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ORIGINAL RESEARCH ARTICLE

Acute chest pain evaluation using coronary computed tomography angiography compared with standard of care: a meta-analysis of randomised clinical trials

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ABSTRACT

Objective Coronary CT angiography (CCTA) has certain advantages compared with stress testing including greater accuracy in identifying obstructive coronary disease. The aim of the study was to perform a systematical review and meta-analysis comparing CCTA with other standard-of-care (SOC) approaches in evaluation of patients with acute chest pain.

Methods Electronic databases were systematically searched to identify randomised clinical trials of patients with acute chest pain comparing CCTA with SOC approaches. We examined the following end points: mortality, major adverse cardiac events (MACE), myocardial infarction (MI), invasive coronary angiography (ICA) and revascularisation. Pooled risk ratios (RR) and their 95% CIs were calculated using random-effects models.

Results Ten trials with 6285 patients were included. The trials used different definitions and implementation for SOC but all used physiologic testing. The clinical follow-up ranged from 1 to 19 months. There were no significant differences in all-cause mortality (RR 0.48, 95% CI 0.17 to 1.36, p=0.17), MI (RR 0.82, 95% CI 0.49 to 1.39, p=0.47) or MACE (RR 0.98, 95% CI 0.67 to 1.43, p=0.92) between the groups. However, significantly higher rates of ICA (RR 1.32, 95% CI 1.07 to 1.63, p=0.01) and revascularisation (RR 1.77, 95% CI 1.35 to 2.31, p<0.0001) were observed in the CCTA arm.

Conclusions Compared with other SOC approaches use of CCTA is associated with similar major adverse cardiac events but higher rates of revascularisation in patients with acute chest pain.

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INTRODUCTION

Coronary CT angiography (CCTA), a non-invasive method for assessing anatomic atherosclerotic disease, represents a promising diagnostic modality for the initial workup of patients with chest pain. Several advantages of CCTA compared with other modalities (such as physiologic testing) have been described including greater accuracy in identifying obstructive coronary artery disease, identification of high-risk disease as well as detection of subclinical atherosclerosis.[1 2] These advantages may potentially improve patient outcomes and reduce downstream testing and unnecessary procedures. Accordingly, this technique has quickly become the subject of prolific comparative effectiveness research over the recent years which used different standard-of-care (SOC) approaches. However, many of these trials were not adequately powered to evaluate clinical and hard safety end points. Moreover, the results of these studies were heterogeneous and need to be reconciled and critically analysed. The current study examined the benefits and risks of CCTA compared with other SOC approaches in evaluating patients with acute chest pain who were either treated in the emergency department or admitted for inpatient evaluation.

METHODS

Search strategy

The meta-analysis was performed based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[3] Electronic databases such as PubMed, EMBASE, SCOPUS and ClinicalTrials.gov were systematically searched for randomised controlled trials published from inception to March 2017 that compared CCTA with SOC in the acute settings. The following keywords and medical subject headings were used: 'chest pain', 'coronary computed tomography', 'coronary computed tomography angiography', 'CCTA', 'standard of care', 'SOC', 'stress imaging', 'stress echocardiography' and 'myocardial perfusion imaging'. Additionally, a manual search of reference lists of original and review studies was performed to identify articles potentially missed by the database searches. Only randomised trials published in peer-reviewed journals were considered for this meta-analysis; observational studies, abstracts, case series and case reports were not included. No language restrictions were enforced.

Study selection

Two authors (CG and CB) independently identified articles eligible for review. Studies were selected if they: (1) were randomised clinical trials; (2) reported clinical outcomes and; (3) included patients presenting with acute chest pain (in emergency department and/or inpatient).

Data extraction and quality assessment

Two authors (CG and CB) independently extracted data from included studies with divergence resolved by consensus. The following primary clinical outcomes were extracted in a standardised manner: (1) all-cause mortality, (2) myocardial infarction (MI), (3) major adverse cardiac events (MACE), (4) invasive coronary angiography (ICA), and (5)

