A simple coronary CT angiography-based jeopardy score for the identification of extensive coronary artery disease: Validation against invasive coronary angiography

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Abstract: PURPOSE The invasive British Cardiovascular Intervention Society Jeopardy Score (iBCIS-JS) is a simple angiographic scoring system, enabling quantification of the extent of jeopardized myocardium related to clinically significant coronary artery disease (CAD). The purpose of this study was to develop and validate the coronary CT angiography-based BCIS-JS (CT-BCIS-JS) against the iBCIS-JS in patients with suspected or stable CAD. MATERIALS AND METHODS Patients who underwent coronary CT angiography followed by invasive coronary angiography, within 90 days were retrospectively included. CT-BCIS-JS and iBCIS-JS were calculated, with a score ≥ 6 indicating extensive CAD. Correlation between the CT-BCIS-JS and iBCIS-JS was searched for using Spearman's coefficient, and agreement with weighted Kappa (κ) analyses. RESULTS A total of 122 patients were included. There were 102 men and 20 women with a median age of 62 years (Q1, Q3: 54, 68; age range: 19-83 years). No differences in median CT-BCIS-JS (4; Q1, Q3: 0, 8) and median iBCIS-JS (4; Q1, Q3: 0, 8) were found (P = 0.18). Extensive CAD was identified in 53 (43.4%) and 52 (42.6%) patients using CT-BCIS-JS and iBCIS-JS, respectively (P = 0.88). CT-based and iBCIS-JS showed excellent correlation (r = 0.98; P < 0.001) and almost perfect agreement (κ = 0.93; 95% confidence interval: 0.90-0.97). Agreement for identification of an iBCIS-JS ≥ 6 was almost perfect (κ = 0.94; 95 % confidence interval: 0.87-0.99). CONCLUSION The CT-BCIS-JS represents a feasible, and accurate method for quantification of CAD, with capabilities not different from those of iBCIS-JS. It enables simple, non-invasive identification of patients with anatomically extensive CAD.

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Original article

A simple coronary CT angiography-based jeopardy score for the identification of extensive coronary artery disease: Validation against invasive coronary angiography

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ABSTRACT

Purpose: The invasive British Cardiovascular Intervention Society Jeopardy Score (iBCIS-JS) is a simple angiographic scoring system, enabling quantification of the extent of jeopardized myocardium related to clinically significant coronary artery disease (CAD). The purpose of this study was to develop and validate the coronary CT angiography-based BCIS-JS (CT-BCIS-JS) against the iBCIS-JS in patients with suspected or stable CAD.
Materials and methods: Patients who underwent coronary CT angiography followed by invasive coronary angiography, within 90 days were retrospectively included. CT-BCIS-JS and iBCIS-JS were calculated, with a score ≥ 6 indicating extensive CAD. Correlation between the CT-BCIS-JS and iBCIS-JS was searched for using Spearman's coefficient, and agreement with weighted Kappa (κ) analyses.
Results: A total of 122 patients were included. There were 102 men and 20 women with a median age of 62 years (Q1, Q3: 54, 68; age range: 19–83 years). No differences in median CT-BCIS-JS (4; Q1, Q3: 0, 8) and median iBCIS-JS (4; Q1, Q3: 0, 8) were found ($P = 0.18$). Extensive CAD was identified in 53 (43.4%) and 52 (42.6%) patients using CT-BCIS-JS and iBCIS-JS, respectively ($P = 0.88$). CT-based and iBCIS-JS showed excellent correlation ($r = 0.98$; $P < 0.001$) and almost perfect agreement ($\kappa = 0.93$; 95% confidence interval: 0.90–0.97). Agreement for identification of an iBCIS-JS ≥ 6 was almost perfect ($\kappa = 0.94$; 95 % confidence interval: 0.87–0.99).
Conclusion: The CT-BCIS-JS represents a feasible, and accurate method for quantification of CAD, with capabilities not different from those of iBCIS-JS. It enables simple, non-invasive identification of patients with anatomically extensive CAD.

1. Introduction

Non-invasive cardiac imaging is increasingly being used in the diagnostic workup of suspected or stable coronary artery disease (CAD) [1,2]. Largely, this trend pertains to a surge in coronary computed tomography angiography (CCTA) examinations that is currently recommended by guidelines as an initial diagnostic test in patients with a low-to-intermediate clinical likelihood for obstructive CAD [3]. Although historically invasive coronary angiography (ICA) is considered the backbone of coronary stenosis severity assessment, advances in CCTA technologies have significantly improved its performance in ruling out angiographically significant CAD. The accuracy of stenosis quantification with CCTA nevertheless does not reach that of the reference standard and overestimation of stenoses might lead to increased downstream tests, primarily ICA [4,5].

Moving away from merely luminal stenosis assessment, several angiographic scoring systems have been developed to evaluate the global atherosclerotic burden and the complexity of CAD, predominantly using ICA but also using CCTA [6–8]. The invasive and CT-based synergy between PCI with TAXUS and Cardiac Surgery (SYNTAX) scores I and II, although complex to calculate in daily practice

Abbreviations: BMI, Body mass index; CAC, Coronary artery calcium; CAD, Coronary artery disease; CI, Confidence interval; ICA, Invasive coronary angiography; CTA, Computed tomography angiography; CCTA, Coronary computed tomography angiography; CABG, coronary artery bypass graft; CT-BCIS-JS, CT-based British Cardiovascular Intervention Society Jeopardy Score; CT-FFR, CT-based fractional flow reserve; EAPCI, European Association of Percutaneous Coronary Intervention; HU, Hounsfield unit; iBCIS-JS, Invasive British Cardiovascular Intervention Society Jeopardy Score; LV, Left ventricle; mSv, Millisievert; SCCT, Society of Cardiovascular Computed Tomography; SD, Standard deviation; SYNTAX, Synergy between PCI with TAXUS and cardiac surgery

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and with a moderate inter-observer agreement, have been shown to be independent predictors of major cardiac events and are used to guide coronary revascularization [9,10]. Calculation of the SYNTAX scores, however, needs multiple anatomical variables potentially explaining the moderate degree of agreement between invasive- and CT-SYNTAX scores [11].

