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Comparison of coronary CT angiography versus functional imaging for CABG patients: A resource utilization analysis

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ABSTRACT

Aims: The impact of anatomical versus functional testing in patients with prior coronary artery bypass surgery (CABG) is poorly defined. We therefore sought to determine the rates of downstream investigations and the attendant healthcare costs in CABG patients undergoing CCTA versus SPECT.
Methods and results: 2754 consecutive CABG patients were imaged by SPECT (2163) or CCTA (591). 425 patients (15.4%) underwent downstream testing which was more common in those imaged with CCTA versus SPECT (23.18% vs 13.31% respectively, $p < 0.01$). When a propensity score adjustment was made for differences in baseline characteristics, the findings in downstream testing persisted ($p < 0.01$). When patients who subsequently underwent repeat revascularization (arguably the highest risk patients) were removed from the analysis, downstream testing remained more frequent in CCTA (12.7%) versus SPECT imaged patients (8.8%) ($p = 0.01$). Costs of downstream tests per patient were two-fold greater in the CCTA group in comparison to the SPECT group ($366.79 ± 29.59 vs $167.35 ± 10.12 respectively, $p < 0.01$). Conversely, total costs which included the index costs were less in the CCTA group, $764.66 ± 29.59 versus $1396.73 ± 1012 for the SPECT cohort, $p < 0.0001$).
Conclusions: Index imaging with SPECT versus CCTA in CABG patients was associated with fewer downstream tests, less ICA, less repeat revascularization but greater expense. Cost however is only part of the decision making process that determines an optimal index test. Until CCTA demonstrates improved risk stratification over SPECT in CABG patients it is likely SPECT will remain the preferred first imaging test.
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1. Introduction

There is a lack of consensus between guidelines regarding the most appropriate test for patients with stable coronary artery disease (CAD) [1–4]. Studies such as the SCOT-heart and PROMISE trials have challenged the notion that functional testing was the optimal initial non-invasive test [5–7]. These and other studies have led recent guideline changes suggesting that coronary computed tomography angiography (CCTA) be a first-line test [8].

Although there is disagreement in patients with suspected CAD, there is consensus that functional imaging should be the first test in stable symptomatic patients with established CAD [1,3,4]. It may be questioned, whether or not this recommendation is applicable to patients who have previously undergone coronary artery bypass surgery (CABG) because the interpretation of functional testing may have limitations. Functional imaging may not discern between native CAD or graft disease [9–12]. Conversely, coronary CT angiography has been demonstrated to reliably assess graft patency and has prognostic value [13–17]. CCTA also appears to be less expensive as an index test and cost effective in comparison to functional imaging [18]. Whether cost effectiveness is maintained in patients with established CAD is unknown, should CCTA increase downstream testing it may counteract any initial potential savings of CCTA as the index test [7]. Given the growing prevalence of CAD, downstream resource utilization and cost are likely to be an important factors in determining whether health service providers should adopt CCTA.

Abbreviations: CABG, Coronary Artery Bypass Grafting; CAD, Coronary Artery Disease; SPECT, Single Photon Emission Tomography; CCTA, Coronary Computed Tomography Angiography; ICA, Invasive Coronary Angiography; MPI, Myocardial Perfusion Imaging.

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We therefore sought to determine the downstream resource utilization and its associated costs in CABG patients receiving CCTA or SPECT myocardial perfusion imaging (MPI) as the initial investigation.

2. Methods

2.1. Study population

Consecutive CABG patients who had undergone a clinical requested SPECT MPI or CCTA between January 2006 to July 2013 were retrospectively identified. This first scan was defined as the index investigation (index scan).

2.2. Index test selection

Selection of the index scan was left to the discretion of the referring clinician. Choice of a particular strategy over the other may have reflected patient symptom characteristics, physician perceptions and/or logistical issues. Both investigation strategies have been available locally for >10 years. Both techniques have excellent clinical and academic standing within the service region [14,19]. In order to improve comparability between the two groups and lessen the impact of selection bias to impact test selection two further analyses of the data were planned. Firstly, a propensity adjustment was made based upon differences in the baseline characteristics. Secondly, we performed an analysis which excluded patients who subsequently received redo-revascularization. This was performed for it might be argued that any downstream testing that lead to revascularization could not be considered to be an effect of the index test.

