Diagnostic Accuracy and Impact of Computed Tomographic Coronary Angiography on Utilization of Invasive Coronary Angiography

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Background—Computed tomographic coronary angiography (CTA), given its high negative predictive value, is a potential gatekeeper for invasive coronary angiography (ICA). Before CTA can be further accepted into clinical practice, its impact on healthcare resources needs to be better understood. We sought to determine the clinical impact of CTA on ICA referrals, CTA accuracy, and normalcy rate.

Methods and Results—To determine the impact of CTA, consecutive patients (n=7017) undergoing ICA before and after implementing a dedicated cardiac CT program were reviewed and compared with 3 other centers (n=11 508). To determine CTA accuracy, we evaluated consecutive CTA patients who underwent ICA. For normalcy rate, we identified patients with a low pretest probability for obstructive coronary artery disease. With the implementation of a cardiac CT program, the frequency of normal ICA decreased from 31.5% (1114 of 3538 patients) to 26.8% (932 of 3479 patients) (P<0.001). These findings were significantly different (P=0.003) from the 3 centers, in which normal ICAs were unchanged (30.0% [1870 of 6224 patients] to 31.0% [1642 of 5284 patients]). CTA had excellent per-patient sensitivity (99% [CI, 95% to 100%]), positive predictive value (92% [CI, 86% to 96%]) and negative predictive value (95% [CI, 72% to 100%]). Because of referral bias, specificity (64% [CI, 44% to 81%]) was low; however, the normalcy rate of CTA was 94% (CI, 90% to 97%). After adjusting for referral bias, the adjusted sensitivity was 90% (CI, 89% to 91%), and the adjusted specificity was 95% (CI, 94% to 96%), with positive and negative predictive values of 92% (CI, 91% to 93%) and 93% (CI, 92% to 94%), respectively.

Conclusion—The clinical implementation of CTA appears to positively impact ICA by reducing the frequency of normal ICA. The operating characteristics of CTA support its potential role as a tool useful in ruling out obstructive coronary artery disease. (Circ Cardiovasc Imaging. 2009;2:16-23.)

Key Words: computed tomography ■ coronary angiography ■ clinical impact ■ accuracy ■ normalcy

Computed tomographic coronary angiography (CTA) is a rapidly emerging diagnostic tool for the detection of coronary artery disease (CAD). However, data supporting widespread utilization of this modality are lacking.

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Single center studies have compared the accuracy of CTA to invasive coronary angiography (ICA) and have reported very good sensitivity and negative predictive value. CTA may be an effective gatekeeper to ICA by identifying patients without significant coronary stenoses thus eliminating their need for ICA and reserving ICA for those patients who may benefit most from coronary revascularization. The clinical impact of CTA on healthcare resource utilization and health economics has not been well studied. Because cardiac CT and cardiac catheterization services are centralized to a single tertiary-care center (University of Ottawa Heart Institute [UOHI] servicing a population of 1.5 to 1.8 million, our center is in a unique position to accurately assess the direct clinical impact of cardiac CT. We sought to understand the potential impact of CTA on referrals to ICA.

As CTA becomes accepted clinically, it is anticipated that future accuracy studies will demonstrate a decline in specificity and rise in sensitivity, as observed with other imaging modalities. Future analyses demonstrating declines in specificity will be attributed to verification and referral bias resulting from ICA performed primarily in patients with
abnormal CTA findings. To account for such bias, the concept of normalcy rate (NR) has been developed and is defined as the frequency of normal studies in a population with a low pretest probability for CAD. Such NRs provide a more accurate estimate of the true specificity of a diagnostic test in clinical practice. As CTA is accepted into clinical practice, studies defining the accuracy and NR of CTA are needed to understand their potential impact in real-life clinical practice. We sought to assess the diagnostic characteristics and NR of CTA in real-life clinical practice.

The objectives of this study were to (1) understand the clinical impact of CTA on referrals to ICA and (2) determine the accuracy and NR of CTA.

Methods

We evaluated the following 3 cohorts:

1. To understand the impact of CTA on ICA, all left heart catheterizations beginning January 1, 2005, were retrospectively screened. Screening of left heart catheterizations was continued for 13 months after the implementation of the CTA program.

2. To ensure that the results at the UOHI were related to establishment of cardiac CT and not because of the changes in ICA referral patterns, ICA patterns (using the same time periods) at 3 academic tertiary-care Canadian institutions (without a dedicated cardiac CT program) were screened using the Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease (APPROACH) database. To ensure that there was no overlap of patients, the 3 chosen institutions were in different provinces and were more than 1000 km away from the UOHI.