Table 1 Baseline characteristics of study patients

Trial	Age, years, mean	Female, %	Hypertension, %	Diabetes, %	Hyperlipidaemia, %	Smoking, %
ACRIN PA[8 9]	50	54	51	14	27	33
BEACON[10]	54	47	27*	13	24*	34
CATCH[7 11]	56	43	42	11	38	64†
CT-COMPARE[12]	52	42	31	7	25	23
CT-STAT[13]	50	54	37	7	34	22
Goldstein *et al*[4]	50	50	39	10	36	18
Nabi *et al*[14]	53	56	50	15	38	27
PERFECT[15]	60	54	69	29	48	46
PROSPECT[16]	57	63	72	32	52	15
ROMICAT-II[17]	54	47	54	17	46	50†

*Treated disease.
†Current or former smoker.

revascularisation. The definition of MI and MACE followed the definition used by individual studies. Revascularisation included percutaneous coronary intervention and coronary artery bypass graft (CABG). The specifications of the different types of revascularisation used by each study are included in online supplementary table 1. In addition, repeat emergency room visit and repeat hospitalisation data were obtained. The efficiency end points included length of stay and the cost of acute care (during the index emergency room visit or hospitalisation) as measured by the original trials.[4] Two investigators (CB and CG) independently assessed the study quality using Cochrane collaboration's tool for assessing the bias in randomised trials focusing on the following domains: sequence generation, allocation concealment, blinding, outcomes assessment and selective reporting.[5] No evidence of high-risk bias was found in the included studies.

Statistical analysis

Pooled risk ratios (RR) and their 95% CIs were calculated for all clinical outcomes using random-effects models. Heterogeneity was assessed using Higgins and Thompson's I^2 statistic. I^2 is the proportion of total variation observed between the trials attributable to differences between trials rather than sampling error (chance) with I^2 values of <25%, 25%–75% and >75% corresponding to low, moderate and high levels of heterogeneity, respectively.[6] Heterogeneity was further assessed using subgroup and sensitivity analyses. Meta-regression analyses were performed to explore the association of mean age and the rates of diabetes in the studies with MACE and revascularisation outcome measures since these variables can most strongly influence the effect estimates. Publication bias was assessed visually by funnel plot graphs. Descriptive statistics are presented as means and SD for continuous variables and as percentages for categorical variables. The analysis was performed using Review Manager (RevMan) V.5.1.7 (Nordic Cochrane Center, The Cochrane Collaboration, Copenhagen, Denmark) and Stata V.11 (StataCorp, College Station, Texas, USA). A two-tailed $p<0.05$ was considered to be statistically significant for all analyses.

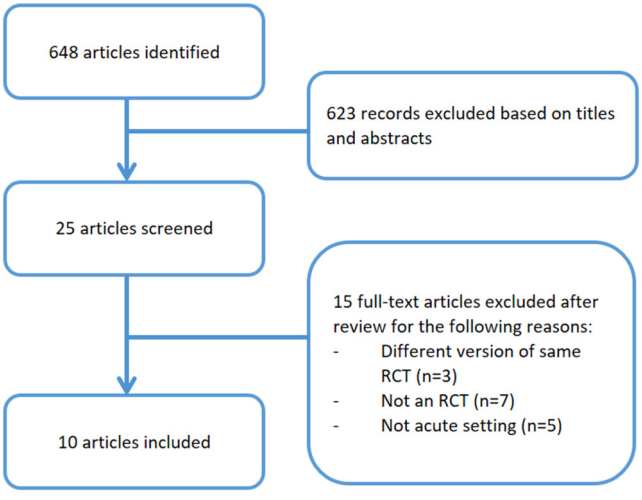

Figure 1 Results of the literature search. Ten randomised clinical trials (RCTs) were identified and included in the meta-analysis.

RESULTS

A total of 648 studies were identified through the electronic and manual search. Of the 25 articles retrieved for full-text review, 10 randomised clinical trials were included in the analysis (figure 1).[4 7–17] The studies were published from 2007 to 2016. The trials were conducted in patients seen in the acute care settings: emergency department or inpatient. At baseline, the mean age ranged from 50 to 60 years and the percentage of female patients ranged from 42% to 63% (table 1). In addition to uniformly accepted exclusion criteria (pregnancy, renal failure, allergy to iodine contrast and inability to obtain informed consent), studies required non-ischaemic ECG and/or negative cardiac biomarkers (see online supplementary table 2). Eight studies excluded patients with known coronary artery disease.[4 10 12–17] Only two studies allowed patients with known coronary artery disease,[7–9 11] but one of these excluded patients with prior CABG surgery.[7 11] Only three studies used the Thrombolysis in Myocardial Infarction (TIMI) score inclusion cut-off.[8 9 12 13] The TIMI risk scores were low in the trial populations (table 2). Therefore, these studies assessed low-risk and low-to-intermediate risk patients with a low expected adverse cardiac event rates.

