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Research paper

Structured reporting platform improves CAD-RADS assessment

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ABSTRACT

Background: Structured reporting in cardiac imaging is strongly encouraged to improve quality through consistency. The Coronary Artery Disease - Reporting and Data System (CAD-RADS) was recently introduced to facilitate interdisciplinary communication of coronary CT angiography (CTA) results. We aimed to assess the agreement between manual and automated CAD-RADS classification using a structured reporting platform.

Methods: Five readers prospectively interpreted 500 coronary CT angiographies using a structured reporting platform that automatically calculates the CAD-RADS score based on stenosis and plaque parameters manually entered by the reader. In addition, all readers manually assessed CAD-RADS blinded to the automatically derived results, which was used as the reference standard. We evaluated factors influencing reader performance including CAD-RADS training, clinical load, time of the day and level of expertise.

Results: Total agreement between manual and automated classification was 80.2%. Agreement in stenosis categories was 86.7%, whereas the agreement in modifiers was 95.8% for "N", 96.8% for "S", 95.6% for "V" and 99.4% for "G". Agreement for V improved after CAD-RADS training ($p = 0.047$). Time of the day and clinical load did not influence reader performance ($p > 0.05$ both). Less experienced readers had a higher total agreement as compared to more experienced readers (87.0% vs 78.0%, respectively; $p = 0.011$).

Conclusions: Even though automated CAD-RADS classification uses data filled in by the readers, it outperforms manual classification by preventing human errors. Structured reporting platforms with automated calculation of the CAD-RADS score might improve data quality and support standardization of clinical decision making.

1. Introduction

State-of-the-art CT imaging allows for robust assessment of coronary artery disease (CAD).[1–3] In recent years, the number of coronary CT Angiography (CTA) examinations increased substantially leading to increased variability in reporting of coronary findings.[4] Performed by cardiologists or radiologists, written in free text or generated by structured reporting platforms, coronary CTA reports should provide a concise, clear description of coronary anatomy and pathologic changes. Considering the high variability and inconsistency in coronary CT angiography reporting, a standardized framework for CAD assessment has long been desired.[5–7]

In a joint effort, cardiology and radiology societies (SCCT, ACR, ACC and NASCI) proposed a scoring system - the Coronary Artery Disease - Reporting and Data System (CAD-RADS) - for standardized reporting and decision making.[8] This expert consensus document aimed to facilitate interdisciplinary communication of CTA results and provide recommendations on patient management.

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Abbreviations

ACC	American College of Cardiology
ACR	American College of Radiology
CAD-RADS	Coronary Artery Disease - Reporting and Data System
CTA	Computed Tomography Angiography
DLP	Dose Length Product
G	graft
IQR	Interquartile Range
N	non-diagnostic
NASCI	North American Society for Cardiovascular Imaging
S	stent
SCCT	Society of Cardiovascular Computed Tomography
V	vulnerability

CAD-RADS holds the potential to substantially improve reporting consistency. Currently there are no data available regarding the use of structured reporting platforms in CAD-RADS classification. Therefore, we sought to assess the utility of a structured reporting platform capable of automated CAD-RADS classification based on reader input as compared to manual scoring alone.

2. Methods

2.1. Study population and design

In this single center study we prospectively enrolled 500 patients who underwent coronary CTA due to stable chest pain between August and December 2016. We included all patients who were older than 18 years. No further inclusion or exclusion criteria were applied to avoid selection bias. Five readers (MK, BS, JK, AP, AJ) interpreted the coronary CTA images (100/reader) using a structured reporting platform that automatically calculates CAD-RADS based on reader input (Structured Online Reporting Tool - iSORT, Bioscreen Ltd, Budapest, Hungary). Reader input consists of the location, severity and extent of CAD, as well as the evaluation of image quality, high-risk plaque features, bypass grafts and stents to describe modifiers. The readers were blinded to the automatically calculated CAD-RADS values. The study was approved by the institutional review board and informed consent was obtained.

