Clinical Radiology 74 (2019) 926–932

Contents lists available at ScienceDirect

Clinical Radiology

journal homepage: www.clinicalradiologyonline.net

# Post-mortem CT: is coronary angiography required in the presence of a high coronary artery calcium score?

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ARTICLE INFORMATION

*Article history:*
Received 23 December 2018
Accepted 14 June 2019

AIM: To test whether a high coronary artery score predicts that the subsequent post-mortem computed tomography (PMCT) with angiography (PMCTA) will diagnose significant coronary artery disease (CAD); to test the diagnostic impact of assuming there is significant CAD based on a high coronary artery calcium (CAC) score alone; and (3) to test whether the clinical CAC score threshold (400) is the most accurate to make this prediction.

MATERIALS AND METHODS: CAC scoring and PMCTA were performed in cases of adult sudden natural death. Angiography was reviewed to determine if there was sufficient CAD to give as the cause of death. Data were analysed to test whether high calcium score predicts significant CAD.

RESULTS: PMCTA with CAC score was successful in 100/104 PMCT examinations and in 87/100 angiography examinations (87%). Forty-six cases (46%) had a CAC score of >400, the clinical level of severe disease. CAD was given as the cause of death in 31 (67%) of these cases. Angiography was successful in 39 of these cases (84.7%) and showed severe CAD in all but one (97%). Twenty-five (25%) cases were diagnosed with a CAD death without a high CAC score.

CONCLUSION: Although CAC score can neither diagnose nor exclude death due to CAD, the addition of angiography adds little diagnostic information to a high CAC score. If PMCT investigation is to exclude trauma and provide a medical cause of death on the "balance of probabilities", angiography is not required when the calcium score >400. This could reduce the number of patients requiring angiography by almost 50%.



## Introduction

Coronary artery disease (CAD) is the most common cause of death (CoD) diagnosed when investigating sudden unexpected adult natural death. This diagnosis can be made using post-mortem computed tomography (PMCT) augmented by angiography (PMCTA)[1–4]; however, the addition of angiography to PMCT increases the cost and invasiveness of the procedure.

Coronary artery calcification (CAC) is related to atheromatous CAD. Evaluation of CAC using CT has been used clinically to predict the likelihood of an adverse cardiovascular disease (CVD) event. Scientific reports of the assessment of CAC in PMCT are generally limited to single case

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https://doi.org/10.1016/j.crad.2019.06.034
0009-9260/

studies[5,6] often considering plaque stability.[7,8] Traditionally measured with the Agatston score, the volume and density of calcification in the coronary arteries can be measured and a clinical risk ratio assigned.[9] A CAC score of >400 indicates a high likelihood of a future coronary event or at least one significant coronary stenosis.[10,11] Studies have also demonstrated that CAC is a predictor of death or myocardial infarction (MI) in both symptomatic and asymptomatic patients.[12–14] High calcium score is associated with higher event rate independent of other risk factors.[15] Calcium scoring can help plan intervention or treatment[16]; however, a low CAC score does not exclude significant pathology, as soft (non-calcified) plaque are at greater risk of rupture.[17] High-risk plaque associated with MI can be identified on CT images with features of positive remodelling as well as low attenuation plaques. These may also have areas of spotty calcification. The napkin ring sign may be present.[18] Furthermore, the development of calcification leading to a high CAC score does not always result in a negative event.[17,19]

CAC scoring of the deceased in cases of non-suspicious natural death could be considered differently where the CoD is required on the "balance of probabilities". The authors, and others, have hypothesised that if the presence of extensive CAC on PMCT is assumed to indicate significant CAD, the addition of PMCTA to the scan is unlikely to change this assumption. Some centres in England do not proceed to coronary PMCTA after PMCT if the CAC score is above a specified threshold, although there are currently no scientific studies to support this approach.