The trials used different definitions and implementation for SOC but all used physiologic testing such as stress electrocardiography, stress echocardiography and myocardial perfusion imaging (MPI) as the comparator (table 3). Nabi *et al* used stress-only MPI if feasible as SOC comparator[14] and BEACON trial used high-sensitivity troponin as a part of SOC with follow-up testing as needed.[10] Follow-up period for the studies ranged from 1 to 19 months (1–12 months for the emergency department studies and 7–19 months for the inpatient studies).

Table 2 Standardised risk assessment based on Thrombolysis in Myocardial Infarction risk score

Trial	CCTA	SOC	p Value	Cut-off for inclusion
ACRIN PA[8 9]	0 (51%) 1 (36%) ≥2 (13%)	0 (51%) 1 (36%) ≥2 (13%)	N/A	≤2
BEACON[10]	Median 1 (0–2) 0 (30%) 1 (34%) ≥2 (36%)	Median 1 (0–2) 0 (33%) 1 (37%) ≥2 (30%)	0.31	No
CATCH[7 11]	0 (49%) 1 (27%) 2 (13%) ≥3 (11%)	0 (54%) 1 (24%) 2 (11%) ≥3 (10%)	0.21 0.50 0.52 0.79	No
CT-COMPARE[12]	N/A	N/A	N/A	<4
CT-STAT[13]	Mean 0.99±0.84 Median 1.0	Mean 1.04±0.87 Median 1.0	0.38	≤4
Goldstein *et al*[4]	Mean 1.24±0.8 Median 1.0	Mean 1.33±0.8 Median 1.0	0.30	No
Nabi *et al*[14]	0 (50.4%) 1 (32.3%) 2 (14.6%) 3 (2.8%)	0 (54.8%) 1 (29%) 2 (14.2%) 3 (1.9%)	0.67	No
PERFECT[15]	N/A	N/A	N/A	No
PROSPECT[16]	Mean 1.3 (1.0)	Mean 1.2 (1.0)	N/A	No
ROMICAT-II[17]	N/A	N/A	N/A	No

CCTA, coronary CT angiography; N/A, not available; SOC, standard of care.

Comparing CCTA and SOC in patients with acute chest pain

Ten clinical trials with a total of 6285 patients were included. There were no significant differences in all-cause mortality (RR 0.48, 95% CI 0.17 to 1.36, p=0.17) (figure 2), MI (RR 0.82, 95% CI 0.49 to 1.39, p=0.47) (see online supplementary figure 1) or MACE (RR 0.98, 95% CI 0.67 to 1.43, p=0.92) (figure 3) between the groups. However, significantly higher rates of ICA (RR 1.32, 95% CI 1.07 to 1.63, p=0.01) (figure 4) and revascularisation (RR 1.77, 95% CI 1.35 to 2.31, p<0.0001) (figure 5) were observed in the CCTA group. The number of mortality events was very low and the mortality comparison should be interpreted with caution. Heterogeneity was low for all-cause mortality, MI and revascularisation and moderate for MACE and ICA. The funnel plots for the assessment of publication bias were fairly symmetric (see online supplementary figures 2-6). Meta-regression analyses showed no significant association of the mean age in the studies with the MACE (p=0.18) (see online supplementary figure 7) and revascularisation (p=0.696) outcome measures comparing CCTA and SOC approaches (see online supplementary figure 8). Similarly, no significant association was seen between the rates of diabetes in the studies and the MACE (p=0.437) (see online supplementary figure 9) and revascularisation (p=0.624) outcome measures (see online supplementary figure 10).