2.3. Downstream testing

The patient electronic medical record was reviewed to ascertain downstream cardiac investigations within six months of the index scan [20]. Downstream testing (coronary angiography, SPECT, CCTA, positron emission tomography (PET) and/or stress echocardiography) was recorded. If multiple investigations were performed all tests were included. Revascularization with (percutaneous coronary intervention (PCI) or redo-CABG) were also captured. This study was approved by the local Research Ethics Board.

3. CCTA and SPECT image acquisition

3.1. Coronary CT angiography

CCTA image acquisition was performed using a single or dual-source 64-slice computed tomography scanners and reported as per SCCT (society of cardiovascular computed tomography) recommendations [21].

3.2. Tc-99 SPECT MPI

Tc-99m SPECT myocardial perfusion imaging was performed and reported as per ASNC (America Society of Nuclear Cardiology) recommendations [22].

3.3. Cost assessment

Calculations were made with reference to Medicare and Medicaid physician fee schedule and the payment rate for medical hospital outpatient prospective system [19,23]. Revascularization procedures were included in the analysis of economic impact.

3.4. Statistical analysis

Continuous variables are presented as means and standard deviations and categorical variables as frequencies with percentages. Categorical variables were compared using Chi Square tests. Continuous variables were assessed using independent sample *t*-tests. Univariable analysis and multivariable analyses were performed using a propensity score adjusting for variables that were statistically different between groups (BMI, age, smoking status, presence of dyslipidemia, diabetes and the presence of symptoms). Data were analyzed using IBM SPSS 25 statistics for Windows (Armonk, NY: IBM Corp). Statistical significance was defined as $p < 0.05$.

4. Results

4.1. Baseline characteristics

A total of 23,553 patients who underwent CCTA (6553) or SPECT (17,000) between 2010 and 2013 were screened. Of these 2754 CABG patients were identified and analysed (591 CCTA and 2163 SPECT). The SPECT cohort was older, had lower BMI and were less likely to smoke. The CCTA cohort had a higher prevalence of dyslipidemia and symptoms (chest pain, and dyspnea) (Table 1).

4.2. Downstream investigations

In total 425 patients (15.4%) underwent downstream testing. Downstream testing was significantly higher in CCTA patients (23.2%) than SPECT patients (13.3%) ($p < 0.001$) (Fig. 1) (Table 2). There was no interaction between the propensity score and modality (CCTA versus SPECT) ($p = 0.979$).

Propensity adjusted analysis included adjustment for baseline differences at index test and included BMI, age, smoking status, presence of dyslipidemia, diabetes and symptoms. The differences in downstream testing were unchanged after adjusting for propensity score (23.2% (95% CI: 20.3–26.1%) and 13.3% (95% CI: 11.8–14.8%), $p < 0.001$)). A total of 33 patients (7.8%) required multiple downstream tests, there was no difference in the number of patient requiring multiple tests between CCTA versus SPECT cohorts (12 following CCTA and 21 in SPECT patients).

4.3. Invasive coronary angiography and revascularization rates

Invasive cardiac catheterization was more common after CCTA than SPECT (18.9% and 9.9%, respectively; $p < 0.001$ (Table 2).

Revascularization rates were greater in the CCTA than the SPECT cohort (71 (12.0%) versus 103 (4.7%) patients, respectively;

Table 1
Patient characteristics.