It is current local practice to perform targeted coronary artery PMCTA on all cases of natural, non-suspicious death where PMCT is requested by HM Coroner to diagnose the CoD on the balance of probabilities. This image data set allows assessment of CAC score, coronary PMCTA findings, and final CoD. The aims of this study were[1]: to test whether a high coronary artery score predicts that the subsequent PMCTA will diagnose significant CAD[2]; to test the diagnostic impact of assuming there is significant CAD based on a high CAC score alone; and[3] to test whether the clinical CAC score threshold (400) is the most accurate to make this prediction.

## Materials and methods

Sequential cases referred by HM Coroner for PMCT and targeted coronary PMCTA investigation of sudden unexpected death, without obvious unnatural or traumatic cause, were selected from the secure database. The data were reviewed under NHS service evaluation/clinical governance guidelines by the same team in the same secure environment that performed the original service image reports.

This retrospective study used the technique described by Agatston (1990)[9] as used in the authors' clinical cardiology practice. Scan reconstructions of the heart with a 3 mm thickness and interval were produced and the Agatston calcium score was measured on a Siemens Syngo.via workstation (Siemens Healthcare, Erlangen, Germany). This method identifies calcium as an area >1 $mm^2$ with a radiodensity ≥130 HU. The volume of calcification in each vessel on each section of the scan is multiplied by a "density-weighting factor", which reflects the plaques greatest density (130–199 HU, 200–299 HU, 300–399 HU and >400 HU, have weighting factors of 1, 2, 3, and 4 respectively). The score for each vessel is calculated and the total Agatston score is the summation of the individual vessels scores.

The scoring was completed by a radiographer experienced in PMCT after training on the Syngo.via workstation from a cardiac radiologist. The scoring software is semi-automated, highlighting all areas in the image with a density over the threshold value of 130 HU. The operator then confirms the specific areas of CAC manually. As part of training, 10 cases were audited by the training radiologist. Scoring for each case was done without reference to the PMCTA images, radiologist interpretation of the PMCTA and the final case report with CoD. The total CAC score and time taken was recorded for each case. CAC scores were graded to normal (score=0), mild (score=0.1–100), moderate (score=100–400) and severe (score >400) disease.

Coronary angiograms were reviewed based on the primary report and assessment of the images independent to the CAC score by a radiologist experienced in PMCT and PMCTA. The PMCTA were assessed based on luminal cross-sectional area for stenotic CAD within the following categories: no significant CAD, CAD present but insufficient as CoD, and CAD sufficient as CoD in the absence of other overt CoD.[2,20,21] Cases where PMCTA failed or was not of diagnostic quality were excluded.

In England and Wales, the CoD on the death certificate is given in two parts. Part 1 consists of up to three related pathologies or processes that have directly caused the death. Diseases or conditions that contributed to, but did not directly cause death, appear in part 2. A CoD was recorded for each case and assigned between categories (Table 1). A CoD related to CAD was given on the balance of probabilities based on the circumstances of death, the medical history, previous clinical imaging, the PMCT scan with targeted coronary angiography, any signs of previous ischaemic event (e.g., myocardial thinning or aneurysm), and the lack of any other visible CoD. As for previous studies using PMCTA, ischaemic heart disease (IHD), atheromatous/atherosclerotic CAD and acute MI as a direct result of CAD, were all classified as CAD as the CoD.[4]

Area under the curve (AUC) analysis of receiver operating characteristic (ROC) curves were produced for the CAC scores against angiographic coronary artery findings (SPSS 2016 version 24, IBM, New York, NY, USA) to ascertain the most accurate score threshold to predict severe luminal stenotic CAD and review sensitivity and specificity at different thresholds with 95% confidence intervals (95% CI). Statistical comparison of accuracy for different thresholds used Fisher's exact test.