Repeat visits and efficiency outcomes

Seven studies reported repeat emergency room visits and nine reported repeat hospitalisations after the index evaluation for chest pain (see online supplementary table 3). The rates of repeat visits varied significantly among the studies due to differences in the study populations and the length of follow-up, but none of the studies demonstrated statistically significant differences in these measures. On the contrary, significant differences were

Table 3 Characteristics of the included studies

Trial	Year	Follow-up, months	Total	CCTA	SOC	Settings	SOC
ACRIN PA[8 9]	2016	12	1368	907	461	ED	Stress ECG 2%, stress imaging 56%
BEACON[10]	2016	1	490	245	245	ED	hs troponin 100%, stress ECG 53%, MPI 3%
CATCH[7 11]	2015	19	576	285	291	IP	Stress ECG 76%, MPI 22%
CT-COMPARE[12]	2014	12	562	322	240	ED	Stress ECG 100%
CT-STAT[13]	2011	6	699	361	338	ED	MPI 100%
Goldstein *et al*[4]	2007	6	197	99	98	ED	MPI 100%
Nabi *et al*[14]	2016	7	598	288	310	IP	MPI 100%*
PERFECT[15]	2016	12	395	198	197	IP	SE 88%, MPI 4%
PROSPECT[16]	2015	12	400	200	200	IP	MPI 95%
ROMICAT-II[17]	2012	1	1000	501	499	ED	Stress ECG 29%, SE 20%, MPI 25%

CCTA, coronary CT angiography; ED, emergency department; IP, inpatient; hs troponin, high-sensitivity troponin; MPI, myocardial perfusion imaging; OP, outpatient; SE, stress echocardiography; SOC, standard of care.
*Stress only MPI if feasible.

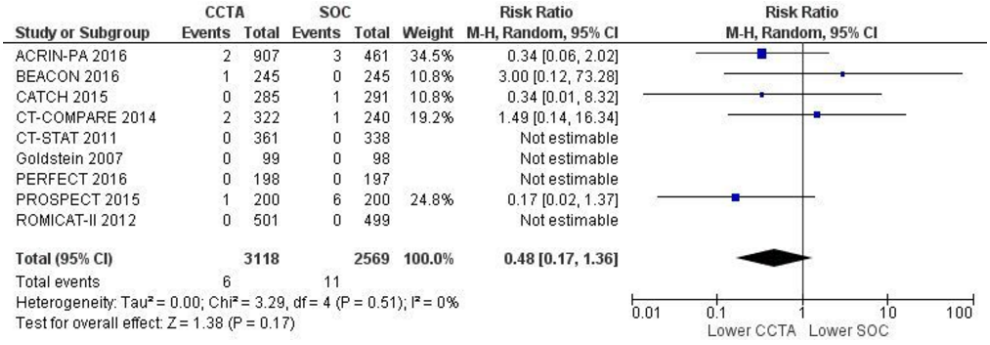

Figure 2 All-cause mortality with coronary CT angiography (CCTA) compared with other standard-of-care (SOC) approaches in patients with acute chest pain. The size of central markers reflects the weight of each study.

seen in the efficiency measures such as length of stay (see online supplementary table 4) and the cost of acute care (see online supplementary table 5). Three studies showed a shorter length of stay for the CCTA group[12 14 17] and three studies did not show a significant difference.[10 15 16] Five studies demonstrated cost savings for CCTA approach[4 10 12–14] and one reported no significant difference.[17]

Subgroup analysis

The subgroup analyses included patients evaluated in the emergency department (n=6)[4 9 10 12 13 17] or admitted for inpatient workup (n=4).[7 14–16] In the emergency department studies, there were no significant differences in all-cause mortality (RR 0.76, 95% CI 0.21 to 2.80, p=0.68), MI (RR 0.90, 95% CI 0.53 to 1.55, p=0.71) and MACE (RR 1.16, 95% CI 0.79 to 1.71 p=0.44) between CCTA versus other SOC approaches. The rates of ICA (RR 1.36, 95% CI 1.09 to 1.69, p=0.006) and revascularisation (RR 1.64, 95% CI 1.20 to 2.26, p=0.002) were significantly higher in the CCTA group (see online supplementary table 6).

For inpatient settings, there were no significant differences between the groups in all-cause mortality (RR 0.21, 95% CI 0.04 to 1.20, p=0.08), MI (RR 0.61, 95% CI 0.10 to 3.81, p=0.60), MACE (RR 0.83, 95% CI 0.38 to 1.80, p=0.63) or ICA (RR 1.35, 95% CI 0.82 to 2.20, p=0.23). Higher rates of revascularisation were observed in the CCTA group (RR, 2.04, 95% CI 1.10 to 3.76, p=0.02) compared with other SOC approaches (see online supplementary table 7).