3. To assess CTA accuracy, all clinical CTA studies were prospectively screened and NR was calculated using all patients prospectively enrolled in a cardiac CT registry. Indications for CTA included chest pain, dyspnea, equivocal stress test result, or heart failure.

Impact of CTA on Referrals to ICA

Between January 1, 2005 and February 28, 2007, 12,108 consecutive patients underwent left heart catheterization at the UOHI. Excluding patients referred for percutaneous coronary intervention and/or emergent angiography, a total of 7017 patients were referred for diagnostic ICA. During this time a dedicated cardiac CT was installed and operational in February 2006. Angiographic information was collected for 13 months before and 13 months after the establishment of cardiac CT. Because the waiting list for ICA was 1 month, we anticipated a 1 month delay in appreciating the clinical effects of CT. Thus, we compared 3538 patients who had ICA between January 1, 2005, and February 28, 2006 (14 months), and 3479 patients between March 1, 2006, and February 28, 2007 (12 months). During the same time period, 1029 patients underwent clinical cardiac CT at the UOHI (Figure 1).

Diagnostic ICA

All ICA reports were reviewed at the UOHI. When reports were inadequate, an observer blinded to the clinical data reviewed the ICA images. Results were categorized as normal if there was no significant obstructive CAD (diameter stenosis $\leq 50\%$) or abnormal if there was $\geq 1$ coronary segment with diameter stenosis $\geq 50\%$. The same criteria were used to query the APPROACH database.

Computed Tomographic Coronary Angiography

Patients, without contraindications, received metoprolol or diltiazem targeting a heart rate of $\leq 65$ bpm and nitroglycerin $0.8$ mg sublingually before image acquisition. A biphasic timing bolus (15 to 25 cc contrast and 40 cc saline) was used to calculate the time interval between intravenous contrast (Visipaque 320 or Omnipaque 350, GE Healthcare, Milwaukee, Wis) infusion and image acquisition. Final images were acquired with a triphasic protocol (100% contrast, 40%/60% contrast/saline, and 40 cc saline). The contrast volume and infusion rate (5 to 8 cc/s) were individualized according to scan time and patient body habitus.

Retrospective ECG-gated data sets were acquired with the GE Volume CT (GE Healthcare) with 64×0.625 mm slice collimation and a gantry rotation of 350 msec (mA = 300 to 800, kV = 120). Pitch (0.16 to 0.24) was individualized to the patient’s heart rate. The CT data sets were reconstructed with an increment of 0.4 mm using the cardiac phase with the least cardiac motion.

CTA Image Analysis

Images were processed using the GE Advantage Volume Share Workstation (GE Healthcare) and visually interpreted by 1 of 2
expert observers blinded to all clinical data. A 17 segment model of the coronary arteries and 4 point grading score (normal, mild [<50%], moderate [50% to 69%], severe [≥70%]) was used for the evaluation of coronary stenosis. Similar to ICA, obstructive CAD was defined as coronary diameter stenosis ≥50%.

CTA Accuracy
Of the 1029 consecutive cardiac CT patients, those without a history of revascularization, who underwent ICA were analyzed. The diagnostic characteristics of CTA (sensitivity, specificity, negative predictive value, and positive predictive value) were calculated on a per-patient basis.\(^8,15,16\)

NR Population
Between February 2006 and September 2007, consecutive patients with a low pretest probability (≥5.5%) for obstructive CAD, imaging heart rate ≤70 and BMI ≤40 kg/m\(^2\) were identified. Patient pretest probability for obstructive CAD was calculated using age, gender, and symptoms.\(^13,14,17\) Two patients were excluded because of repaired anomalous origin of the left coronary artery from the pulmonary artery.

Measurement of NR
Normal was defined as the absence of obstructive CAD,\(^11,13,14\) and NRs were calculated using 2 definitions for obstructive CAD (≥50% and ≥70% coronary artery diameter stenosis), as defined by Diamond-Forrester and the CASS Registry.\(^13,14\)

The study was approved by the institutional human research ethics board. The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Statistical Analysis
Statistical analyses were performed (G.W. and L.C.) using SAS (version 9.1.3, SAS Institute Inc, Cary, NC), and statistical significance was defined as \(P<0.05\). Continuous variables are presented as means and standard deviations, and categorical variables are presented as frequencies with percentages. The Wilcoxon rank sum test was used to compare continuous variables, and Fisher exact test was used for categorical variables.