**Table 1**
Primary cause of death ascertained using post-mortem computed tomography as recorded in part 1 of the death certificate.

| System causing death | Causes of death | Frequency | CAC category |
|---|---|---|---|
| Coronary artery disease ($n$=56) | Ischaemic heart disease | 36 | Normal = 3 |
| | Coronary atherosclerosis/vascular disease | 9 | Mild = 10 |
| | Hypertensive and ischaemic heart disease | 6 | Mod = 12 |
| | Myocardial infarction/rupture due to CAD | 3 | Severe = 31 |
| | Ischaemic and valvular disease | 2 | |
| Non-coronary heart ($n$=7) | Cor pulmonale | 2 | Normal = 1 |
| | Cardiomegaly | 1 | Mild = 3 |
| | Cardiomyopathy | 1 | Mod = 2 |
| | Congestive cardiac failure due to chest infection and chronic pulmonary thromboembolism | 1 | Severe = 1 |
| | Aortic stenosis and left ventricular hypertrophy | 1 | |
| | Left ventricular hypertrophy | 1 | |
| Respiratory system ($n$=13) | Pneumonia or bronchopneumonia | 12 | Normal = 2 |
| | Asthma | 1 | Mild = 5 |
| | | | Mod =2 |
| | | | Severe = 4 |
| Vascular system ($n$=10 | Ruptured aneurysms | 5 | Normal = 2 |
| | Dissecting aneurysms | 5 | Mild = 0 |
| | | | Mod = 2 |
| | | | Severe =6 |
| Other ($n$=14) | Intracranial bleeds | 5 | Normal = 3 |
| | Pulmonary thromboembolism | 3 | Mild = 3 |
| | Acute renal failure due to chronic kidney disease diabetes mellitus and hypertension | 1 | Mod = 4 |
| | | | Severe = 4 |
| | Gastrointestinal bleed | 1 | |
| | Large bowel perforation | 1 | |
| | Alzheimer's disease | 1 | |
| | Cancer | 1 | |
| | Unascertained after autopsy | 1 | |

CAD, coronary artery disease.

## Results

One hundred and four sequential cases were identified from the database. Four cases were excluded due to significant metal artefact from pacing wires or sternal wiring making CAC score impossible. This left 100 study cases: 56 men and 44 women, age range 36–96 years (mean 74 years). PMCTA was successful in 87 (87%) of these cases. Failure was mainly due to due to misplacement of the PMCTA catheter.

The radiologist agreed with the radiographer's CAC scoring in the 10 audited cases. The CAC scoring took an average of 2 minutes (range <1–11 minutes). Cases with grafts and complex anatomy took the longest. The frequency of the CAC grades and the range of CAC scores are given in Fig 1 and ranged from 0 to 3778 (mean 668).

The causes of death (CoD) are given in Table 1. Fifty-six cases had CAD as the CoD. Forty-six cases (46%) had a severe CAC score of which 31 (67%) had a CAD-related CoD. Twenty-five (25%) cases were diagnosed with a CAD death without a high CAC score, due to a combination of medical history, clinical record of event, and PMCTA where successful. No CoD was found on PMCTA in one case and was still unascertained after autopsy, histology, and toxicology. The CAC score was 0.

PMCTA analysis in relation to CAC score is shown in Table 2. Thirteen cases were excluded due to non-diagnostic angiograms. These cases generally had a high CAC score, which is not surprising because increasing peripheral vascular calcification can make cannulation more difficult. Of the 62 cases with sufficient CAD to give as a CoD (regardless of actual CoD) as diagnosed by luminal stenoses on PMCTA, the mean CAC score was 915 (range 0–3,778) and 21 had a score in excess of 1,000. In 76% (47/62) of these cases, CAD was given as the final CoD, and in 15 cases (24%) a non-coronary CoD was given, based on clinical history and clear significant non-coronary PMCT findings, including ruptured aneurysm, intra-cerebral haemorrhage, and pneumonia. In 24 of the 62 cases (39%) with significant CAD diagnosed on PMCTA, the CAC score was <400.