Sensitivity analysis

Fixed effects models showed results consistent with the main analysis (see online supplementary table 8). After excluding BEACON trial, which employed high-sensitivity troponin in the study design, the differences remained not significant for all-cause mortality (RR 0.38, 95% CI 0.13 to 1.16, p=0.09), MI (RR 0.70, 95% CI 0.33 to 1.47, p=0.35) and MACE (RR 0.92, 95% CI 0.58 to 1.48, p=0.74), but higher rates of ICA (RR 1.33, 95% CI 1.04 to 1.70, p=0.02) and revascularisation (RR 1.88, 95% CI 1.40 to 2.52, p<0.0001) were in the CCTA group (see online supplementary table 9).

DISCUSSION

The comparative clinical effectiveness of cardiac tests has been the focus of numerous studies recently due to both an increasing number of cardiac imaging and escalating healthcare costs.[15] CCTA has been one of the most promising modalities extensively studied in both observational studies and clinical trials.[1] Recent guidelines by the National Institute of Health and Clinical Excellence (NICE) recommend no routine non-invasive testing in the initial assessment of acute cardiac chest pain with non-ischaemic ECG and negative troponin but prioritise anatomic testing in patients with suspected myocardial ischaemia, a recommendation that sparked considerable debate.[18 19] Based on the results of the current study, the CCTA-based strategy does not result in reduction in mortality and MACE for patients with acute chest pain syndrome requiring evaluation in the emergency room or admission for inpatient testing. While CCTA-based strategy may improve the efficiency measures in the acute care settings, it

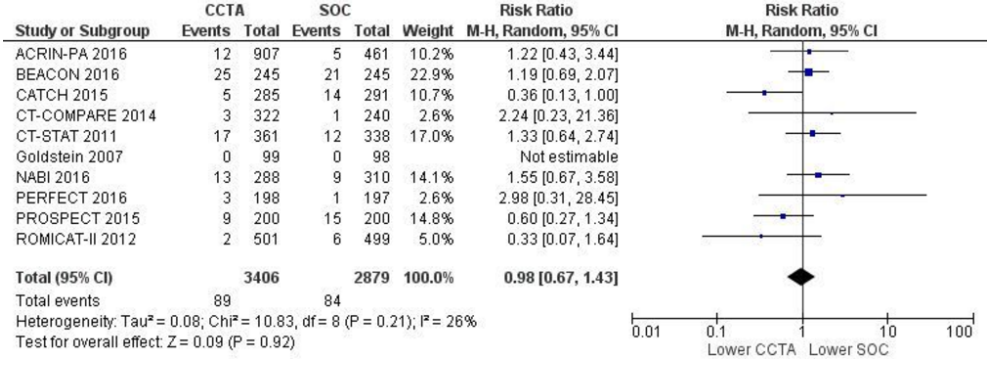

Figure 3 Major adverse cardiac events with coronary CT angiography (CCTA) compared with other standard-of-care (SOC) approaches in patients with acute chest pain. The size of central markers reflects the weight of each study.

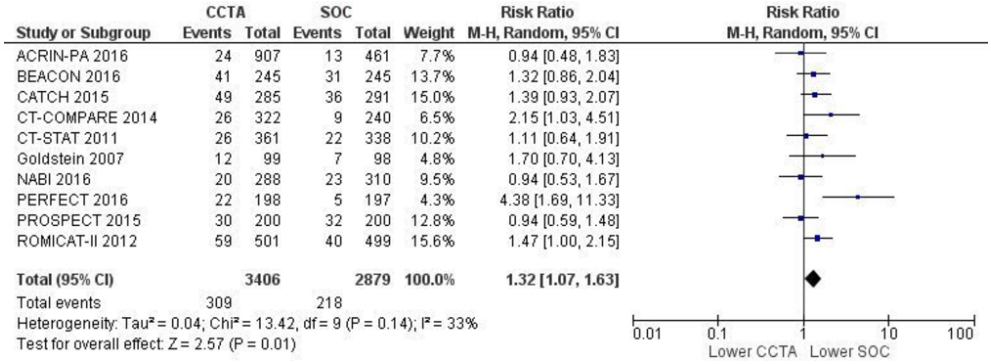

Figure 4 Invasive coronary angiography with coronary CT angiography (CCTA) compared with other standard-of-care (SOC) approaches in patients with acute chest pain. The size of central markers reflects the weight of each study.

leads to consistently higher rates of revascularisation procedures in low-risk and low-to-intermediate risk patients.