Impact of CTA on ICA Referrals
To assess the impact of CTA on ICA referrals, an autoregressive integrated moving-average model with binary intervention term (0, \(<\)March 2006 and 1, \(≥\)March 2006) was used to compare the monthly frequency of normal ICA before and after the establishment of a dedicated cardiac CT in the time series of January 1, 2005, to February 28, 2007. The seasonal pattern was also considered in the autoregressive integrated moving-average model. The change of the frequency of normal ICA was compared between our institution and the controls at 3 APPROACH institutions using the ANOVA.

CTA Accuracy
Diagnostic test characteristics (sensitivity, specificity, negative predictive value, and positive predictive value) are reported with 95% CIs. Positive and negative likelihood ratios were weighted for the prevalence of CAD in the study cohort. Adjusted sensitivity, specificity, negative predictive value, and positive predictive value were generated to correct for referral bias using the Diamond\(^15\) method and 95% CI for the adjusted estimates were obtained using bootstrap approach.

Results
Impact of CTA on Referrals to ICA
Over a 26-month period, a total 7017 patients had elective diagnostic ICA. Data were collected for 13 months after the implementation of cardiac CT. At the time of CT implementation, the waiting time for elective coronary angiography was 1 month. As such, it was estimated that any impact of CTA would become evident after 1 month. Thus, the patient population was divided into the 14 months before the effects of CTA (3538 patients) and the 12 months after the effects of CTA (3479 patients) (Figure 1).

The impact assessment model showed that there was a reduction in the frequency of normal angiograms (31.5% versus 26.8%; \(P<0.001\)) at the UOHI with the implementation of cardiac CT (Figure 2A). Similarly, there was a reduction in the frequency of normal angiograms performed in elective patients without prior revascularization (39.4% versus 34.7%; \(P=0.006\)) (Figure 2B). Comparing the 2 populations (before versus after CT), ICA patients after CTA implementation were older and had a greater frequency of cardiac risk factors (Table 1).

During the exact same time period, a total of 11508 patients underwent elective ICA at 3 APPROACH institutions (Table 2). The frequency of normal angiograms was unchanged for all elective patients (30.0% [1870 of 6224] versus 31.0% [1642 of 5284]; \(P=0.473\)) and for elective patients without a history of revascularization (38.1% [1690 of 4440] versus 38.9% [1503 of 3861]; \(P=0.584\)) (Figure 2).

The reduction of normal angiograms at the UOHI was significantly different from the control group (all elective patients \(P=0.003\)) and elective patients without prior revascularization \(P=0.01\)).

CTA Accuracy
A total of 1029 patients who underwent clinically indicated cardiac CT. Of these, 482 (46.8%) patients had stress tests performed within the preceding 3 months. CTA was requested to rule out CAD in 705 patients and/or to clarify equivocal stress test results in 251 patients.

A total of 543 (52.8%) CTA were normal (no significant coronary stenoses), 37.7% were abnormal (≥1 coronary stenoses [≥50%]), and 9.5% had incomplete CTA evaluation or were nondiagnostic (≥1 nonevaluable coronary segment in the absence of coronary stenoses in evaluable segments). A total of 148 patients underwent both CTA and clinically indicated ICA. The prevalence of obstructive CAD was 81%. CTA had excellent per-patient sensitivity (99% [CI, 95% to 100%]), positive predictive value (92% [CI, 86% to 96%]) and negative predictive value (95% [CI, 72% to 100%]) for CAD (Tables 3 and 4). As expected, the specificity was lower (64% [CI, 44% to 81%]). The positive likelihood and negative likelihood ratios (weighted for prevalence) were 11.9 (CI, 6.5 to 21.6) and 0.06 (CI, 0.01 to 0.38), respectively. After adjusting for referral bias, the adjusted sensitivity was 90% (CI, 89% to 91%), the adjusted specificity was 95% (CI, 94% to 96%) with positive and negative predictive values of 92% (CI, 91% to 93%) and 93% (CI, 92% to 94%), respectively.

NR
Of the 210 patients in the normalcy study, 9 (4.3%) were excluded from analysis for ≥1 unevaluable coronary segment because of patient motion (1 patient), premature ventricular complexes (2 patients), and cardiac motion (6 patients). Of the remaining 201 patients, 68 (34%) patients had evidence of coronary atherosclerosis with 10 patients having moderate stenoses and 3 with severe stenoses (Table 5). Using thresh-
olds of ≥50% and ≥70% stenoses, the NR of CTA was 94% (CI, 90% to 97%) and 99% (CI, 96% to 100%), respectively. Two patients with severe stenoses had their CTA findings confirmed by ICA and were revascularized. The third patient, with a severe stenosis in a diagonal branch, had a corresponding myocardial perfusion defect.