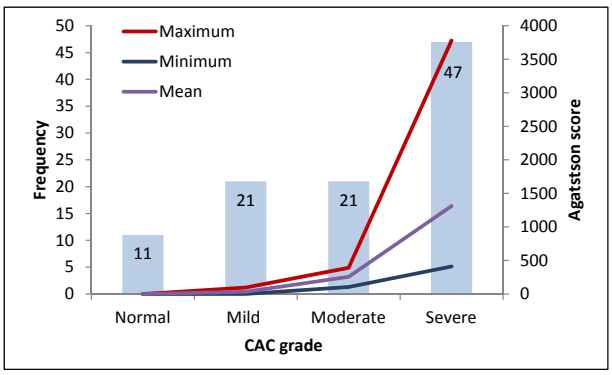


**Figure 1** Frequency of CAC grades and the range of the scores.

**Table 2**
Coronary artery calcium (CAC) score for the post-mortem computed tomography with angiography (PMCTA) analysis categories.

| CAC score | PMCT analysis category | | | | Total |
|---|---|---|---|---|---|
| | Excluded | No significant CAD | CAD but insufficient for CoD | Sufficient CAD to give as CoD | |
| 0 | 3 | 6 | 0 | 2 | 11 |
| 1–100 | 3 | 4 | 7 | 7 | 21 |
| 101–400 | 2 | 0 | 5 | 15 | 22 |
| 400+ | 7 | 0 | 1 | 38 | 46 |
| Total | 15 | 10 | 13 | 62 | 100 |

CoD, cause of death; CAD, coronary artery disease.

Table 3 is a simplified version of Table 2 showing that, although significant luminal CAD may be present with low CAC score, only one case with CAC score >400 (CAC score = 478) was assessed as having "insufficient luminal disease to confidently give as a CoD" on PMCTA. The CoD in this case was cor pulmonale and chronic obstructive pulmonary disease based on imaging findings and clinical history.

As expected, increasing artery calcification is significantly associated with increased luminal stenotic disease (chi squared test $p$=0.001, Table 3). The data therefore show that, although only 76% of cases with a high CAC score have a CAD CoD, the presence of a CAC score >400 predicts significant CAD with a specificity of 97.4%.

If a decision not to perform PMCTA at a CAC score of ≥400 was made, assuming the PMCTA would show significant CAD, this would result in 47/100 fewer angiograms in this series. All cases had at least moderate CAD, but 1/39 (2.6%) of these cases (with a CAC score of 478) would have been incorrectly assumed to have sufficient CAD as CoD based on subsequent PMCTA (95% confidence interval 0 to 5 cases). This case had clear clinical history and imaging signs to support cor pulmonale and chronic obstructive pulmonary disease as the CoD; however, CAD may have been added to the part 2 of their death certificate based on CAC scoring alone.

ROC analysis showed a cut-off CAC score of 197 had the best accuracy to predict significant CAD, increasing from 70.6% (95% CI: 59.7–80%) to 87.1%, (95% CI: 78–93.4%; p=0.014, chi-squared test). Using this threshold would increase sensitivity from 61.3% to 85.5%, but at a cost of one extra false-positive case. Increasing the threshold to predict severe CAD to 500 increases the specificity from 95.7% (95% CI: 78.1–99.9%) to 100% (95% CI: 85.2–100%), but this is not statistically significant.

## Discussion

This study shows that a high CAC score does not diagnose CAD as the CoD; however, if there is significant CAC, as demonstrated by a CAC (Agatston) score of >400, the subsequent targeted coronary PMCTA will demonstrate significant CAD in 97.4% cases, and that CAD will likely be given as the CoD unless there is a clear alternative cause based on the clinical history and PMCT findings.