Characteristics	CCTA index (n = 591)	SPECT index (n = 2163)	P Values
Age (year) ± SD	66.8 ± 9.2	68.8 ± 9.8	P < 0.001
Male (n) %	481 (81.4%)	1725 (80.2%)	P = 0.189
BMI (kg/m^2) ± SD	29.3 ± 5.6	28.2 ± 5.1	P < 0.001
Cardiac Risk Factors			
Hypertension (n) %	405 (68.5%)	1783 (82.4%)	P < 0.001
Dyslipidemia (n) %	550 (93.1%)	1869 (86.4%)	P < 0.001
Diabetes (n) %	190 (32.1%)	711 (32.9%)	P = 0.370
Current smoker (n) %	70 (11.8%)	257 (11.9%)	P = 0.490
Ex-Smoker (n) %	337 (57%)	1143 (52.8%)	P = 0.035
Symptoms			
Chest pain (n) %	324 (54.8%)	881 (40.7%)	P < 0.001
Dyspnea (n) %	358 (60.6%)	1122 (51.9%)	P < 0.001

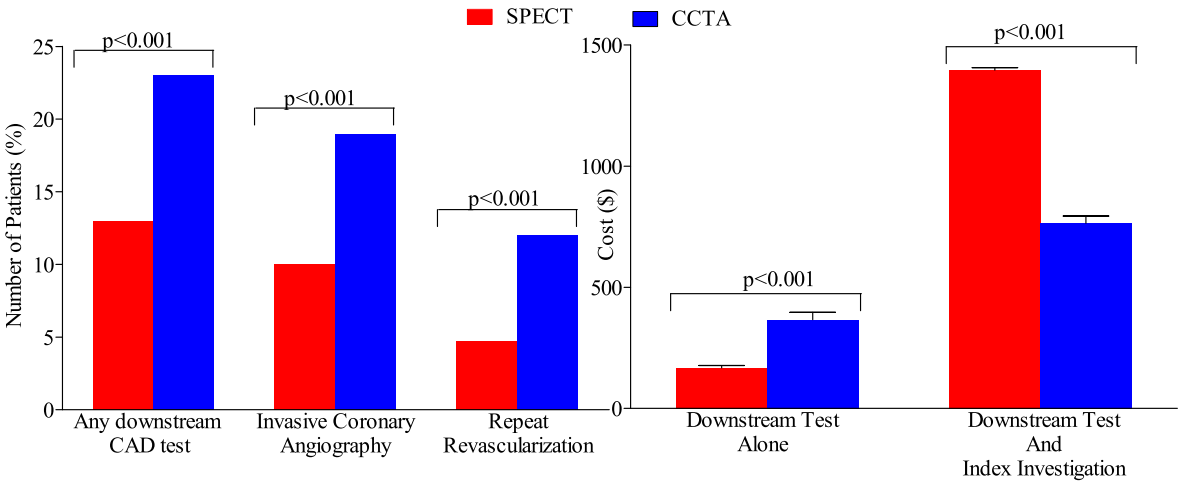

Fig. 1. Further investigations and associated costs for patients undergoing index testing with CCTA versus SPECT.

Table 2
Downstream diagnostic testing.

	CCTA index (n = 591)	SPECT index (n = 2163)	P values
CCTA (n) %	0	54 (2.5%)	–
SPECT (n) %	17 (2.9%)	0	–
PET (n) %	17 (2.9%)	27 (1.2%)	P = 0.003
Coronary angiogram (n) %	112 (18.9%)	217 (9.9%)	P < 0.001
Stress echocardiogram (n) %	1 (0.2%)	13 (0.6%)	P = 0.432
Patients undergoing downstream tests (%)	23.2%	13.3%	P < 0.001
Number of tests per patients (propensity adjusted mean- 95% CI)	0.252 (0.223–0.298)	0.143 (0.118–0.156)	P < 0.001

Table 3
Downstream costs.