The invasive British Cardiovascular Intervention Society Jeopardy Score (iBCIS-JS) is a simpler angiographic scoring system, enabling quantification of the extent of the myocardium at risk rather than merely the anatomic complexity [12]. Ranging from 0 (no significant CAD) to 12 (CAD jeopardizing the whole LV-myocardium), the score can be used for the entire spectrum of CAD including left main coronary artery disease and lesions at the level of a coronary artery bypass graft (CABG) disease and holds prognostic value following revascularization [13]. A score of ≥ 6 identifies patients with anatomically extensive (high-risk) CAD and non-invasive, standardized and reproducible identification of this group might be valuable for the selection of the optimal management approach [14].

The purpose of this study was to assess the feasibility and reproducibility of the CT-based BCIS-JS in patients with suspected or stable CAD and to validate the score against the reference iBCIS-JS.

2. Material and methods

2.1. Study population

The study protocol was approved by the local ethics committee (BASEC-Nr. 2018-00508) and only patients with signed informed consent were included. The electronic health records were searched in order to identify consecutive patients who underwent cardiac CT examination and an ICA within 90 days at the University Hospital Zurich during the period from December 2014 to October 2021. Patients who underwent cardiac CT without the indication of CAD assessment (*i.e.*, planning CT for structural interventions) were excluded. A total of 143 patients were identified and 15 of them had to be excluded for further analysis accounting for non-retrievable CCTA data (n = 1), presence of coronary stents (n = 4) and for CT examinations performed without nitroglycerine and beta-blockers (structural heart disease intervention planning CT; n = 10). Prior to calculation of the CT-BCIS-JS, two readers (J.S. and A.A.G.) with several years of experience in cardiovascular imaging assessed the image quality of the CCTA data on a dedicated workstation (CardIQ Xpress-Auto Coronary Analysis, GE Healthcare) in consensus using a five-point Likert scale, as follows: 1: non-diagnostic (severe artifacts), 2: poor (pronounced artifacts or low contrast), 3: fair (moderate artifacts), 4: good (mild artifacts), 5: excellent (absence of artifacts). A total of six patients with a score Likert score of 1–2 were excluded and the final population included 122 patients (n = 5 with Likert score of 3, n = 17 with Likert score of 4 and n = 100 with Likert score of 5). Fig. 1 depicts the flowchart of the selection of patients. Electronic health records were also reviewed to record the demographic and clinical characteristics for the included patients at the time of the CCTA, including: weight, height, and body mass index (BMI); risk factors for CAD, presence of symptoms, and use of medication. All CCTA and ICA datasets were exported from PACS and pseudo-anonymized for further analysis.

2.2. CCTA examinations

Both unenhanced CT scans for coronary artery calcium (CAC) scoring and CCTA were performed using a 256-section CT scanner (Revolution CT, GE Healthcare,) using prospectively electrocardiogram (ECG)–triggered axial mode. CT scanning parameters for CAC scoring included 2.5 mm slice thickness, 120 kVp tube voltage, and 200 mAs tube current. CAC was calculated on a dedicated workstation using a commercially available semiautomatic software package (SmartScore, GE Healthcare).

CCTA was performed, as previously described [15]. Briefly, patients with a heart rate > 65 beats per minute received up to 30 mg of metoprolol (Beloc®, AstraZeneca) intravenously and all patients received 2.5 mg of sublingual isosorbide dinitrate (Isoket®, Schwarz Pharma). Tube current and voltage were adapted based on BMI. Similarly, a BMI-adapted contrast agent volume/flow rate protocol was employed. Iodixanol® (Visipaque 320, 320 mg/mL, GE Healthcare) was injected into an antecubital vein, followed by a 50 mL saline solution, and the total volume of contrast agent used was recorded. In patients with CABG, CCTA examinations were performed with additional 20 mL of contrast agent. CCTA images were generated from a 1-beat wide-cone cardiac axial acquisition, at 75% of the R-R interval, with the following parameters: z-coverage 12–16 cm, collimation 256 × 0.625 mm and gantry rotation time of 280 ms. The effective radiation dose for CCTA was determined by the dose length product (DLP) multiplied with a conversion factor (0.014 $mSv \times mGy^{-1} \times cm^{-1}$).

2.3. CT-based BCIS-JS analysis

CCTA images were assessed using dedicated software (CardIQ Xpress-Auto Coronary Analysis, GE Healthcare) by a board-certified radiologist (J.S.) with four years of experience in cardiac imaging, who was blinded to the results of the ICA. For the calculation of CT-BCIS-JS, an online calculator was developed and utilized (https://www.ct-bcis-js.com/). Fig. 2 depicts the flowchart for the score calculation. The investigator used axial, multiplanar reformatted images, maximum-intensity projection, and cross-sectional views and the coronary arteries were assessed for the presence and localization of lesions, while the visual degree of luminal stenosis was recorded. For the definition of the coronary segments, the 18-segment model of the Society of Cardiovascular Computed Tomography (SCCT) was used [16]. The CT-based jeopardy score was calculated on-site, assigning points only to coronary or graft conduits with lesions of ≥ 70% luminal stenosis, except for left main artery lesions whereby a luminal stenosis ≥ 50% was considered significant [12,13]. Conceptually based on the Duke jeopardy score [17], for the BCIS-JS the left ventricular myocardium is divided into six territories (subtended by a. the left anterior descending artery, b. diagonal branch, c. left circumflex artery, d. obtuse marginal branch, e. right coronary artery and f. posterior descending artery) and each of them is assigned with two points. Two points are assigned to each lesion plus two additional points if the lesion affects two of the six downstream territories. The summation of each partial score provides the total score that ranges from a minimum of 0 to a maximum of 12. When multiple branches arise from a main artery, only lesions in the branch artery supplying the largest territory are scored. Coronary artery dominance is determined depending on the left or right coronary system that supplied the posterior descending branch. In the right dominant systems, the proximal circumflex artery was scored as a major obtuse marginal branch. For true anatomic co-dominance, the right coronary artery was considered dominant for scoring. In patients with CABG, the native coronary arteries were scored and points were then deducted for patent grafts to these territories, where applicable. The time for the calculation of the score was recorded.