CCTA has been shown to have a high sensitivity for detection of obstructive coronary artery disease, which is a potential advantage of CCTA-based strategy in patients presenting with acute chest pain.[1] Missed acute coronary syndrome has been associated with worse outcomes. Also, CCTA has a higher accuracy in detecting high-risk coronary artery disease while the results of functional testing may not always reflect the full extent of the anatomic severity of the disease.[1 20] On the other hand, the anatomic atherosclerosis severity may not correlate with physiologic lesion characteristics.[20] Anatomic detection of 'incidental' coronary artery disease without physiologic corroboration may prompt revascularisation. An increased use of ICA and revascularisation with CCTA-based strategy has been demonstrated in this study similar to prior meta-analyses and observational studies.[21–23] Stress testing, especially using exercise has the advantage of demonstrating the physiologic lesion severity as well as correlating physiologic findings with patient symptoms.[1 2]

The overall adverse cardiac event rates in the included trials were low since the studies recruited low-risk and low-to-intermediate risk patients. Along with safety measures, many trials focused on efficiency demonstrating a likely benefit of CCTA-based strategy in terms of length of stay and the costs of acute care. These measures should be interpreted with caution due to a wide variation in the SOC approaches and the fact that many of the low-risk patients may not require emergency room or inpatient non-invasive testing and can be safely discharged with outpatient follow-up.[18] At the same time, our study results indicate no significant difference between CCTA-based strategy and other SOC approaches in all-cause mortality, MACE and MI. While current study confirmed prior observations, it includes a larger number of randomised trials making the findings more robust.[24] Our findings contrast with observations that CCTA-based strategy may result in a significant reduction in MI in stable chest pain patients.[22 25 26] Use of stress electrocardiography as a comparator arm in some studies performed in outpatient settings may exaggerate the benefits of CCTA-based strategy due to relatively inferior performance of stress electrocardiography in ischaemia detection compared with stress imaging.[27] Alternatively, detection of anatomic coronary artery disease (regardless of individual lesion severity) may prompt adjustment of medical regimen such as aggressive lipid-lowering therapy and lifestyle modification that decrease the long-term risk of acute coronary events.[28] While this is a potentially important advantage of anatomic imaging, further corroboration of this hypothesis is needed in prospective trials.[15]

LIMITATIONS

Heterogeneity of SOC represents a major limitation for the current study, despite sensitivity analysis. The results of our study are only applicable to short-term clinical outcomes. Due to a relatively small number of clinical trials we cannot exclude publication bias. Some of the advantages of CCTA such as detection of subclinical coronary artery disease are likely to be more apparent with long-term follow-up.[26] Only several of the included trials prespecified the criteria for downstream testing such as invasive angiography based on the findings on CCTA and/or functional testing leaving the decision to the managing

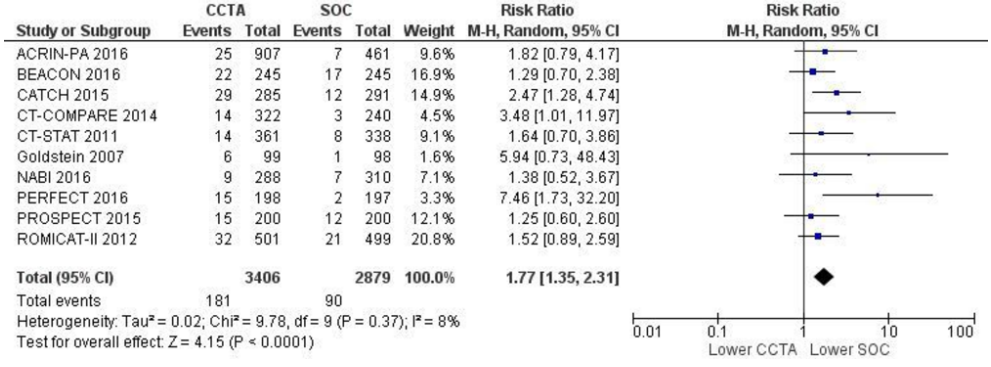

Figure 5 Coronary revascularisation with coronary CT angiography (CCTA) compared with other standard-of-care (SOC) approaches in patients with acute chest pain. The size of central markers reflects the weight of each study.