This suggests that, in cases where there are no suspicious circumstances or findings and the main purpose of the post-mortem investigation is to provide a medical CoD on a balance of probabilities, it is appropriate not to proceed to PMCTA in order to reduce the cost and invasiveness of the procedure. This would result in reducing the number of targeted coronary angiograms by nearly 50%. The need for coronary PMCTA could be reduced further if a clear non-coronary CoD is recognised during scanning, for example cerebral haemorrhage, ruptured aortic aneurism, or gastrointestinal tract perforation. This could have a significant impact on practice in England and Wales, where in 2017 there were 85,552 HM Coroner post-mortem examinations performed to investigate death, with the majority (71%) being sudden adult deaths without obvious unnatural cause. These HM Coroner statistics also show increasing use of PMCT and PMCTA to replace autopsies.[22]

This is a different logic to the use of CAC scoring clinically. The present data support the clinical approach that, although there is strong correlation between CAC score and clinical outcome,[23] the score cannot definitely predict this outcome; however, for PMCT a high CAC score should not be used to diagnose cardiac death, simply that it is indicative of significant CAD which, in the absence of any other overt CoD, could lead us to diagnose a cardiac death "on the balance of probabilities". Although this paper supports the use of CAC testing to give a CoD in PMCT, the present data do not add to the large studies studying the relationship of CAC to coronary events and significant coronary disease in the living.

For the present data, reducing the CAC score threshold from 400 to 197 increases accuracy, but at a reduction in specificity. Specificity is the most important factor, as an

**Table 3**
Table using a threshold coronary artery calcium (CAC) score of 400 to predict post-mortem computed tomography with angiography (PMCTA) demonstrating sufficient stenotic disease as a cause of death (CoD; chi-squared test $p$<0.001).

| CAC score | Angiography result | | Total |
|---|---|---|---|
| | Insufficient CAD to give as CoD | Sufficient CAD to give as COD | |
| 0–400 | 22 | 24 | 46 |
| 400+ | 1 | 38 | 39 |
| Total | 23 | 62 | 85 |

CAD, coronary artery disease.

incorrect assumption of CAD may lead to an incorrect CoD, whereas false negatives (sensitivity failure) would lead to more diagnostic angiograms being performed but would not change the outcome. Furthermore, there is inherent variability in CAC measurement, which increases for lower scores [16], meaning that the cut-off value needs to be higher than the most accurate value to preserve specificity. Increasing the cut-off to 500 would increase specificity, but not statistically significantly. The present data therefore do not support a change from the established clinical cut-off of 400 for significant CAD.

Using the CAC score to reduce the number of angiograms performed depends on logistics, availability of trained staff, and practical challenges. Currently, in the interests of efficiency locally, bodies are prepared for PMCTA in the mortuary prior to the scan. In order to maximise savings and reduce intervention, cannulation would ideally only occur after the initial PMCT examination has been performed and reviewed. This depends on staff being present who can assess the scan for CAC, confidently review for a clear non-coronary CoD, and perform the cannulation. Training staff to do this is feasible, and this is already achieved in some centres, but mainly in purpose-built mortuary-based scanners, rather than services that use clinical scanners outside standard clinical hours.[24] This triage approach has been suggested previously and a possible process is suggested in Fig 2.

There are weaknesses to the present study. Although PMCTA will identify significant non-calcified vessel occlusions where there is low calcification, blooming artefacts can cause an artificially high calcium score from areas of dense calcification outside the vessels, metal implants, coronary stents, and pacing wires; however, these problems can be recognised with training, and it is arguable that the presence of coronary artery stents, although often patent on PMCTA, imply the presence of CAD, and therefore have the same implication to the "balance of probabilities" as a high CAC score. Small areas of high density due to the partial volume may artificially increase the Agatston score. This can be exacerbated by the weighting system for the maximum density in a plaque. Other methods, such as the volume of calcification, have also been found to be strong predictors of negative outcomes,[17,25–29] but the Agatston score is still the most widely used. The location and pattern of the calcified plaque should also be considered. A small area of calcification at a vessel ostium may have a low score, but could have a large physiological effect as the calcified area may only account for 20% of the total plaque burden.[30] A further