An additional cardiologist (A.A.G.), with eight years of post-training experience in cardiac CT, similarly assessed the CT-BCIS-JS in a subset of 49 randomly selected patients. In addition, the first investigator (J.S.) repeated the CT-BCIS-JS assessment in 37 randomly selected patients, eight weeks after completion of the baseline CT-BCIS-JS calculation.

2.4. Invasive coronary angiography and invasive BCIS-JS analysis

Clinically indicated ICA was performed according to current standards and guideline recommendations, either via the femoral or radial approach [9]. Analysis of the invasive coronary angiographies

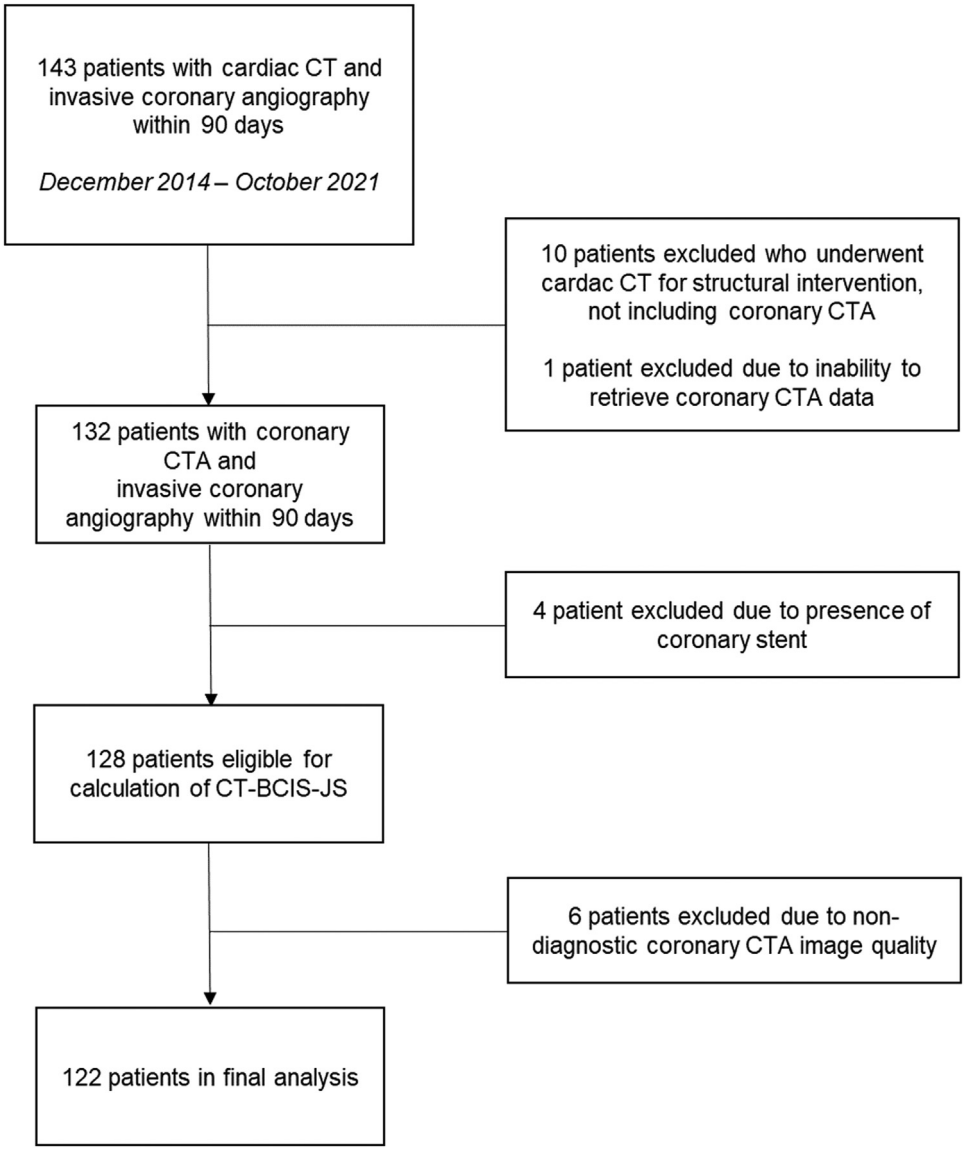

Fig. 1. Study flowchart of patient selection. CTA indicates computed tomography angiography. CT-BCIS-JS indicates coronary CTA-based British Cardiovascular Intervention Society jeopardy score.

was performed using dedicated software (Synedra, Synedra Schweiz AG) by a European Association of Percutaneous Coronary Intervention (EAPCI) board-certified interventional cardiologist (A.C.) with five years of experience in interventional cardiology, who was blinded to the results of the CCTA. iBCIS-JS was calculated with visual assessment of the invasive coronary angiograms using all available projections and as previously described [12]. To estimate ICA radiation dose, the total fluoroscopy time as a surrogate for total effective radiation dose was used and converted from the dose-area product to effective radiation dose using a conversion factor of 0.22 mSv/(Gy×cm^2) [18]. The total volume of iodinated contrast use was extracted from the ICA report.