Cost items	CCTA index (n = 591)	SPECT index (n = 2163)	P values
CCTA (n) %	0	$21484.98	–
SPECT (n) %	$20899.46	0	–
PET (n) %	$23384.18	$37139.58	P = 0.005
Coronary angiogram (n) %	$115601.92	$223978.72	P < 0.001
Stress echocardiogram (n) %	$236.78	$3078.14	P = 0.191
Repeat revascularization	$56652.09	$76289.28	P = 0.585
Downstream Costs	$216774.73	$361970.70	P < 0.001
Total Costs Including Index Test	$451915.60	$3021119.64	P < 0.001

p < 0.001). Redo CABG rates were low in both groups (0.34% in the CCTA and 0.14% in the SPECT groups (p = 0.642)). PCI was more frequent when the initial investigation started with CCTA (68 (11.5%)) versus SPECT (101 (4.6%); p < 0.001).

4.4. Additional testing in patients not proceeding to repeat revascularization

When patients who either underwent PCI or repeat CABG were excluded from the analysis there were 520 patients whose index test was a CCTA and 2060 patients whose index test was SPECT. The number of downstream tests was still 36% greater in the CCTA group in comparison to the SPECT cohort: the mean number of downstream tests per patient for CCTA index group was 0.131 ± 0.35 (68 tests) versus 0.096 ± 0.33 (SD) for SPECT (200 tests) p = 0.018.

4.5. Financial costs

When index test costs were included with downstream test expenses, the CCTA cohort demonstrated cost savings in comparison with the SPECT first cohort (mean cost per patient in CCTA group $764.66 ± 29.59 versus $1396.72 ± 10.12 for SPECT, p < 0.001 Table 3, Fig. 1). In contrast when only downstream costs were considered without the inclusion of the index test expense, the average costs were 2 fold greater in the CCTA first group in comparison to the SPECT group ($366.79 ± 29.59 versus $167.35 ± 10.12, respectively; p < 0.001, Table 3).

Total costs for the downstream investigations using 2019 Medicare fee schedule [23] were $578745.10 (Table 3). The majority of downstream costs were attributable to invasive coronary angiography which occurred at almost twice the frequency in the CCTA group as compared to the SPECT group. Increased costs were also seen as a result of the downstream functional perfusion testing in the CCTA group from PET and SPECT.

5. Discussion

We performed a retrospective study of 2754 consecutive CABG patients who underwent non-invasive testing for established coronary artery disease. We determined that there are downstream resource utilization and cost consequences associated with the first-test strategy selected. Previous studies have considered downstream utilization and financial implications in patients with suspected coronary disease [5,7,20,24–28]. Our study adds to the existing literature by examining the CABG population and suggests that a CCTA strategy leads to increased downstream investigation, increased invasive testing, and increased revascularization but reduced costs in comparison to a SPECT first strategy.

5.1. Subsequent investigations

Downstream testing was performed in 15% of patients. This is similar to the frequency of further testing in patients without prior coronary revascularization [5,29]. For patients undergoing further testing this was usually a single test (92% of those undergoing downstream testing had a single test) and the most commonly test was invasive coronary angiography (72% of further tests were ICA). The rates of ICA in our study were comparable to those seen in

prior studies, however the differences in frequency of downstream ICA between the index investigative strategies were greater than those previously seen [5,7,27,29].

Some of the differences in downstream ICA rates following index testing may be related to the follow up period in prior studies. Trials associated with short term follow up of 2 years or less have noted increases rates of ICA associated with CCTA as the first test versus usual care or functional testing [5,7,27,29]. In contrast studies that have included a longer term follow up of more than 4 years the rates of ICA were similar between the two strategies [6].

5.2. Repeat revascularization

In the current investigation repeat revascularization rates were higher in the CCTA group than the SPECT group (12% versus 5% of CCTA versus SPECT respectively, $p < 0.001$). In patients with suspected CAD, there are conflicting reports in the literature as to whether CCTA increases revascularization [6,7,24]. In CABG patients it is possible that the presence of diffuse severe coronary disease seen at CCTA might have proactively influenced revascularization decisions toward PCI in contrast to normal or low risk SPECT findings.

