receiver coil. However, false-positive rates remain high. Currently, the greatest value of coronary MRA is that found with a negative study in a patient with low pretest probability of CAD (25).

Coronary bypass graft patency has also been examined with CMR using MRA and MR flow measurement techniques. While the positive predictive value for the detection of patent bypass graft has been reported to be as high as 95%, limitations such as metallic clip artifacts reduce the negative predictive value to approximately 44%.

The course of anomalous coronary arteries, which can induce ischemia, especially if the artery passes between the aorta and pulmonary artery, may be more clearly delineated with CMR than x-ray angiography.

Stress wall motion

Using CMR, stress is induced pharmacologically because physical exercise is difficult to perform within the magnet bore and often induces motion artifacts. Dobutamine stress-induced wall motion abnormalities are easily appreciated using the high-quality imaging of CMR. This technique is well-established, and trials have shown it to be as good as or better than dobutamine stress echocardiography in the diagnosis of CAD. Data from eight studies involving a total of 893 patients show an average sensitivity and specificity of 90% and 84%, respectively (Table 8) (27).

Stress perfusion

Myocardial perfusion may also be measured during stress (either with dobutamine or dipyridamole) following a first pass of an intravenous bolus of gadolinium contrast. Hypoperfused myocardial segments are seen as dark regions of low signal during first pass of the contrast. Validation in human studies has also been performed with good correlation with x-ray angiography, PET and SPECT. Data from 11 studies involving a total of 647 patients show an average sensitivity and specificity of 84% and 86%, respectively (Table 9). Recently, the Magnetic Resonance Imaging for Myocardial Perfusion Assessment in Coronary Artery Disease Trial (MR-IMPACT) study of 241 patients showed that first pass perfusion CMR was superior to SPECT in detecting obstructive CAD.

Myocardial viability

CMR uses two techniques to examine myocardial viability: dobutamine stress magnetic resonance (DSMR) and late gadolinium enhancement (LGE). DSMR has been shown to have similar or improved ability to predict contractile improvement after revascularization compared with that of dobutamine stress echocardiography. Data from 10 studies of 401 patients demonstrate a sensitivity and specificity of 91% and 94%, respectively (Table 10). LGE is a CMR technique that images nonviable or infarcted myocardium. The extravascular contrast agent gadolinium accumulates in infarcted tissue, which has larger extravascular space than does normal tissue. LGE has been widely studied in humans to show good correlation with PET and superiority to SPECT in quantifying viable and nonviable myocardium. Data from 13 studies in 357 patients reveal a sensitivity and specificity of 81% and 83%, respectively, for predicting recovery or lack of recovery of LV function (Table 11) (28-30). The transmural extent of the infarct can also be determined, and this may be used to improve the ability of LGE to predict recovery after revascularization.