2.5. Statistical analysis

Normality was assessed with D'Agostino-Pearson test. Continuous variables with normal distribution were presented as means ± standard deviations (SD) and ranges and non-normally distributed variables as medians, inter-quartile range (Q1, Q3) and ranges [min - max]. Categorical variables were presented as percentages [19]. Chi-squared test was used for comparing categorical variables, while Student test (or Wilcoxon tests as appropriate) for continuous ones. Spearman rank correlation coefficient (r) was used to assess the correlation between total CT-BCIS-JS and total iBCIS-JS. The agreement analysis between the two scores was performed using Cohen weighted kappa (κ) for ordinal data at the level of the total scores for a given patient. Similarly, κ analysis was employed for the agreement between the two total scores in detecting extensive CAD using a binary cut-off value of 6 or more defining extensive CAD.

Correlation and agreement analyses for the total scores were also performed stratifying the cohort according to the total CAC score [no calcifications: zero AU; mild calcifications: ≥1 and less than 100 AU; moderate calcifications ≥100 and less than 299 AU; severe calcifications: ≥ 300 AU and massive calcifications ≥ 1000 AU [20]. Agreement was further assessed also at the single coronary segments level (partial scores; defined by BCIS-JS), whereby each segment of the BCIS-JS scored as positive was assigned a binary value, and by using the Bland Altman analysis to assess bias and 95% limits of agreement. Furthermore, the diagnostic performance, using sensitivity, specificity, accuracy, and positive and negative predictive values of the CT-BCIS-JS for each partial score was calculated to identify the corresponding iBCIS-JS.

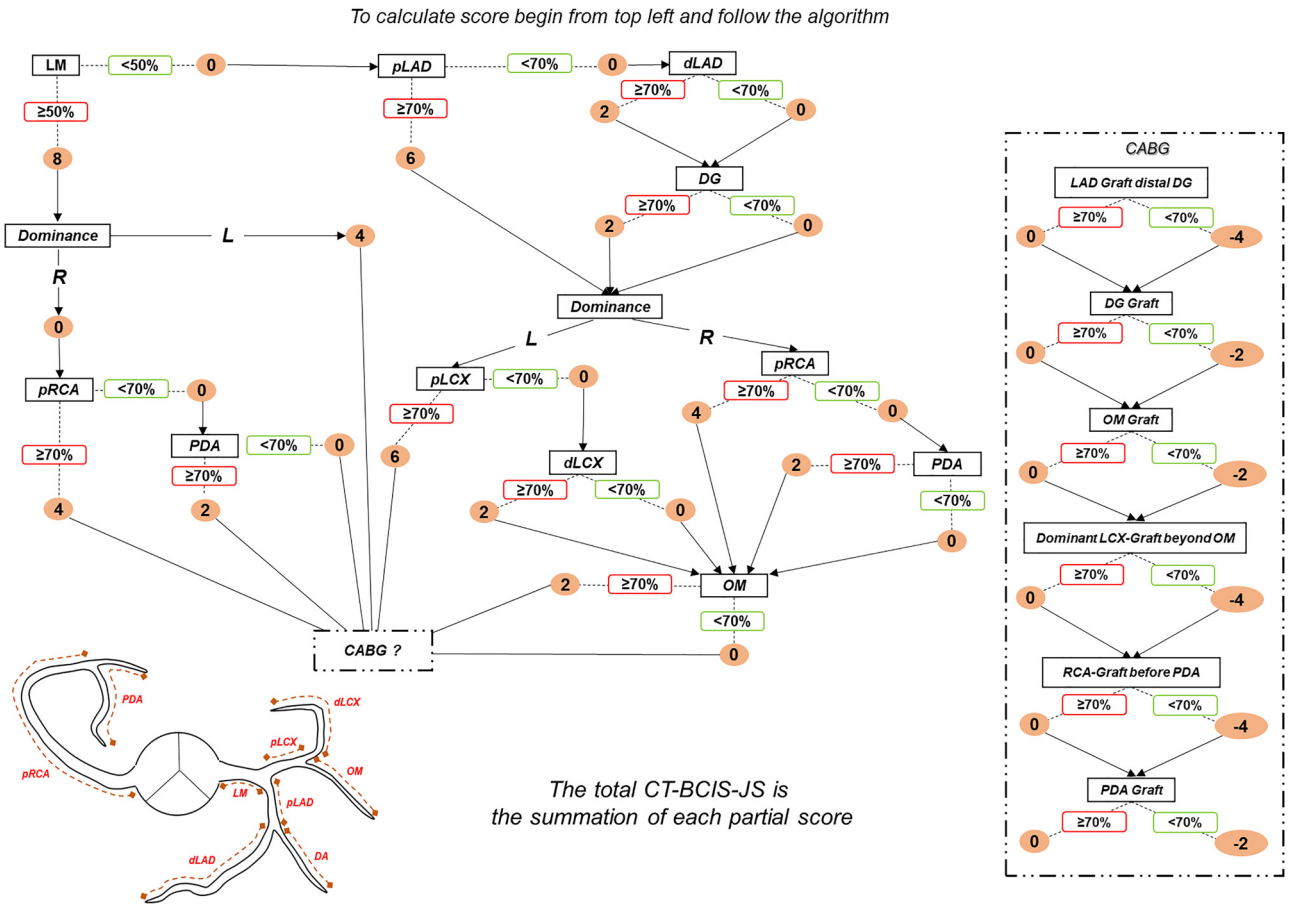

Fig. 2. Diagram shows the algorithm for the calculation of the computed tomography-based British Cardiovascular Intervention Society jeopardy score (BCIS-JS). LM indicates left main coronary artery; pLAD indicates proximal LAD; dLAD indicates distal LAD; DG indicates diagonal branch; L indicates left dominance; R indicates right dominance; pLCX indicates proximal LCX; dLCX indicates distal LCX; pRCA indicates proximal RCA up to the PDA; PDA indicates posterior descending artery; OM indicates obtuse marginal; CABG indicates coronary artery bypass graft.