5.3. Economic impact

Index testing with CCTA in CABG patients almost doubled the per-patient costs of downstream tests from $167.35 with SPECT to $366.79 with CCTA ($p < 0.001$) (Table 3). Prior studies have indicated a neutral effect on downstream tests following CCTA versus usual care or functional testing [29,30]. In addition cost savings with CCTA have been noted in other comparisons when the index test was included in the cost calculation [28]. This was observed in the present study as a consequence of the expense of SPECT in comparison to CCTA. (Table 3 and Fig. 1).

There are however more financial costs involved with downstream testing that have not been accounted for in these results such as, office visits, routine blood work or day case admission for ICA with attendant ward and catheterization laboratory care. These may have had an important bearing on the true financial cost of a downstream test.

A further factor in the economic analysis is the initial expenditure for procurement of the imaging camera. Modern SPECT cameras which are approximately $400,000 to $600,000 are much less expensive that current CT machines which are $2–2.5 million for a 256 or 320 detector camera. Whether the addition cost of the equipment can be recouped over time will depend on the efficiency of camera use, and the longevity of the equipment's service life. Thus although there are additional downstream costs from performing an index CCTA in CABG patients in comparison to SPECT, once index test cost and equipment costs are considered, the additional costs maybe cost neutral/saving.

5.4. Limitations

This was a retrospective study of consecutive patients. Although a propensity score was used to adjust for potential confounding variables it is possible that selection bias variables not accounted for in the propensity score influenced the results. A prospectively randomized study of CCTA versus SPECT in this population would be useful to better control for such potential confounders. Clinical outcomes were not considered in the current study. Whether the increase in ICA and subsequent increased revascularization in the CCTA group improves prognosis will be important to determine in future investigations.

This was a single centre study and although performed at a central tertiary referral centre with the regional cardiac catheterization and coronary interventional suite it is possible that some cases underwent further functional or ICA procedures at other centres and these investigations were not captured.

5.5. Conclusions

In CABG patients, the choice of initial investigation for stable ischemic coronary artery disease has an important influence on downstream testing, subsequent revascularization and health care costs. Our findings heighten the controversy regarding first test strategy in CABG patients by demonstrating that any potential cost saving of CCTA must be weighed against the increase in downstream testing associated with this modality. Prospective data that included more extensive evaluation of costs and clinical outcome data will be required therefore before CCTA replaces functional imaging as the first line investigation in CABG patients.

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Statement of authorship

These authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

CRediT authorship contribution statement

Gary R. Small: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Supervision, Project administration. **Fernanda Erthal:** Investigation. **Ali Alenazy:** Investigation. **Yeung Yam:** Data curation. **Michael Edwards:** Investigation. **Andrew Crean:** . **Rob S. Beanlands:** . **Terrence D. Ruddy:** Investigation and Supervision. **Benjamin J.W. Chow:** Conceptualization, Methodology, Resources, Data curation, Investigation, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcha.2020.100494.

References

[1] J. Knuuti, W. Wijns, A. Saraste, D. Capodanno, E. Barbato, C. Funck-Brentano, et al., 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes, Eur. Heart J. (2019 Aug 31).