TABLE 7
Magnetic resonance angiography

Author	Year	Patients, n	Assessable, % (number of segments)	Sensitivity, % (number of segments)	Specificity, % (number of segments)	PPV, % (95% CI)	NPV, % (95% CI)
Two-dimensional breath-hold							
Manning	1993	39	98 (147/150)	90 (47/52)	92 (87/95)		
Pennell	1993	7	Not applicable	83 (5/6)	Not applicable		
Mohiaddin	1996	16	90 (43/48)	56 (5/9)	82 (28/34)		
Pennell	1996	39	Not applicable	85 (47/55)	Not applicable		
Post	1997	35	89 (125/140)	63 (22/35)	89 (80/90)		
Total		136				84 (78–90)	86 (82–91)
Weighted mean			93 (315/338)	80 (126/157)	89 (195/219)		
Three-dimensional breath-hold							
Kessler	1999	6	Not applicable	60 (3/5)	Not applicable		
van Geuns	2000	38	69 (187/272)	68 (21/31)	97 (151/156)		
Regenfus	2000	50	77 (268/350)	86 (48/56)	91 (193/212)		
Regenfus	2002	32	76 (171/224)	87 (26/30)	91 (129/141)		
Jahnke	2004	40	45 (143/320)	63 (12/19)	82 (102/124)		
Total		166				65 (58–72)	95 (93–97)
Weighted mean			66 (769/1166)	78 (110/141)	91 (575/633)		
Three-dimensional navigator							
Post	1996	20	96 (77/80)	38 (8/21)	95 (53/56)		
Muller	1997	35	Not applicable	83 (45/54)	94 (115/122)		
Kessler	1997	73	52 (236/455)	65 (28/43)	88 (169/193)		
Woodard	1998	10	Not applicable	70 (7/10)	Not applicable		
Sandstede	1999	30	77 (92/120)	81 (30/37)	89 (49/55)		
van Geuns	1999	32	74 (151/203)	50 (13/26)	91 (114/125)		
Kessler	1999	6	Not applicable	60 (3/5)	Not applicable		
Sardanelli	2000	42	86 (234/273)	82 (55/67)	89 (149/167)		
Kim	2001	109	86 (374/434)	83 (78/94)	73 (204/280)		
Plein	2002	10	93 (37/40)	88 (15/17)	85 (17/20)		
Weber	2002	11	70 (62/88)	88 (14/16)	93 (43/46)		
Wittlinger	2002	25	85 (102/120)	75 (18/24)	100 (78/78)		
Regenfus	2002	32	69 (155/224)	60 (15/25)	88 (115/130)		
Watanabe	2002	12	70 (49/70)	80 (12/15)	85 (29/34)		
van Geuns	2002	27	69 (139/201)	46 (12/26)	90 (102/113)		
Bogaert	2003	21	72 (134/186)	56 (15/27)	83 (89/107)		
Ikonen	2003	69	84 (233/276)	75 (64/85)	62 (92/148)		
Jahnke	2004	40	79 (254/320)	72 (26/36)	92 (200/218)		
Gerber	2005	27	100 (294/294)	62 (36/58)	84 (198/236)		
Muller	2004	30	100 (221/221)	85 (35/41)	84 (151/180)		
Sommer	2005	18	87 (109/126)	82 (14/17)	88 (80/91)		
Total		679				61 (58–64)	91 (90–92)
Weighted mean			82 (2953/3731)	73 (543/744)	85 (2047/2399)		
Total for 1.5 Tesla		981			87 (2600/2997)	65 (62–68)	90 (89–91)
Weighted mean			83 (3441/4147)	72 (749/1043)			
3 Tesla							
Sommer	2005	18	86 (108/126)	82 (14/17)	89 (80/90)		

For complete reference list, see the full text at <www.ccs.ca>. NPV Negative predictive value; PPV Positive predictive value. Adapted from reference 33

In Kim et al (28), for example, examination of severe hypokinetic, akinetic or dyskinetic segments with less than 25% transmural LGE had a 79% chance of functional recovery postrevascularization, compared with a 6% chance of recovery if LGE showed greater than 50% transmural (28).

For both LGE MRI and dobutamine stress MRI for viability, the number of studies in patients with more significant LV

dysfunction (EF less than 40%) is limited. Further studies are required in the patient population with severe LV dysfunction.

Currently, there are few studies evaluating the impact of DSMR and LGE CMR on cardiac outcomes, but several studies are underway. Outcome studies in patients with severe LV dysfunction are limited.

TABLE 8
Dobutamine stress magnetic resonance coronary artery disease (CAD) diagnosis – results table

Author	Year	Patients, n	Maximum dose, µg/kg/min	Reference	Sensitivity			Specificity		
					Positive test	Patients with CAD	% (DSE)	Negative test	Patients without CAD	%
van Ruge	1994	39	20	CAG ≥50%	30	33	91	5	6	83
Nagel	1999	172	40+1 mg atropine	CAG ≥50%	94	109	86 (74*)	60	70	86 (70*)
Hundley	1999	41†	40+1 mg atropine	CAG ≥50%	37	41	90	5	6	83
Schalla	2002	22	40+1 mg atropine	QCA ≥75%	14	16	88	5	6	83
van Dijkman‡	2002	95	40	CAG ≥50%	41	42	98	NA	NA	NA
Kuijpers‡	2003	194	40	CAG ≥50%	65	68	96	NA	NA	NA
Wahl	2004	151	40+2 mg atropine	QCA ≥50%	101	113	89	32	38	84
Paetsch	2004	79	40+2 mg atropine	QCA ≥50%	47	53	89	21	26	80
Totals + weighted mean		893			429	475	90	128	152	84