Inter-observer and intra-observer agreement of CT-BCIS-JS were assessed using two-way mixed, single-measures, intraclass correlation coefficient (ICC). ICC was classified as: poor, < 0.50; moderate, 0.50–0.74; good, 0.75–0.99; and excellent, ≥ 0.90. Kappa coefficients were classified as: none, ≤ 0.00; slight, 0.01–0.20; fair, 0.21–0.40; moderate, 0.41–0.60; substantial, 0.61–0.80; and almost perfect, 0.81–1.00 [21]. Significance in differences was set at *P*-value ≤ 0.05. Statistical analyses were performed with IBM SPSS Statistics 25.0 (IBM Corp.), MedCalc 19.6.4 (MedCalc Software Ltd) and STATA 17.0 (StataCorp).

3. Results

3.1. Baseline patients and scores characteristics

A total of 122 patients were ultimately included. There were 102 men and 20 women with a median age of 62 (Q1, Q3: 54, 68; age range: 19–83 years) (Table 1). The primary indication for CCTA was the investigation of chest pain (83 patients; 68%). Median time between CCTA and ICA was 14 days (range: 0–87 days). Left coronary dominance was present in 16 out of 122 patients (13%) at CCTA and no balanced dominance anatomies were observed. Comparison between CCTA and diagnostic-only ICA examinations (60 patients; 49% of the study population) was possible in 58 out of 60 patients (97%) and revealed significantly lower median effective radiation dose (1.37 mSv [Q1, Q3: 0.56, 1.19; range: 0.21–7.67 mSv] *vs.* 4.7 mSv [Q1, Q3: 2.6, 8.0; range: 1.0–120.6 mSv], respectively; $P < 0.0001$] and less iodinated contrast administration (45 mL [Q1, Q3: 40, 55; range: 35–170 mL] *vs.* 80 mL [Q1, Q3: 59, 118; range: 15–210 mL], respectively; $P < 0.0001$] in favor of the CCTA examinations. The mean time required to calculate the CT-BCIS-JS was 110 ± 40 (SD) s (range: 29–229 s) computed upon loading the CCTA images to completion of the analysis. Fig. 3 shows a representative example of a patient with the CT-based and the invasive BCIS-JS calculation.

3.2. Comparison of CT-based vs. invasive BCIS-JS

No significant differences in median total CT-BCIS-JS (4; Q1, Q3: 0, 8; range: 0–12) and iBCIS-JS (4; Q1, Q3: 0, 8; range: 0–12) were found ($P = 0.33$). Correlation of the two scores was excellent with $r = 0.980$ (95% confidence interval [CI]: 0.972–0.986) ($P < 0.001$). Agreement of the total CT-BCIS-JS *vs.* iBCIS-JS was almost perfect, with a κ value of 0.93 (95% CI: 0.90–0.97). Extensive CAD (score ≥ 6) was observed in 53 patients (43.4%) using CT-BCIS-JS and in 52 patients (42.6%; $P = 0.88$) using iBCIS-JS with almost perfect agreement between scores ($\kappa = 0.95$; 95% CI: 0.894–1.00).

Table 2 reports the partial scores agreement between the CT-based and invasive approach and the diagnostic performance of the CT-BCIS-JS to correctly identify an invasive partial score. Very good agreement (overall bias range −0.01 ± 0.05, with small limits of agreement) was observed and an overall negative predictive value > 90% for all segments (range: 92.2–100%) and accuracy of the CT-BCIS-JS.