Discussion

Impact of CTA on Referrals to ICA
Cardiac CTA has a very high negative predictive value and thus may be effective in ruling out obstructive CAD. The high negative predictive value and NR in our study supports
this previously reported diagnostic characteristics\(^1\)–\(^6\)\(^,\)\(^9\) and may account for the reduction of normal ICA observed following the implementation of cardiac CT. The ability of CTA to rule out disease is extremely desirable, enabling clinicians to restrict the use of ICA to patients requiring revascularization. Because cardiac CT and cardiac catheterization services are centralized to a single tertiary care center servicing a population of 1.5 to 1.8 million, our center is in a unique position to accurately assess the direct clinical impact of cardiac CT.

These observations are further supported by the fact that our cardiac CT program had restricted access and is primarily limited to cardiologists, internists, and cardiac surgeons who refer patients to ICA. To ensure that our observations were unique to our institution, normal angiogram rates were assessed at 3 academic tertiary-care Canadian institutions without dedicated cardiac CT programs. These institutions demonstrated that the frequency of normal angiograms were unchanged during the same time periods.

To further ensure that our control population was not biased by regional practices, 3 other institutions from a different province were queried using the APPROACH database. Because of unavailable patient baseline characteristics, these data were not included in our primary analysis. However, these 3 centers reported an increase in normal angiograms from 27.8% (1290 of 4640) to 30.2% (1234 of 4088) during the same time periods.

We also observed that following the implementation of cardiac CT program, patients who subsequently were referred to ICA had greater risk factors. One may speculate that once CTA has been implemented, lower risk individuals would be excluded from ICA and thus explaining the apparent rise in cardiac risk factors.

Thus CTA is available as an alternative to ICA and its use may have facilitated better patient selection for ICA. Whether or not such patient selection improves overall population outcomes warrants further evaluation.

### Accuracy of CTA

The results of this study confirm that CTA, when accepted into clinical practice has high sensitivity, negative predictive value, and positive predictive value. Additionally, when

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**Table 1. Patient Characteristics Before and After the Cardiac CT Program**

<table>
<thead>
<tr>
<th></th>
<th>Before CT: January 1, 2005, to February 28, 2006 (n=3538)</th>
<th>After CT: March 1, 2006, to February 28, 2007 (n=3479)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>63.8±11.8</td>
<td>64.8±11.8</td>
<td>0.001</td>
</tr>
<tr>
<td>Cardiac risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker/ex-smoker</td>
<td>1365 (38.6)</td>
<td>1439 (41.5)</td>
<td>0.008</td>
</tr>
<tr>
<td>Hypertension</td>
<td>1940 (55.1)</td>
<td>2018 (58.5)</td>
<td>0.024</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>2193 (62.3)</td>
<td>2161 (63.5)</td>
<td>0.244</td>
</tr>
<tr>
<td>Diabetes</td>
<td>883 (25.0)</td>
<td>977 (28.4)</td>
<td>0.005</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>303 (8.6)</td>
<td>347 (10.0)</td>
<td>0.060</td>
</tr>
<tr>
<td>Previous revascularization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI</td>
<td>483 (13.7)</td>
<td>454 (13.4)</td>
<td>0.726</td>
</tr>
<tr>
<td>CABG</td>
<td>375 (10.6)</td>
<td>348 (10.2)</td>
<td>0.611</td>
</tr>
</tbody>
</table>

Data are presented as mean±SD or n (%). PCI indicates percutaneous coronary intervention; CABG, coronary artery bypass grafting.