For complete reference list, see the full text at <www.ccs.ca>. *Values for dobutamine stress echocardiography; †Total of 153 patients in study; only 41 patients underwent a coronary angiogram (CAG) and are shown in this analysis; ‡Only patients with positive dobutamine stress magnetic resonance underwent CAG. DSE Dobutamine stress echocardiography; QCA Quantitative coronary angiography

TABLE 9
Dobutamine stress and magnetic resonance coronary artery disease (CAD) diagnosis – results table

Author	Year	Number	Stress agent	Reference	Sensitivity			Specificity		
					Positive test	Patients with CAD	%	Negative test	Patients without CAD	%
Al-Saadi	2000	34	Dipyridamole	CAG ≥75%	26	29	90	4	5	83
Schwitzer	2001	48	Dipyridamole	CAG ≥75%, PET (¹³ NH ₃)	32	37	87 (91*)	9	11	85 (94*)
Al-Saadi	2002	27	Dobutamine	QCA ≥75%	19	23	81	3	4	73
Ibrahim†	2002	39	Adenosine	QCA ≥75%, PET (¹³ NH ₃)	17	25	69 (86*)	12	14	89 (86*)
Nagel	2003	84	Adenosine	CAG ≥75%	38	43	88	37	41	90
Paetsch	2004	79	Adenosine	QCA ≥50%	48	53	91	16	26	62
Plein	2004	68	Adenosine	CAG ≥70%	54	56	96	10	12	83
Kawase	2004	50	Nicorandil	CAG ≥75%	31	33	94	16	17	94
Wolff‡	2004	75	Adenosine	QCA ≥70%	11	37	93	29	38	75
Plein	2005	92	Adenosine	CAG ≥70%	52	59	88	27	33	82
Giang‡§	2004	51	Adenosine	QCA ≥50%	31	33	93	14	18	75
Totals + weighted mean		647			359	428	84	177	219	81

For complete reference list, see the full text at <www.ccs.ca>. *Comparison with second reference; †Comparison with normal controls; ‡Multicentre trial; §Gadolinium dose-finding study; results reported for two highest doses (0.10 mmol/kg and 0.15 mmol/kg). CAG Coronary angiogram; ¹³NH₃ N-13 ammonia; QCA Quantitative coronary angiography

TABLE 10
Dobutamine stress magnetic resonance viability diagnosis – results table

Author	Year	Number	EF, %	Other reference	Method	Sensitivity			Specificity		
						Positive test	Patients with recovery	%	Negative test	Patients without recovery	%
Dendale	1998	28	45±12		WM/EF, 3 m – 4 m FU	9	10	90	11	14	79
Sandstede	1999	25	–		WM/EF, 6 m FU	13	17	77	12	12	100
Baer	2000	103	39±13	TEE	WM/EF, 4.9 m FU	24	28	86	22	24	92
Trent	2000	25	54±15		WM/EF, 4 m FU	6	6	100	23	25	92
van Dijkman	2002	95	30		WM + EF, 17 m FU	38	39	97	NA*	NA*	NA*
Kramer	2002	22	46±10	DSE	WM + EF, 2 m FU	C/T	C/T	86†	C/T	C/T	69†
Motoyasu	2003	23	51	LGE	WM, 3 m – 11 m FU	C/T	C/T	89†	C/T	C/T	80†
Schmidt	2004	40	42±10	¹⁸ FDG PET	WM, 4 m – 6 m FU	24	25	96	15	13	87
Uemura	2004	20	50	SPECT (Tl ²⁰¹)	WM, 4 m FU	C/T	C/T	89†	C/T	C/T	89†
Gutberlet	2005	20	27±9	SPECT (Tl ²⁰¹), LGE	WM + EF, 6 m FU	C/T	C/T	88†	C/T	C/T	90†
Totals + weighted mean‡		401				114	125	91	83	88	94