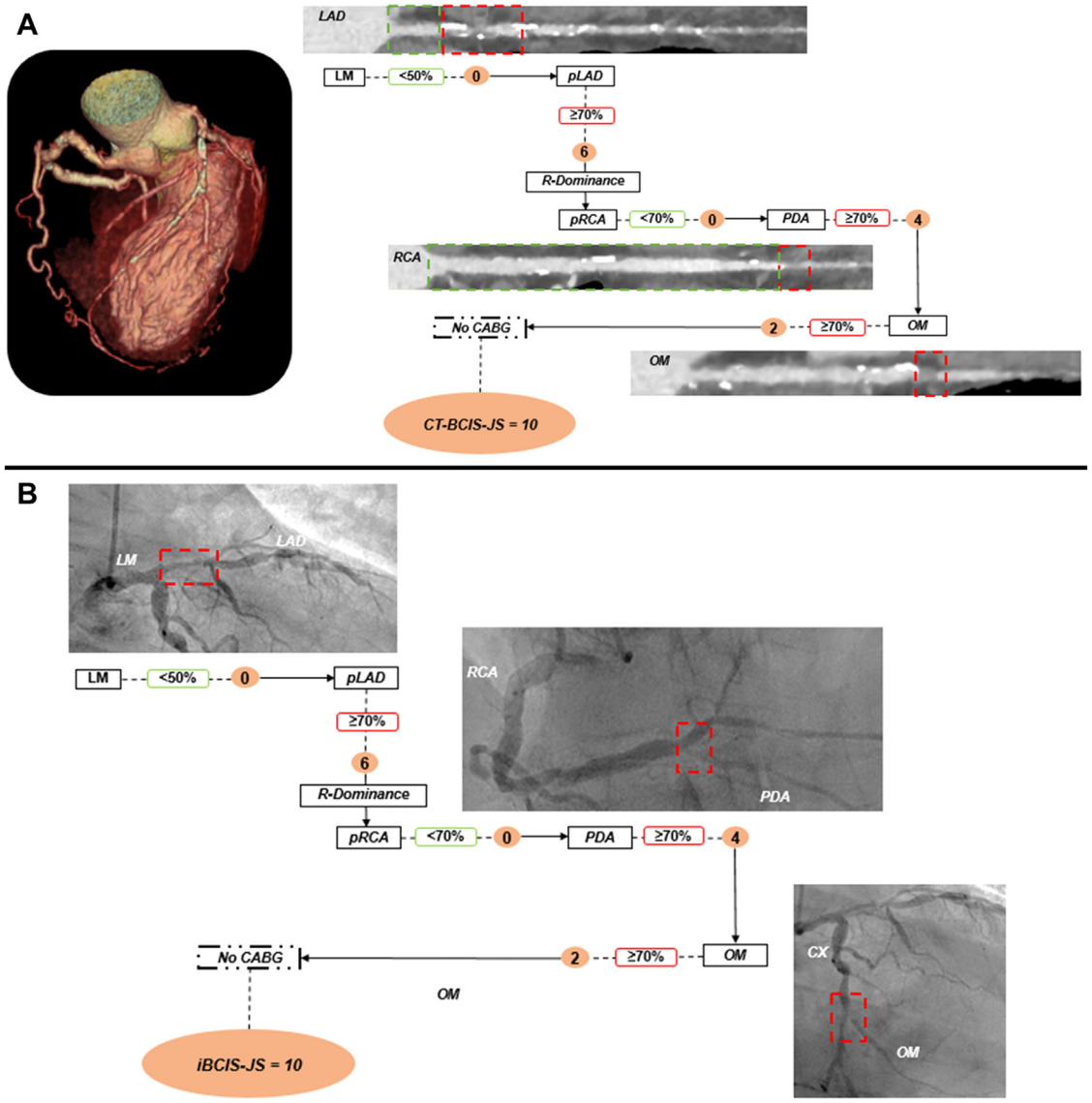

Fig. 3. Representative example of a 63-year-old man with typical chest pain who underwent coronary CT angiography and invasive coronary angiography. Comparison of the calculation of the CT-based British Cardiovascular Intervention Society Jeopardy Score (A) and the respective invasive British Cardiovascular Intervention Society Jeopardy Score (B) with perfect agreement between the two scores. pLAD indicates proximal LAD; R-Dominance indicates right dominance; CT-BCIS-JS indicates coronary CTA-based British Cardiovascular Intervention Society Jeopardy Score; iBCIS-JS indicates invasive British Cardiovascular Intervention Society Jeopardy Score.

3.3. Inter-observer and intra-observer CT-BCIS-JS agreement

Inter-observer agreement of CT-BCIS-JS in 49 randomly selected patients was very high, with an intraclass correlation coefficient of 0.98 (95% CI: 0.968–0.989). For the intra-observer analysis in 37, randomly selected patients intraclass correlation coefficient was 0.975 (95% CI: 0.952–0.987).

3.4. Calcium score-based analysis

CAC scores were was available in l08 patients, with median CAC score of 234 AU (Q1, Q3: 61, 853; range: 0–3953 AU). There was a moderate positive correlation between the total CAC and the CT-BCIS-JS (r = 0.53; CI: 0.38–0.654) (P < 0.0001) as well as with the iBCIS-JS (r = 0.5; P < 0.0001). Table 3 summarizes the correlation and agreement analysis in the several CAC score categories. Throughout all subgroups, correlation was excellent (r: 0.94–1) with almost perfect agreement (κ range: 0.83–1).

4. Discussion

The present study evaluated for the first time the feasibility of simplified non-invasive anatomical quantification of the extent of jeopardized myocardium related to clinically significant CAD using CCTA. The CT-BCIS-JS was shown to be clinically feasible and was validated against the reference iBCIS-JS with almost perfect agreement between the two scores (kappa = 0.93). The CCTA-based jeopardy score can be calculated in less than 2 min and was shown to be reproducible with high inter-observer (ICC = 0.98) and intra-observer (ICC = 0.98) agreement.

CCTA, owing to its excellent negative predictive value, can safely exclude patients with obstructive CAD, notwithstanding significant overestimation of the degree of stenosis compared to ICA [22]. Several CT-based angiographic scores have been developed and reported in the literature, primarily grading the complexity of CAD, and their incremental prognostic value beyond clinical risk scores has been repeatedly demonstrated [7,23,24]. CT-based scoring systems can also accurately assess and quantify global coronary atherosclerotic

Table 1
Demographic characteristics of 122 patients who underwent coronary computed tomography angiography and invasive coronary angiography.

Variables	Values
Sex	
Women	20 (20/122; 16.4%)
Men	102 (102/122; 83.6%)
Age (years)	62 (54, 68) [19–83]
BMI (kg/m^2)	25.6 (22.8, 28.3) [19.0 – 55.9]
Risk factors	
Hyperlipidemia	42 (42/122; 34.4%)
Diabetes type 2	17 (17/122; 13.9%)
Family history of CAD	24 (24/122; 19.7%)
Smoking	33 (33/122; 27.0%)
Hypertension	54 (54/122; 44.3%)
Obesity (BMI ≥ 30 kg/m^2)	20 (20/122; 16.4%)
Symptoms	
Typical angina	16 (16/122; 13.1%)
Atypical angina	22 (22/122; 18.0%)
Non-anginal pain	45 (45/122; 36.9%)
Dyspnea	12 (12/122; 9.8%)
No symptoms	27 (27/122; 22.1%)
Prior intervention	
PCI/Stenting	0 (0/122; 0%)
CABG	3 (3/122; 2.5%)
Medication	
Aspirin	27 (27/122; 22.1%)
Statins	27 (27/122; 22.1%)
Beta-blockers	11 (11/122; 9.0%)
ACEI or ARB	34 (34/122; 27.9%)

Quantitative variables are expressed as medians, followed by interquartile ranges (Q1, Q3) into parentheses and ranges into brackets. Qualitative variables are expressed as raw numbers; numbers in parentheses are proportions followed by percentages. ACEI = angiotensin-converting enzyme inhibitor; ARB = angiotensin-II-receptor blocker; BMI = body mass index; CABG = coronary artery bypass graft; CAD = coronary artery disease; PCI = percutaneous coronary intervention.

plaque burden [25,26,27]. Except for the CT-SYNTAX score, however, none of them has been validated against the respective invasive angiographic scores [7]. CT-SYNTAX score and CT-SYNTAX II score, which also incorporate clinical factors and evaluate the complexity of CAD, albeit robust and in high agreement with invasive SYNTAX scores, need a multipart online calculator and their estimation is more complex than the CT-BCIS-JS [11,28,29]. Our study shows that an easy-to-assess, fast and reproducible CT-based score is in high agreement with its invasive reference standard. Importantly, the accurate identification of patients with anatomically extensive CAD, which is tethered with more adverse outcomes, can potentially individualize informed risk assessment and facilitate the selection of the optimal management strategy [30].