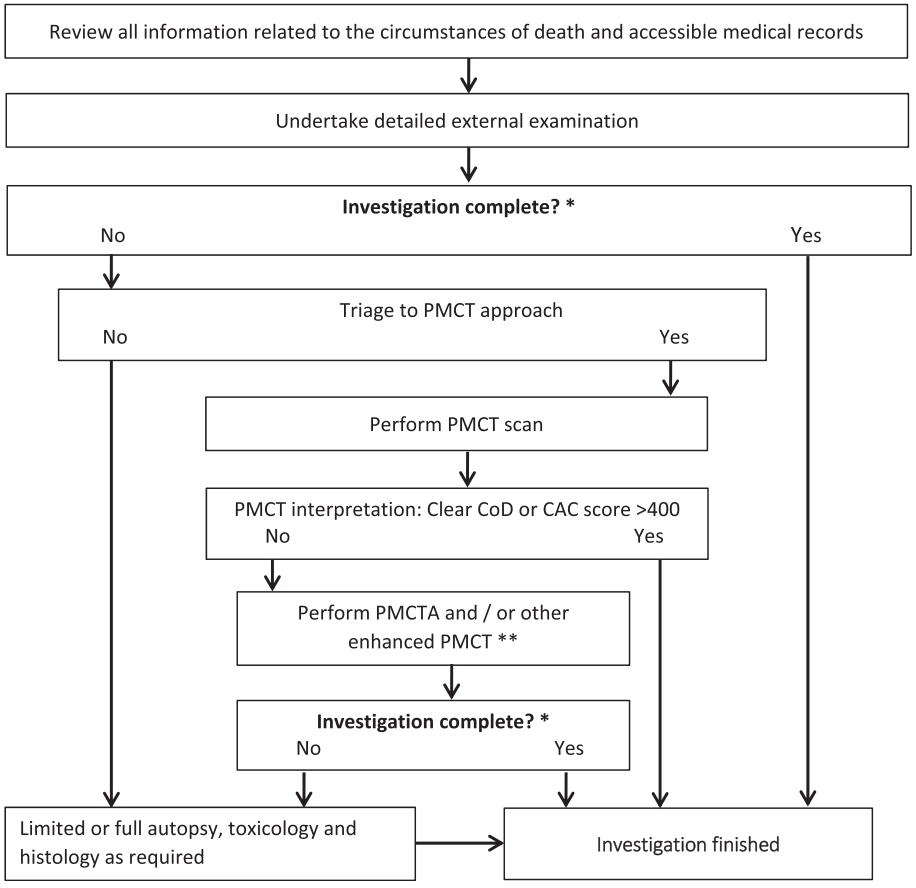


**Figure 2** Flow chart showing proposed triage process for the use of computed tomography in post-mortem investigation. Footnotes: * The investigation is complete when all relevant questions have been answered to the level of evidence required by the investigating authority e.g. HM Coroner, police etc. ** Further PMCT enhancements include multiphase PMCT angiography (MPPMCTA)[15] and ventilated (V)PMCT.[25] CoD = Cause of death, CAC = Coronary artery calcium score.

problem is that the evaluation of the vessel luminal patency on PMCTA cannot be performed "blind" to the level of mural calcification. This may inherently bias the reader to diagnose "significant" luminal stenotic disease on PMCTA, which they may have called "moderate or less" in the absence of heavy calcification; however, this bias is not specific to PMCT and may also occur at autopsy, particularly as difficulties in cutting heavily calcified vessels may give an exaggerated appearance of stenosis on macroscopic inspection at autopsy.[20]

The case with high CAC score in this study, but only moderate disease on PMCTA, had an alternate diagnosis based on unenhanced PMCT; however, in the wider population there will be further cases where not proceeding to PMCTA in the presence of a CAC score >400 could give an incorrect CAD CoD when the actual CoD is occult to PMCT; for example, in some cases of pulmonary thromboembolism. This is an inherent problem to PMCT and post-mortem investigation in general, where every technique in isolation has strengths and weaknesses. Where the results of a post-mortem investigation are considered of the highest importance, it is now becoming clear that the reference standard of post-mortem investigation is the combination of PMCT, PMCTA, and autopsy with any necessary ancillary laboratory tests.[24] It is also recognised that by adopting this approach, evaluation of other areas of the heart, such as the myocardial thickness or perfusion, would be more difficult.