For complete reference list, see the full text at <www.ccs.ca>. *Patients without evidence of viability by dobutamine stress magnetic resonance were not revascularized; †Reported by segment; ‡Mean weighted by number of patients. C/T Cannot tell from data presented; DSE Dobutamine stress echocardiography; EF Ejection fraction; FU Follow-up; LGE Late gadolinium enhancement; m Month; NA Not applicable; PET Positron emission tomography; SPECT Single photon emission computed tomography; TEE Transesophageal echocardiography; WM Wall motion

TABLE 11
Late gadolinium enhancement (LGE) magnetic resonance viability diagnosis – results table

Author	Year	Number	EF, %	Other reference	Reference method	Sensitivity			Specificity		
						Positive test*	Segment with recovery	%	Negative test†	Segment without recovery	%
Kim	2000	50	43±13		WM/EF, 3 m FU	329	256	78	124‡	110‡	98‡
Sandstede	2000	12	C/T		WM, 3 m FU	47	39	83	26	25	96
Choi	2001	24	C/T		WM, 2 m – 3 m FU	275	213	77	64	61	95
Gerber	2002	20	C/T		WM, 7 m FU	170	109	64	219	179	82
Klein	2002	31	28±9	¹⁸ FDG PET	PET	NA	NA	83	NA	NA	88
Beek	2003	30	51		WM/EF, 2 m – 4 m FU	151	119	79	35§	31§	89
Kitagawa	2003	22	–	SPECT (²⁰¹ Tl)	WM, 2 m – 4 m FU	196	192	98	68	51	75
Kuhl	2003	26	31±11	¹⁸ FDG PET, SPECT	PET	NA	NA	96	NA	NA	84
Motoyasu	2003	23	51	DSMR	WM, 3 m – 11 m FU	175	146	83	103‡	74‡	72‡
Schvartzman	2003	29	28±10		WM/EF, 3 m – 8 m FU	44	36	82	33‡	27‡	82‡
Selvanayagam	2004	52	62±11		WM/EF, 5 m FU	190	156	82	88‡	71‡	81‡
Van Hoe	2004	18	–	DSMR	WM, 7 m – 11 m FU	61	56	92	24§	22§	92§
Gutberlet	2005	20	27±9	SPECT (²⁰¹ Tl), DSMR	WM + EF, 6 m FU	C/T	C/T	99	C/T	C/T	94
Totals + weighted mean¶		357				1638	1322	81	784	651	83

For complete reference list, see the full text at <www.ccs.ca>. Knuesal et al showed good agreement between positron emission tomography (PET), but data for chart could not be obtained from the paper, so it was excluded. *Dysfunctional segment and no LGE; †Dysfunctional segment and LGE; ‡LGE > 50%; §LGE > 75%; ¶Mean weighted by number of segments. C/T Cannot tell from data presented; DSMR Dobutamine stress magnetic resonance; EF Ejection fraction; ¹⁸FDG F-18 fluorodeoxyglucose; FU Follow-up; NA Not applicable; SPECT Single photon emission computed tomography; ²⁰¹Tl Thallium-201; WM Wall motion

CAD DETECTION USING MRI

Recommendations

The interpretation of cardiac MRI should be carried out only by physicians and institutions with adequate training and experience.

Class I indications

1. Assessment of anomalous coronary arteries (Level C evidence);
2. Detection of coronary stenosis greater than 50%
 - a. stress function with dobutamine (Level B evidence).

Class IIa indication

1. Detection of coronary stenosis greater than 50%
 - a. stress first-pass perfusion (Level B evidence).

Class IIb indications

1. Detection of coronary stenosis greater than 50%
 - a. coronary MRA (Level B evidence);
2. Graft patency
 - a. coronary MRA (Level C evidence).