physician. Moreover, it is unclear how the decision to proceed with revascularisation was guided after the diagnostic angiography was performed, since use of advanced invasive techniques (such as fractional flow reserve and direct coronary imaging) may significantly affect this decision. The issue of radiation exposure pertinent to different testing strategies was not addressed by this study. Also, we could not study the long-term effect of diagnostic strategy on subsequent testing and treatment as well as quality of life but the evidence in this regard is relatively limited. CT-derived fractional flow reserve analysis that can provide anatomic and physiologic information with a single test may significantly influence the testing strategies once further validated and implemented in routine clinical practice.[29]

CONCLUSIONS

Anatomic imaging using CCTA is not associated with reduction in major adverse cardiac events in patients presenting to the emergency room or admitted for chest pain evaluation. There is consistent increase in revascularisation procedures with CCTA-based strategy.

Key messages

What is already known on this subject?
Coronary CT angiography (CCTA) has been a subject of comparative effective research in patients evaluated for acute chest pain. Randomised trials have been underpowered to detect meaningful differences in cardiac events when comparing CCTA with other standard-of-care (SOC) approaches.

What might this study add?
In this meta-analysis of 10 randomised clinical trials, there were no significant differences in clinical outcomes between CCTA-based strategy and other SOC. While efficiency measures favoured CCTA, higher rates of revascularisation were observed in the CCTA arm.

How might this impact on clinical practice?
The study adds to the current evidence regarding non-invasive testing in evaluation of chest pain in the acute settings. Potential higher efficiency with CCTA strategy should be balanced against consistently higher revascularisation rates without significant improvement in major adverse cardiac events.

Contributors CG contributed with data extraction, analysis, interpretation and drafting. CB contributed with data extraction, analysis and interpretation. SU contributed with drafting of the manuscript and revising it critically for important intellectual content. EA contributed with interpretation of data as well as drafting of the manuscript and revising it critically for important intellectual content. All authors approve the final version of the manuscript.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement This is a meta-analysis of randomised clinical trials. The data information for this paper is widely available to people with access to the information in each journal.