**Table 2. Characteristics of Control Group During the Same Study Periods**

<table>
<thead>
<tr>
<th></th>
<th>Before CT: January 1, 2005, to February 28, 2006 (n=6224)</th>
<th>After CT: March 1, 2006, to February 28, 2007 (n=5284)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>63.1±11.2</td>
<td>63.7±11.2</td>
<td>0.004</td>
</tr>
<tr>
<td>Cardiac risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker/ex-smoker</td>
<td>2885 (46.5)</td>
<td>2208 (44.7)</td>
<td>0.056</td>
</tr>
<tr>
<td>Hypertension</td>
<td>4500 (72.3)</td>
<td>3645 (69.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>5052 (81.2)</td>
<td>3990 (75.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1687 (27.1)</td>
<td>1404 (26.6)</td>
<td>0.527</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>535 (8.6)</td>
<td>432 (8.2)</td>
<td>0.438</td>
</tr>
<tr>
<td>Previous revascularization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI</td>
<td>1362 (21.9)</td>
<td>1129 (21.4)</td>
<td>0.510</td>
</tr>
<tr>
<td>CABG</td>
<td>660 (10.6)</td>
<td>504 (9.4)</td>
<td>0.063</td>
</tr>
</tbody>
</table>

Data are presented as mean±SD or N (%). PCI indicates percutaneous coronary intervention; CABG, coronary artery bypass grafting.
weighted for the CAD prevalence in our study cohort, the high positive likelihood ratio and low negative likelihood ratio, suggest that CTA may be an effective diagnostic test. As expected due to referral and verification bias, the specificity of CTA fell to 64%; however, the adjusted specificity was 95%. To address this fall in specificity, the NR was also calculated.

NR
Single center studies have demonstrated that CTA has excellent operating characteristics for the identification of patients with significant CAD. However, these accuracy studies are subject to referral bias because the study patients had clinical indications for ICA. CTA has been quickly adopted into clinical practice and it is anticipated that future accuracy studies may demonstrate a decline in specificity.11 Such changes in specificity are attributed to verification and referral bias because ICA would typically be performed in patients with abnormal CTA and uncommonly in patients with nonobstructive CAD or normal CTA.12 To account for such bias, the notion of NR has been developed.

The NR of other noninvasive imaging modalities has been reported. The majority of these studies used single photon emission computed tomography and demonstrated a mean NR of 91%.11,19–23 Bach et al showed that the NR of dobutamine stress echocardiography was 94% in patients with a pretest probability ≤5% and 92% in patients with a pretest probability ≤10%.24 Sampson et al determined that the NR of positron-emission tomography/CT in 64 patients was 100%.25 Our study demonstrates that CTA has a very good NR and is similar to other noninvasive imaging modalities.

Though it is desirable to attain high NR, the NR should not be 100%. By screening large populations with a pretest probability >0% for obstructive CAD, one would expect to diagnose patients with CAD. Because our study population had a mean pretest probability of 3.1%, it was not unexpected to have made the diagnosis of obstructive CAD in some patients.

Role of CTA in the Diagnostic Pathway for Patients With Suspected CAD
The role of CTA in the diagnostic algorithm has yet to be determined; however, the diagnostic characteristics and NR are encouraging. Given the high sensitivity, negative predictive value, and NR of CTA, one may speculate that CTA is useful in ruling out CAD. Such benefit would be further supported if there was also a cost-benefit associated with

Table 3. Accuracy of CTA

<table>
<thead>
<tr>
<th></th>
<th>Invasive Coronary Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=148</td>
</tr>
<tr>
<td>Obstructive CAD</td>
<td>119</td>
</tr>
<tr>
<td>No Obstructive CAD</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>120</td>
</tr>
</tbody>
</table>

Table 4. Characteristics of Patients Undergoing Both CTA and ICA and Patients Undergoing CTA Only