Class III (no benefit or harmful)

1. Contraindication to MRI;
2. Contraindication to gadolinium contrast;
3. Inability to perform sufficient breath-holds.

MYOCARDIAL VIABILITY USING MRI

Recommendations

The interpretation of cardiac MRI should be carried out only by physicians and institutions with adequate training and experience.

Class I indications

1. Assessment of myocardial viability in patients with LV dysfunction or akinetic segments for predicting recovery of ventricular function following revascularization:
 - a. LGE (Level B evidence);
 - b. dobutamine stress wall motion (Level B evidence).

Class IIa indications

1. Assessment of myocardial viability to determine prognosis following revascularization in patients with moderate/severe LV dysfunction:
 - a. LGE (Level B/C evidence);
 - b. dobutamine stress wall motion (Level B/C evidence).

ROLE OF ECHOCARDIOGRAPHY AND SPECT IMAGING

Echocardiography and nuclear SPECT imaging will continue to play key frontline roles in the assessment of CAD patients. There is large clinical experience for each, and each has its own ongoing advances in imaging technology (see full text for more details at <www.ccs.ca>). As the advanced imaging techniques continue to develop, and as experience and availability of long-term prognostic data increase, these newer modalities will likely play a greater role in the management of patients with IHD. Currently, advanced imaging methods may serve as complementary tests when results of initial imaging tests are equivocal or nondiagnostic.

An approach combining a functional assessment of wall motion and perfusion, using nuclear SPECT, PET, or echocardiographic or MRI techniques, with an anatomical assessment with cardiac CTA or MRI holds a certain appeal in the evaluation of patients with IHD. New hybrid imaging cameras with

SPECT/CT or PET/CT capabilities, or the use of fusion software will provide comprehensive evaluation of anatomical and functional characterization of disease. New algorithms for patient evaluation will evolve, but will continue to involve SPECT and echocardiography.

Radiation exposure

Table 12 lists the radiation exposure from common non-invasive radionuclide or x-ray based cardiac procedures. CTA appears to be comparable with other standard noninvasive imaging methods (21,31,32).

Cost considerations

Economic evaluation is an important consideration in the development of new technologies. In any cost-effectiveness analysis, it is important to determine the population under consideration, the intervention, the comparator or comparators, the perspective of the study, the outcomes and the costs involved. For PET MPI imaging, cost data have been conflicting. In one study that compared PET with treadmill, SPECT MPI and coronary angiography, PET had the most favourable incremental cost-effectiveness ratio. In another study that compared PET MPI, stress echocardiography, SPECT MPI and coronary angiography, PET had the worst cost-effectiveness ratio. However, these studies apply theoretical models that depend very much on the studies selected, clinical care assumptions rather than real patient populations, as well as recent data. Also, they may not be valid in Canada. Despite these limitations, one evaluation regarding the selection of patients for angiography suggested that PET and SPECT MPI are both cost-effective approaches in patients with intermediate pretest likelihood of CAD.

One study evaluated the incremental cost of FDG PET viability imaging in patients with IHD and LV dysfunction, and concluded that FDG PET viability imaging was cost-effective in the selection of patients with LV dysfunction referred for coronary artery bypass grafting.

To our knowledge, no published studies have evaluated the incremental cost-effectiveness of MRI or CTA in patients with CAD. For new technologies, there will need to be careful prospective consideration of costs in real patient populations.

CONCLUDING REMARKS

The recommendations in the present position statement are based on literature to 2005 (with some updates for 2006). The best available evidence is combined with clinical expertise and opinion to determine the recommendations noted above. The recommendations demand that any imaging technique be performed and interpreted at institutions and by physicians who have adequate experience and training.

It is anticipated that the availability of these advanced imaging techniques will increase in Canada. This document serves as an initial guideline for clinical use. Given the rapid evolution of technologies and emerging literature, such recommendations will require regular updates, so much so that by the time the present position statement is published, some of the recommendations may be outdated. Therefore, the present position statement should be used as a guide and taken in the context of time and available data.