REFERENCES

1 Marwick TH, Cho I, Ó Hartaigh B, *et al*. Finding the Gatekeeper to the cardiac catheterization laboratory: coronary CT angiography or stress testing? *J Am Coll Cardiol* 2015;65:2747–56.
2 Agarwal V, Argulian E. Living up to the PROMISE: is there an Ultimate winner? *J Am Coll Cardiol* 2015;66:2267–8.
3 Moher D, Liberati A, Tetzlaff J, *et al*. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med* 2009;1519:264–9.
4 Goldstein JA, Gallagher MJ, O'Neill WW, *et al*. A randomized controlled trial of multi-slice coronary computed tomography for evaluation of acute chest pain. *J Am Coll Cardiol* 2007;49:863–71.
5 Higgins JP, Altman DG, Gøtzsche PC, *et al*.The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ* 2011;343:d5928.
6 Higgins JP, Thompson SG, Deeks JJ, *et al*. Measuring inconsistency in meta-analyses. *BMJ* 2003;327:557–60.
7 Linde JJ, Hove JD, Sørgaard M, *et al*. Long-Term clinical impact of coronary CT angiography in patients with recent Acute-Onset chest pain: the Randomized Controlled CATCH Trial. *JACC Cardiovasc Imaging* 2015;8:1404–13.
8 Litt HI, Gatsonis C, Snyder B, *et al*. CT angiography for safe discharge of patients with possible acute coronary syndromes. *N Engl J Med* 2012;366:1393–403.
9 Hollander JE, Gatsonis C, Greco EM, *et al*. Coronary Computed Tomography Angiography Versus traditional care: comparison of One-Year Outcomes and Resource Use. *Ann Emerg Med* 2016;67:460–8.
10 Dedic A, Lubbers MM, Schaap J, *et al*. Coronary CT angiography for suspected ACS in the era of High-Sensitivity Troponins: randomized Multicenter Study. *J Am Coll Cardiol* 2016;67:16–26.
11 Linde JJ, Kofoed KF, Sørgaard M, *et al*. Cardiac computed tomography guided treatment strategy in patients with recent acute-onset chest pain: results from the randomised, controlled trial: cardiac cT in the treatment of acute CHest pain (CATCH). *Int J Cardiol* 2013;168:5257–62.
12 Hamilton-Craig C, Fifoot A, Hansen M, *et al*. Diagnostic performance and cost of CT angiography versus stress ECG--a randomized prospective study of suspected acute coronary syndrome chest pain in the emergency department (CT-COMPARE). *Int J Cardiol* 2014;177:867–73.
13 Goldstein JA, Chinnaiyan KM, Abidov A, *et al*.The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Triage of Acute chest pain patients to treatment) trial. *J Am Coll Cardiol* 2011;58:1414–22.
14 Nabi F, Kassi M, Muhyieddeen K, *et al*. Optimizing evaluation of patients with Low-to-Intermediate-Risk acute chest pain: a Randomized Study comparing stress myocardial Perfusion Tomography Incorporating Stress-Only Imaging Versus cardiac CT. *J Nucl Med* 2016;57:378–84.
15 Uretsky S, Argulian E, Supariwala A, *et al*. Comparative effectiveness of coronary CT angiography vs stress cardiac imaging in patients following hospital admission for chest pain work-up: the prospective first evaluation in chest pain (PERFECT) Trial. *J Nucl Cardiol* 2016.
16 Levsky JM, Spevack DM, Travin MI, *et al*. Coronary Computed Tomography Angiography Versus Radionuclide Myocardial Perfusion Imaging in Patients with chest pain admitted to Telemetry: a Randomized Trial. *Ann Intern Med* 2015;163:174–83.
17 Hoffmann U, Truong QA, Schoenfeld DA, *et al*. Coronary CT angiography versus standard evaluation in acute chest pain. *N Engl J Med* 2012;367:299–308.
18 Timmis A, Roobottom CA. National Institute for Health and Care Excellence updates the stable chest pain guideline with radical changes to the diagnostic paradigm. *Heart* 2017;103:982–6.
19 Cremer PC, Nissen SE. The National Institute for Health and Care Excellence update for stable chest pain: poorly reasoned and risky for patients. *Heart* 2017;103:972–4.
20 Gould KL. Does coronary flow trump coronary anatomy? *JACC Cardiovasc Imaging* 2009;2:1009–23.
21 Shreibati JB, Baker LC, Hlatky MA. Association of coronary CT angiography or stress testing with subsequent utilization and spending among Medicare beneficiaries. *JAMA* 2011;306:2128–36.
22 Bittencourt MS, Hulten EA, Murthy VL, *et al*. Clinical outcomes after evaluation of stable chest pain by Coronary Computed Tomographic Angiography Versus Usual Care: a Meta-Analysis. *Circ Cardiovasc Imaging* 2016;9:e004419.
23 El-Hayek G, Benjo A, Uretsky S, *et al*. Meta-analysis of coronary computed tomography angiography versus standard of care strategy for the evaluation of low risk chest pain: are randomized controlled trials and cohort studies showing the same evidence? *Int J Cardiol* 2014;177:238–45.
24 Hulten E, Pickett C, Bittencourt MS, *et al*. Outcomes after coronary computed tomography angiography in the emergency department: a systematic review and meta-analysis of randomized, controlled trials. *J Am Coll Cardiol* 2013;61:880–92.
25 SCOT-HEART investigators. CT coronary angiography in patients with suspected angina due to coronary heart disease (SCOT-HEART): an open-label, parallel-group, multicentre trial. *Lancet* 2015;385:2383–91.
26 Jørgensen ME, Andersson C, Nørgaard BL, *et al*. Functional Testing or Coronary Computed Tomography Angiography in Patients With Stable Coronary Artery Disease. *J Am Coll Cardiol* 2017;69:1761–70.
27 Karthikeyan G, Guzic Salobir B, Jug B, *et al*. Functional compared to anatomical imaging in the initial evaluation of patients with suspected coronary artery disease:

An international, multi-center, randomized controlled trial (IAEA-SPECT/CTA study). *J Nucl Cardiol* 2017;24:507–17.
28 Rozanski A, Gransar H, Shaw LJ, *et al*. Impact of coronary artery calcium scanning on coronary risk factors and downstream testing the EISNER (Early identification of subclinical atherosclerosis by Noninvasive Imaging Research) prospective randomized trial. *J Am Coll Cardiol* 2011;57:1622–32.
29 Hecht HS, Narula J, Fearon WF. Fractional flow Reserve and Coronary Computed Tomographic Angiography: a Review and critical analysis. *Circ Res* 2016;119:300–16.

Heart

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