Correlation of the CT-BCIS-JS with the iBCIS-JS was in this study particularly high; over and above the respective results of studies that have investigated the CT-SYNTAX score, with very good agreement and only a minimal underestimation [7,11,28]. These results most probably reflect the simplicity of the presented score given that it ranges from zero to twelve and with only seven available scores. Similarly, the agreement between readers was excellent, to some extent reflecting the high inter-observer reproducibility of CCTA in localizing lesions and quantifying the degree of stenosis, especially among expert and early-career readers [31].

Notably, when assessing the diagnostic performance per separate segments, the ability of CT-BCIS-JS to exclude the presence of high-grade stenosis was consistently high across all coronary segments. Sensitivity was moderate in distal regions of the right coronary artery (*i.e.*, posterior descending artery) and the distal left circumflex artery as well as in proximal left circumflex artery, however with only very few samples/lesions available for analysis. In segments where more than five samples/lesions were available, the agreement between the

Table 2
Partial scores agreement and diagnostic performance of CT-BCIS-JS *vs.* iBCIS-JS.

Partial score values	Bias (*LOA*)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
PS 1 *[LM]*	−0.01 (−0.19–0.17)	85.7 (6/7) [42.3–99.6]	100 (115/115) [96.8–100]	100 (6/6) [54.1–100]	99.1 (115/116) [94.9–99.9]	99.2 (121/122) [95.8–99.7]
PS 2 *[pLAD]*	0.02 (−0.51–0.56)	89.3 (25/28) [71.8–97.7]	93.6 (88/94) [85.8–97.1]	80.7 (25/31) [65.5–90.1]	96.7 (88/91) [91.0–98.9]	92.6 (113/122) [86.5–96.6]
PS 3 *[mLAD]*	0.02 (−0.56–0.51)	90.9 (30/33) [75.7–98.1]	93.3 (83/89) [85.9–97.5]	83.3 (30/36) [69.6–91.6]	96.5 (83/86) [90.4–98.8]	92.6 (113/122) [86.5–96.6]
PS 4 *[DG]*	0.02 (−0.76–0.77)	58.8 (10/17) [32.9–81.6]	90.5 (95/105) [83.2–95.3]	50.0 (10/20) [32.9–67.1]	93.1 (95/102) [88.5–96.0]	86.1 (105/122) [78.6–91.7]
PS 5						
PS 6 *[pRCA]*	0.05 (−0.47–0.38)	100 (24/24) [85.7–100]	93.9 (92/98) [87.2–97.7]	80.0 (24/30) [64.8–89.7]	100 (92/92) [96.1–100]	95.1 (116/122) [89.6–98.2]
PS 7 *[PDA]*	0.02 (−0.42–0.37)	50 (1/2) [1.26–98.7]	96.7 (116/120) [91.7–99.1]	20 (1/5) [0.44–57.5]	99.2 (116/117) [96.7–99.8]	95.9 (117/122) [90.7–98.7]
PS 8 *[pCx]*	−0.01 (−0.19–0.17)	66.7 (2/3) [9.43–99.2]	100 (119/119) [97.0–100]	100 (2/2) [15.8–100]	99.2 (119/120) [96.0–99.8]	99.2 (121/122) [95.5–99.9]
PS 9 *[dCx]*	−0.01 (−0.30–0.32)	66.7 (2/3) [9.43–99.2]	98.3 (117/119) [94.1–99.8]	50 (2/4) [16.9–83.1]	99.2 (117/118) [95.9–99.8]	97.5 (119/122) [92.9–99.5]
PS 10 *[OM]*	−0.02 (−0.68–0.65)	63.6 (14/22) [40.7–82.8]	94.0 (94/100) [87.4–97.8]	70 (14/20) [50.2–84.4]	92.2 (94/102) [87.1–95.3]	88.5 (108/122) [81.5–93.6]
PS 11 *[Left dominance]*	−0.02 (−0.27–0.23)	33.3 (1/3) [0.84–90.6]	100 (119/119) [96.9–100]	100 (1/1) [2.5–100]	98.4 (119/121) [96.4–99.3]	98.4 (120/122) [94.2–99.8]
PS 12 *[pRCA]*	−0.01 (−0.32–0.30)	50 (2/4) [6.76–93.2]	99.2 (117/118) [95.4–99.9]	66.7 (2/3) [18.4–94.7]	98.3 (117/119) [95.6–99.4]	97.5 (119/122) [92.9–99.5]
PS 13 *[PDA]*	0.01 (−0.17–0.19)	100 (1/1) [2.5–100]	99.2 (120/121) [95.5–99.9]	50 (1/2) [12.4–87.6]	100 (120/120) [96.9–100]	99.2 (121/122) [95.5–99.9]
PS 14						
PS 15 *[LAD graft beyond DG]*	0.0	100 (2/2) [15.8–100]	100 (120/120) [96.9–100]	100 (2/2) [15.8–100]	100 (120/120) [96.9–100]	100 (122/122) [97.0–100]
PS 16 *[Major DG graft]*	0.01 (−0.17–0.19)	100 (1/1) [2.5–100]	99.2 (120/121) [95.5–100]	50 (1/2) [12.4–87.6]	100 (120/120) [96.9–100]	99.2 (121/122) [95.5–99.9]
PS 17 *[Major OM graft]*	NA	NA	NA	NA	NA	NA
PS 18 *[Cx graft beyond OM, Cx dominance]*	NA	NA	NA	NA	NA	NA
PS 19 *[RCA graft before PDA]*	NA	NA	NA	NA	NA	NA
PS 20 *[PDA graft]*	NA	NA	NA	NA	NA	NA

Sensitivity, specificity, positive predictive value, negative predictive value and accuracy are expressed as percentages followed by proportions into parentheses and 95 % confidence intervals into brackets.
dCx = distal left circumflex artery; DG = diagonal branch; LM = left main artery; mLAD = mid left anterior descending artery; NA = not available samples for analysis; NPV = negative predictive value; OM = obtuse marginal; pCx = proximal left circumflex artery; PDA = posterior descending artery; pLAD = proximal left anterior descending artery; PPV = positive predictive value; pRCA = proximal right coronary artery.