It is acknowledged that this approach may not be as relevant in countries with a lower rate of post-mortem investigation for non-suspicious natural death than in England and Wales. It could, however, help decision-making processes where PMCTA is not routinely used for PMCT.

In conclusion, for cases of non-suspicious natural death, where the reason for investigation is to provide a medical CoD on a balance of probabilities, by assuming that a measured CAC score >400 predicts the presence of significant CAD, the number of minimally invasive catheterisations and angiograms could be reduced by approximately 50%, without significantly altering the given CoD.

## Conflict of interest

The authors declare no conflict of interest.

## Acknowledgments

This report is independent research arising from a Clinical Doctoral Research Fellowship supported by the National Institute for Health Research and Health Education England. The views expressed in this publication are those of the authors and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health.

## References

1. Grabherr S, Doenz F, Steger B, *et al*. Multi-phase post-mortem CT angiography: development of a standardized protocol. *Int J Leg Med* 2011;**125**(6):791–802.
2. Roberts ISD, Benamore RE, Peebles C, *et al*. Diagnosis of coronary artery disease using minimally invasive autopsy: evaluation of a novel method of post-mortem coronary CT angiography. *Clin Radiol* 2011;**66**(7):645–50.
3. Saunders SL, Morgan B, Raj V, *et al*. Targeted post-mortem computed tomography cardiac angiography: proof of concept. *Int J Leg Med* 2011;**125**(4):609–16.
4. Rutty G, Morgan B, Robinson C, *et al*. Diagnostic accuracy of post-mortem CT with targeted coronary angiography versus autopsy for coroner-requested post-mortem investigations: a prospective, masked, comparison study. *Lancet* 2017;**390**(10090):145–54.
5. Rusu C, Cuzino D, Dermengiu D, *et al*. Coronary artery calcium scoring in post mortem specimens. Methoc report. *Rom J Leg Med* 2009;**4**:271–6.
6. Wan L, Zhang J, Huang P, *et al*. Assessment of a sudden death case due to coronary artery disease based on the PMCT and forensic autopsy. *Fa Yi Xue Za Zhi* 2012;**28**(5):379–82.
7. Norizal N, Faizuddin R, Singh M, *et al*. Coronary artery calcium scoring on post mortem computed tomography is strongly associated with coronary atherosclerotic plaque stability [abstract]. *Malay J Pathol* 2013;**35**(2):198.
8. Moss A, Adamson J, Newby D, *et al*. Vulnerable plaque detection in sudden cardiac death: post-mortem CT coronary angiography. *Heart* 2018;**104**(Suppl. 5):A4.
9. Agatston A, Janowitz W, Hildner F, *et al*. Quantification of coronary artery calcium using ultrafast computed tomography. *J Am Coll Cardiol* 1990;**15**(4):827–32.
10. Budoff M, Nasir K, McClelland R, *et al*. Coronary calcium predicts events better with absolute calcium scores than age-gender-race percentiles — the Multi-ethnic Study of Atherosclrosis (MESA). *J Am Coll Cardiol* 2009;**53**(4):245–352.
11. Rumberger J, Brumage B, Rader D, *et al*. Electron beam computed tomographic coronary calcium scanning: a review and guidelines for use in asymptomatic persons. *Mayo Clin Proc* 1999;**74**:243–52.
12. Shah S, Bellam N, Leipsic J, *et al*. Prognostic significance of calcified plaque among symptomatic patients with nonobstructive coronary artery disease. *J Nucl Cardiol* 2014;**21**(3):453–66.
13. Shaw LJ, Giambrone AE, Blaha MJ, *et al*. Long-term prognosis after coronary artery calcification testing in asymptomatic patients: a cohort study. *Ann Intern Med* 2015;**163**:14–21.
14. Takamura K, Fujimoto S, Kondo T, *et al*. Incremental prognostic value of coronary computed tomography angiography: high-risk plaque characteristics in asymptomatic patients. *J Atheroscler Thromb* 2017;**24**(11):1174–85.
15. Silverman MG, Blaha MJ, Krumholz HM, *et al*. Impact of coronary artery calcium on coronary heart disease events in individuals at the extremes of traditional risk factor burden: the Multi-Ethnic Study of Atherosclerosis. *Eur Heart J* 2014;**35**(33):2232–41.
16. European Society of Cardiology. Guidelines on the management of stable coronary artery disease. *Eur Heart J* 2013;**34**:2949–3003.
17. Criqui M, Denenberg J, Ix J, *et al*. Calcium density of coronary artery plaque and risk of incident cardiovascular events. *J Am Med Assoc* 2014;**311**(3):271–8.
18. Williams MC, Moss AJ, Dweck M, *et al*. Coronary artery plaque characteristics associated with adverse outcomes in the SCOT-HEART study. *J Am Coll Cardiol* 2019;**73**(3):291–301.
19. Virmani R, Burke A, Farb A, *et al*. Pathology of the vulnerable plaque. *J Am Coll Cardiol* 2005;**47**(Suppl. 8):C13–8.
20. Morgan B, Biggs M, Barber J, *et al*. Accuracy of targeted post-mortem computed tomography coronary angiography compared to assessment of serial histology sections. *Int J Leg Med* 2013;**127**(4):809–17.
21. Michaud K, Grabherr S, Doenz F, *et al*. Evaluation of postmortem MDCT and MDCT-angiography for the investigation of sudden cardiac death related to atherosclerotic coronary artery disease. *Int J Cardiovasc Imaging* 2012 Oct;**28**(7):1807–22.
22. Ministry of Justice. *Coroners statistics 2017*. 2018. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/706052/coroners-statistics-bulletin-2017.pdf. [Accessed 18 August 2018].
23. Budoff M, Shaw L, Liu S, *et al*. Long-term prognosis associated with coronary calcification observations from a registry of 25,253 patients. *J Am Coll Cardiol* 2007;**49**(18):1860–70.