[2] G.B. Mancini, G. Gosselin, B. Chow, W. Kostuk, J. Stone, K.J. Yvorchuk, et al., Canadian Cardiovascular Society guidelines for the diagnosis and management of stable ischemic heart disease, Can. J. Cardiol. 30 (8) (2014 Aug) 837–849.
[3] S.D. Fihn, J.C. Blankenship, K.P. Alexander, J.A. Bittl, J.G. Byrne, B.J. Fletcher, et al., 2014 ACC/AHA/AATS/PCNA/SCAI/STS focused update of the guideline for the diagnosis and management of patients with stable ischemic heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines, and the American Association for Thoracic Surgery, Preventive Cardiovascular Nurses Association, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons, J. Am. Coll. Cardiol. 64 (18) (2014 Nov 4) 1929–1949.
[4] S.D. Fihn, J.M. Gardin, J. Abrams, K. Berra, J.C. Blankenship, A.P. Dallas, et al., 2012 ACCF/AHA/ACP/AATS/PCNA/SCAI/STS Guideline for the diagnosis and management of patients with stable ischemic heart disease: 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. 60 (24) (2012 Dec 18) e44–e164.
[5] CT coronary angiography in patients with suspected angina due to coronary heart disease (SCOT-HEART): an open-label, parallel-group, multicentre trial. Lancet 385(9985) (2015) 2383–2391.
[6] D.E. Newby, P.D. Adamson, C. Berry, N.A. Boon, M.R. Dweck, M. Flather, et al., Coronary CT angiography and 5-year risk of myocardial infarction, N. Engl. J. Med. 379 (10) (2018 Sep 6) 924–933.
[7] P.S. Douglas, U. Hoffmann, M.R. Patel, D.B. Mark, H.R. Al-Khalidi, B. Cavanaugh, et al., Outcomes of anatomical versus functional testing for coronary artery disease, N. Engl. J. Med. 372 (14) (2015 Apr 2) 1291–1300.
[8] National Institute for Health and Care Excellence. NICE London. Chest pain of recent onset: assessment and diagnosis of recent onset chest pain or discomfort of suspected cardiac origin (update). Clin. Guideline 95 (2016).
[9] A.F. Khoury, J.M. Rivera, J.J. Mahmarian, M.S. Verani, Adenosine thallium-201 tomography in evaluation of graft patency late after coronary artery bypass graft surgery, J. Am. Coll. Cardiol. 29 (6) (1997 May) 1290–1295.
[10] M. Pfisterer, H. Emmenegger, H.E. Schmitt, J. Muller-Brand, J. Hasse, E. Gradel, et al., Accuracy of serial myocardial perfusion scintigraphy with thallium-201 for prediction of graft patency early and late after coronary artery bypass surgery. A controlled prospective study, Circulation 66 (5) (1982 Nov) 1017–1024.
[11] A. Elhendy, J.J. Bax, D. Poldermans, Dobutamine stress myocardial perfusion imaging in coronary artery disease, J. Nucl. Med. 43 (12) (2002 Dec) 1634–1646.
[12] S.L. Rasmussen, S.L. Nielsen, O. Amtorp, K. Folke, P. Fritz-Hansen, 201-Thallium imaging as an indicator of graft patency after coronary artery bypass surgery, Eur. Heart J. 5 (6) (1984 Jun) 494–499.
[13] B.J. Chow, O. Ahmed, G. Small, A.A. Alghamdi, Y. Yam, L. Chen, et al., Prognostic value of CT angiography in coronary bypass patients, JACC Cardiovasc Imaging 4 (5) (2011 May) 496–502.
[14] G.R. Small, Y. Yam, L. Chen, O. Ahmed, M. Al-Mallah, D.S. Berman, et al., Prognostic assessment of coronary artery bypass patients with 64-slice computed tomography angiography: anatomical information is incremental to clinical risk prediction, J. Am. Coll. Cardiol. 58 (23) (2011 Nov 29) 2389–2395.
[15] A.C. Weustink, K. Nieman, F. Pugliese, N.R. Mollet, W.B. Meijboom, M.C. van et al., Diagnostic accuracy of computed tomography angiography in patients after bypass grafting: comparison with invasive coronary angiography, JACC Cardiovasc Imaging 2(7) (2009) 816–824.
[16] H. Bassri, F. Salari, F. Noohi, M. Motevali, S. Abdi, N. Givtaj, et al., Evaluation of early coronary graft patency after coronary artery bypass graft surgery using multislice computed tomography angiography, BMC Cardiovasc Disord 9 (2009) 53.