Table 3
Coronary artery calcium score subgroups-based correlation and agreement between CT-British Cardiovascular Intervention Society Jeopardy Score and invasive British Cardiovascular Intervention Society Jeopardy Score.

CAC score	Nb. of patients	Correlation (*r*)	Agreement (kappa)
0	9	1	1 (1.00–1.00)
1– 99	24	0.97	0.93 (0.85–1.00)
100 – 299	25	0.99	0.98 (0.93–1.00)
≥ 300	9	0.95	0.87 (0.79–0.95)
≥ 1000	22	0.94	0.83 (0.70–0.96)

Numbers in parentheses are 95% confidence intervals of kappa values; CAC indicates coronary artery calcium score.

two scores was excellent with only a minimal overestimation. As outliers, CCTA underestimated the score in 36% of obtuse marginal segments and in 41% of diagonal branches segments compared to the invasive score, potentially accounting for the small arterial caliber [16]. The overall high accuracy of the CT-based score analysis compared with the invasive score throughout all segments might also be attributed to the inherent nature of the BCIS-JS, which focuses on proximal segments of large epicardial arteries, whereby the presence of a high-grade luminal stenosis is precluding investigation of the distal part of the same artery.

Coronary calcifications challenge the diagnostic performance of CCTA and could potentially affect the accuracy of anatomical jeopardy scores that incorporate the degree of luminal stenosis. Throughout the entire range of coronary calcifications the two scores were in almost perfect agreement. This again lays on the simplicity of the CT-BCIS-JS since the prime focus is the localization and identification of high-grade stenosis, features that CCTA shows very high concordance with ICA. Although in patients with a CAC score ≥ 1000 agreement was also almost perfect, similar to the CT-SYNTAX score, studies in larger populations are necessary to better evaluate the CT-based score in such patients [11].

Technological advancements in cardiac CT scanners and improvements in scanning protocols have enhanced diagnostic image quality [32]. In our study, only 5% of patients were excluded due to non-diagnostic CCTA quality. The amount of iodinated contrast material was significantly lower at CCTA as well as the effective radiation dose in patients who underwent solely diagnostic ICA. Recognizing the growing evidence of the benefits of a CCTA-first diagnostic approach for patients with low-to-intermediate pretest probability for obstructive CAD, swift and reliable calculation of the CT-BCIS-JS could be potentially used as an additional, safe and reliable gatekeeper for downstream invasive or non-invasive tests, informing patients-physicians and improving pre-procedural planning [18]. A recent prospective study demonstrated that the integration of CT-FFR with CCTA in patients with multivessel CAD was non-inferior to ICA and invasive assessment of physiological significance for decision-making [33]. Combining non-invasive assessment of the extent of anatomically but also functionally jeopardized myocardium might be proven important in the diagnostic and treatment strategies of CAD patients.

Our study has limitations, primarily due to its retrospective nature and the single-center design. The number of patients enrolled, however, provides adequate sample power to assess the agreement between the two scores. Given that, all patients were scanned with a single wide-volume CT scanner with 12–16 cm coverage, our results might not be readily generalizable for CCTA scans acquired by older-generation scanners. Patients with prior PCI/stenting, whereby the diagnostic accuracy of CCTA is known to be lower, were not included [34]. Similarly, the entire spectrum of arterial/venous graft-conduits could not be assessed in patients with CABG given the small prevalence in the population studied and therefore our results might not be generalizable to this patients' group. Finally, the long-term prognostic value of the score was not assessed and certainly, data on its additional value for patients' survival would be necessary prior to clinical adoption.

In conclusion, estimation of the CT-BCIS-JS in patients with suspected or stable CAD is feasible and reproducible across the entire spectrum of coronary artery calcifications, yielding high accuracy and very good agreement with the reference invasive BCIS-JS. Simplified but accurate, non-invasive identification of anatomically extensive CAD may serve as a gatekeeper for downstream invasive testing.

Human rights

The authors declare that the work described has been performed in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patients.

Author contributions

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

Declaration of Competing Interest

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Jan A. Schaab: Conceptualization, Methodology, Investigation, Formal analysis, Data curation. **Alessandro Candreva:** Conceptualization, Methodology, Investigation, Formal analysis, Data curation. **Alexia Rossi:** Data curation, Formal analysis, Writing - review & editing. **Susanne Markendorf:** Formal analysis, Writing - review & editing. **Dominik Sager:** Formal analysis, Writing - review & editing. **Michael Messerli:** Investigation, Writing - review & editing. **Aju P. Pazhenkottil:** Investigation, Writing - review & editing. **Dominik C. Benz:** Investigation, Writing - review & editing. **Philipp A. Kaufmann:** Conceptualization, Funding acquisition, Writing - review & editing. **Ronny R. Buechel:** Conceptualization, Funding acquisition, Investigation, Writing - review & editing. **Barbara E. Stähli:** Conceptualization, Investigation, Formal analysis, Writing - review & editing. **Andreas A. Giannopoulos:** Conceptualization, Methodology, Investigation, Formal analysis, Resources, Data curation, Supervision, Funding acquisition, Project administration, Validation, Visualization, Writing - original draft, Writing - review & editing.

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