<table>
<thead>
<tr>
<th></th>
<th>All Patients (n=1029)</th>
<th>Both CTA and ICA (n=148)</th>
<th>CTA Only (n=881)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>58.2±12.3</td>
<td>65.3±10.9</td>
<td>57.7±12.5</td>
</tr>
<tr>
<td>Men</td>
<td>567 (55.1)</td>
<td>78 (52.7)</td>
<td>489 (55.5)</td>
</tr>
<tr>
<td>Symptoms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asymptomatic or dyspnea</td>
<td>376 (36.5)</td>
<td>40 (27.0)</td>
<td>336 (38.1)</td>
</tr>
<tr>
<td>Noncardiac CP</td>
<td>258 (25.1)</td>
<td>24 (16.2)</td>
<td>234 (26.6)</td>
</tr>
<tr>
<td>Atypical angina</td>
<td>191 (18.6)</td>
<td>33 (22.3)</td>
<td>158 (17.9)</td>
</tr>
<tr>
<td>Typical angina</td>
<td>204 (19.8)</td>
<td>51 (34.5)</td>
<td>153 (17.4)</td>
</tr>
<tr>
<td>Pretest likelihood for CAD, %</td>
<td>47.75±39.96</td>
<td>59.10±36.68</td>
<td>45.80±40.17</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>29.32±7.03</td>
<td>29.49±6.21</td>
<td>29.30±7.16</td>
</tr>
<tr>
<td>Cardiac risk factors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoker/ex-smoker</td>
<td>579 (58.6)</td>
<td>94 (63.5)</td>
<td>485 (55.1)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>532 (51.7)</td>
<td>86 (58.1)</td>
<td>446 (50.6)</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>615 (59.8)</td>
<td>97 (65.5)</td>
<td>518 (58.8)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>190 (18.5)</td>
<td>36 (24.3)</td>
<td>154 (17.5)</td>
</tr>
<tr>
<td>Family history of CAD</td>
<td>428 (41.6)</td>
<td>77 (52.0)</td>
<td>351 (39.8)</td>
</tr>
<tr>
<td>CT imaging parameters</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imaging heart rate, bpm</td>
<td>59.1±8.7</td>
<td>58.9±9.1</td>
<td>59.0±8.6</td>
</tr>
<tr>
<td>Contrast infusion rate, cc/sec</td>
<td>5.79±0.92</td>
<td>5.7±0.9</td>
<td>5.81±0.93</td>
</tr>
<tr>
<td>Total contrast volume, cc</td>
<td>96.4±26.5</td>
<td>92.5±11.2</td>
<td>97.1±28.3</td>
</tr>
</tbody>
</table>

Data are presented as mean±SD or n (%). CP indicates chest pain.
Increased prevalence of cardiac risk factors at the UOHI after changes in baseline characteristics across all sites. The relatively homogeneous, one would have expected similar risk factors. Because the population across Canada is relatively similar to possible differences in the definitions used to identify them to. Our study did not evaluate upstream or downstream utilization of other noninvasive modalities after CTA nor did we compare CTA to other noninvasive methods. Other ongoing studies such as study of Perfusion Versus Anatomy’s Role in CAD (SPARC) are considering these questions.26 However, these studies will not compare cohorts before and after the availability of CTA as has been done in the current study.

Our CTA accuracy data are limited by referral and verification bias and therefore we reported the NR of CTA which is believed to be an indirect measure of specificity after a test has been adopted into clinical practice. Though some have advocated the use of normal volunteers to determine NR, the radiation exposure associated with CTA does not permit the screening of normal volunteers. The American College of Cardiology Practice Guidelines for Radionuclide Imaging has indicated that patients with a low pretest probability should be preferentially chosen because they reflect the clinical population.11

### Conclusions

The implementation of a cardiac CT program reduced the rate of normal angiography compared with controls in this study population. The ability of CTA to rule out disease may have a positive impact on clinical practice, specifically the patient selection for ICA, and may be accompanied by a potential cost savings. Further studies examining the cost-effectiveness of cardiac CT are required. The diagnostic characteristics and NR of CTA suggest that it may be a clinically useful diagnostic tool.

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### References


**CLINICAL PERSPECTIVE**

Currently, invasive coronary angiography (ICA) is the gold standard for the diagnosis of obstructive coronary artery disease (CAD). However, ICA is best reserved for patients who benefit most from coronary revascularization. Identifying a noninvasive modality that can accurately diagnose obstructive CAD is desirable. Computed tomographic coronary angiography (CTA) is an emerging modality that has a high negative predictive value and, given its ability to rule out CAD, may have a role as a gatekeeper for ICA. To better understand the impact of cardiac CT on clinical practice, a study was undertaken to determine the diagnostic accuracy and clinical impact of CT coronary angiography on the utilization of ICA. CTA had excellent per-patient sensitivity (99%), positive predictive value (92%), and negative predictive value (95%) for obstructive CAD. As expected (due to referral and verification bias), the specificity (64%) was lower than that of previously published studies; however, the normalcy rate of CTA was 94%. After adjusting for referral bias, the adjusted sensitivity was 90%, and the adjusted specificity was 95%. With the implementation of a cardiac CT program, the frequency of normal ICA decreased significantly from 31.5% to 26.8% which was significantly different from centers without dedicated cardiac CT (30.0% to 31.0%) during the same time periods. The results of this study confirm the potential utility of CTA for the diagnosis of obstructive CAD and its potential for improving utilization of ICA by reducing the frequency of patients with nonobstructive CAD requiring ICA.
Diagnostic Accuracy and Impact of Computed Tomographic Coronary Angiography on Utilization of Invasive Coronary Angiography

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