24. Grabherr S, Heinemann A, Vogel H, *et al*. Postmortem CT angiography compared with autopsy: a forensic multicenter study. *Radiology* 2018;**288**(1):270–6.
25. Criqui M, Knox J, Denenberg J, *et al*. Coronary artery calcium volume and density. Potential interactions and overall predictive value: the multi-ethnic study of atherosclerosis. *J Am Coll Cardiol Cardiovasc Imaging* 2017;**10**(8):845–54.
26. Chiles C, Duan F, Gladish G, *et al*. Association of coronary artery calcification and mortality in the national lung screening trial: a comparison of three scoring methods. *Radiology* 2015;**276**(1):82–90.
27. Shemesh J, Henschke C, Shaham D, *et al*. Ordinal scoring of coronary artery calcifications on low-dose CT scans of the chest is predictive of death from cardiovascular disease. *Radiology* 2010; **257**(2):541–8.
28. Brown E, Kronmal R, Bluemke D, *et al*. Coronary calcium coverage score: determination, correlates, and predictive accuracy in the Multi-Ethnic Study of Atherosclerosis. *Radiology* 2008;**247**(3): 669–75.
29. Callister TQ, Cooil B, Raya SP, *et al*. Coronary artery disease: improved reproducibility of calcium scoring with an electron-beam CT volumetric method. *Radiology* 1998;**208**(3):807–14.
30. Rumberger J, Simons D, Fitzpatrick L, *et al*. Coronary artery calcium area by electron-beam computed tomography and coronary atherosclerotic plaque area. *Circulation* 1995;**92**:2157–62.