[17] R. Lee, J. Lim, G. Kaw, G. Wan, K. Ng, K.T. Ho, Comprehensive noninvasive evaluation of bypass grafts and native coronary arteries in patients after coronary bypass surgery: accuracy of 64-slice multidetector computed tomography compared to invasive coronary angiography, J Cardiovasc Med (Hagerstown) 11 (2) (2010 Feb) 81–90.
[18] J.K. Min, A. Gilmore, M.J. Budoff, D.S. Berman, K. O'Day, Cost-effectiveness of coronary CT angiography versus myocardial perfusion SPECT for evaluation of patients with chest pain and no known coronary artery disease, Radiology 254 (3) (2010 Mar) 801–808.
[19] G.R. Small, T.D. Ruddy, O. Simion, M. Alam, L. Fuller, L. Chen, et al., Lessons from the Tc-99m shortage: implications of substituting Tl-201 for Tc-99m single-photon emission computed tomography, Circ. Cardiovasc Imaging 6 (5) (2013 Sep) 683–691.
[20] V. Tandon, D. Hall, Y. Yam, H. Al-Shehri, L. Chen, K. Tandon, et al., Rates of downstream invasive coronary angiography and revascularization: computed tomographic coronary angiography vs. Tc-99m single photon emission computed tomography, Eur. Heart J. 33 (6) (2012 Mar) 776–782.
[21] J. Leipsic, S. Abbara, S. Achenbach, R. Cury, J.P. Earls, G.J. Mancini, et al., SCCT guidelines for the interpretation and reporting of coronary CT angiography: a report of the Society of Cardiovascular Computed Tomography Guidelines Committee, J. Cardiovasc. Comput. Tomogr. 8 (5) (2014 Sep) 342–358.
[22] S. Dorbala, K. Ananthasubramaniam, I.S. Armstrong, P. Chareonthaitawee, E.G. DePuey, A.J. Einstein, et al., Single photon emission computed tomography (SPECT) myocardial perfusion imaging guidelines: instrumentation, acquisition, processing, and interpretation, J. Nucl. Cardiol. 25 (5) (2018 Oct) 1784–1846.
[23] Centers for Medicare and Medicaid Services, 2019 Physician Fee Schedule, CMS gov 2019 May 7Available from: URL: www.cms.gov/medicare/medicare-fee-for-service-payment/physicianfeessched/.
[24] R. Hachamovitch, B. Nutter, M.A. Hlatky, L.J. Shaw, M.L. Ridner, S. Dorbala, et al., Patient management after noninvasive cardiac imaging results from SPARC (Study of myocardial perfusion and coronary anatomy imaging roles in coronary artery disease), J. Am. Coll. Cardiol. 59 (5) (2012 Jan 31) 462–474.
[25] M.A. Hlatky, D. Shilane, R. Hachamovitch, M.F. Dicarli, Economic outcomes in the study of myocardial perfusion and coronary anatomy imaging roles in coronary artery disease registry: the SPARC study, J. Am. Coll. Cardiol. 63 (10) (2014 Mar 18) 1002–1008.
[26] J.A. Goldstein, K.M. Chinnaiyan, A. Abidov, S. Achenbach, D.S. Berman, S.W. Hayes, et al., The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment) trial, J. Am. Coll. Cardiol. 58 (14) (2011 Sep 27) 1414–1422.
[27] P. McKavanagh, L. Lusk, P.A. Ball, R.M. Verghis, A.M. Agus, T.R. Trinick, et al., A comparison of cardiac computerized tomography and exercise stress electrocardiogram test for the investigation of stable chest pain: the clinical results of the CAPP randomized prospective trial, Eur. Heart J. Cardiovasc Imaging 16 (4) (2015 Apr) 441–448.
[28] J.K. Min, S. Koduru, A.M. Dunning, J.H. Cole, J.L. Hines, D. Greenwell, et al., Coronary CT angiography versus myocardial perfusion imaging for near-term quality of life, cost and radiation exposure: a prospective multicenter randomized pilot trial, J. Cardiovasc. Comput. Tomogr. 6 (4) (2012 Jul) 274–283.
[29] M.C. Williams, A. Hunter, A.S.V. Shah, V. Assi, S. Lewis, J. Smith, et al., Use of coronary computed tomographic angiography to guide management of patients with coronary disease, J. Am. Coll. Cardiol. 67 (15) (2016 Apr 19) 1759–1768.