Future research and evaluation studies of diagnostic imaging would be helped by consistently reporting details of the patient population, methods of recruitment and blinded

TABLE 12
Radiation

Modality	Radiation source	Total dose, mCi	Radiation dose, mSv
SPECT MPI (one-day protocol)	Tc-99m	32–40	9.2–11.4
SPECT MPI (two-day protocol)	Tc-99m	50	14.8
SPECT MPI	²⁰¹ Tl	2.5–3.0	15.7–18.9
PET MPI	⁸² Rb		
Camera (3D BGO)		20–40	3.6–7.1
Camera (2D BGO/LSO/GSO and 3D LSO/GSO)		60–120	10.6–21.2
PET MPI	¹³ NH ₃	20–40	2.0–4.0
PET ¹⁸ FDG		5–15	5.0–15.0
PET viability			
Camera (3D BGO)	⁸² Rb/ ¹⁸ FDG	10–20/10	6.8–18.6
Camera (2D BGO/LSO/GSO and 3D LSO/GSO)	⁸² Rb/ ¹⁸ FDG	30–60/10	10.3–25.6
and 3D LSO/GSO)	¹³ NH ₃ / ¹⁸ FDG	10–20/10	6.0–17.0
CT (16-slice MDCT)	x-ray		7–15
CT (64-slice MDCT)	x-ray		5–15
Invasive coronary angiography	x-ray		2.1–2.5
Magnetic resonance imaging	NA		NA

BGO Bismuth germanate; CT Computed tomography; ¹⁸FDG 18-F fluoro-deoxyglucose; GSO Gadolinium orthosilicate; LSO Lutetium orthosilicate; MDCT Multidetector computed tomography; MPI Myocardial perfusion imaging; Tc-99m Technetium-99m; NA Not applicable; ¹³NH₃ 13-N ammonia; PET Positron emission tomography; ⁸²Rb Rubidium-82; SPECT Single photon emission computed tomography

analysis. The gold standard method used for comparison should not be influenced by the test being evaluated. Studies should consider applicability and potential impact to patient management and outcome. Studies should consider criteria developed and being applied to evaluate quality of data and evidence.

Imaging laboratories and facilities should engage in the collection of patient registry data to allow characterization and improvement in appropriate use of these technologies for which access is currently limited. Standardized reports appropriate for the specific technology should be developed and used across facilities. This, combined with network integration of images, may reduce the need for repeat testing.

Continued research will always be required to better characterize the use, as well as the diagnostic and prognostic value, of these tests. This will assist in the development of evidence-based patient care pathways and algorithms for an increasingly complex array of tests that are now available.

Finally, with the rapid emergence of these technologies, training guidelines are also needed. Imaging specialties and clinical specialties must further integrate their practices. This need must be transmitted to trainees, who will become the experts in performing and interpreting these tests in the future. A joint effort among specialties is recommended to achieve this goal.

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APPENDIX 1

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APPENDIX 2

The American College of Cardiology and American Heart Association classifications I, II and III are used to summarize indications as follows:

- Class I Conditions for which there is evidence and/or general agreement that a given procedure or treatment is useful and effective.
- Class II Conditions for which there is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of a procedure or treatment.
- Class IIa Weight of evidence/opinion is in favor of usefulness/efficacy.
- Class IIb Usefulness/efficacy is less well established by evidence/opinion.
- Class III Conditions for which there is evidence and/or general agreement that the procedure/treatment is not useful/effective and, in some cases, may be harmful.

Levels of evidence for individual class assignments are designated as:

- A Data derived from randomized clinical trials
- B Data derived from a single randomized trial, or from nonrandomized studies
- C Consensus opinion of experts
- Techniques considered investigational are not further classified.

In considering the use of a specific technique in individual patients, the following factors are important:

- The quality of the available laboratory and equipment used for performing the study, as well as the quality, expertise and experience of the professional and technical staff performing and interpreting the study.
- The sensitivity, specificity and predictive accuracy of the technique.
- The cost and accuracy of the technique compared with that of other diagnostic procedures.
- The effect of positive or negative results on subsequent clinical decision making.

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