2.2. Image acquisition

We performed ECG-gated CTA of the coronary arteries according to the guidelines of the SCCT.[9] All patients were scanned with a 256-slice CT scanner (Philips Healthcare, Best, The Netherlands). We administered oral beta-blockers (metoprolol) if heart rate exceeded 65 beats per minute one hour before the coronary CTA examination. All patients received 0.8 mg of sublingual nitroglycerin shortly prior to the contrast enhanced scan. Intravenous beta-blocker (metoprolol) was administered immediately before the scan if the patient's heart rate was above 60 bpm and systolic blood pressure was higher than 100 mmHg. All coronary CTA images were acquired using prospective ECG triggering, 270 msec rotation time, 128×0.625 mm collimation, tube voltage of 100–120 kVp based on patient's anthropometrics. Images were acquired and reconstructed at diastole (75–81% of the R-R interval) or at systole (37–43% of the R-R interval) if heart rate was still above 70 bpm despite premedication. Axial images were reconstructed with 0.4 mm slice thickness using iterative reconstruction (iDose[4] and IMR, Philips Healthcare, Cleveland, OH, USA). Dose length product (DLP) was registered and converted to an estimated effective radiation dose in millisieverts by multiplying by the k factor of 0.014.[10]

2.3. Image analysis

All readers assessed the location, type and severity of coronary lesions according to SCCT guidelines using the 18-segment coronary tree model and also evaluated high-risk plaque features.[11] Coronary segments with a diameter of >1.5 mm were analyzed. All reports were generated by a structured reporting platform, which uses single and multiple-choice questions and numeric fields for data input (Fig. 1.). All readers recorded the CAD-RADS stenosis categories (0: 0%, 1: 1–24%, 2: 25–49%, 3: 50–69%, 4A 70–99%, 4B: Left main >50% or 3-vessel disease, 5: 100%) and modifiers (N: Non-diagnostic, S: Presence of stent, V: Vulnerable or high-risk plaque features, G: Presence of bypass grafts) according to the CAD-RADS consensus document.[8] Stenosis category accounts for the highest degree of stenosis on a patient level. Readers can describe non-diagnostic studies or segments using the CAD-RADS modifier N. In the presence of a moderate or higher grade stenosis and a remote non-diagnostic segment, N should be assigned next to the stenosis category (e.g. 3/N), however if there is a mild or minimal stenosis N is used as a category by itself, since further testing is recommended. The modifier S indicates that there is at least one stent in any segment of the coronary tree, whereas G stands for bypass grafts. The coronary stenoses bypassed by the graft(s) are not considered by the CAD-RADS scheme. However, any stenosis of the graft or coronary stent has to be acknowledged when assigning stenosis categories. Importantly, the consensus document also incorporated high-risk plaque features in CAD-RADS assessment. Modifier V indicates plaque vulnerability, and has to be assigned in case of the presence of two or more high-risk plaque features in a single lesion; these high-risk plaque features include low attenuation plaque, positive remodeling, spotty calcification, and the napkin ring sign.[12,13]

Low attenuation plaque was defined as a non-calcified coronary lesion with attenuation values below 30 Hounsfield Units (HU). To evaluate plaque attenuation, we selected the pixels within the lesion with the lowest density. Spotty calcification is defined as a small (less than 3 mm) calcified nodule (>130 HU) that is surrounded by non-calcified plaque tissue. Outward or positive remodeling is assigned if a given plaque has 10% increase in the vessel diameter at the site of maximal stenosis as compared to the average of proximal and distal reference segments' diameters. The napkin ring sign in non-calcified plaques is a qualitative plaque feature that is characterized by the joint presence of a central area of low CT attenuation that is apparently in contact with the lumen; and a ring-like higher attenuation plaque tissue surrounding this central area [14].

The reporting platform automatically determined the CAD-RADS category based on the data provided by the readers, which remained hidden to the readers. Readers were able to fill in any score as a free text on the reporting platform. In the field designated to indicate the CAD-RADS classification readers were able to fill in any CAD-RADS category including non-existing ones as free text (e.g. 2/N). Mismatches between the automated and manually derived scores were re-evaluated by two experienced readers and the correct score was derived by consensus between them. These readers did not take part in the coronary CTA interpretation. We assessed total agreement (both for stenosis categories and modifiers) and also the agreement for every component of the scoring system between the automated and manual classification. Change in management was defined as discrepancy in stenosis categories

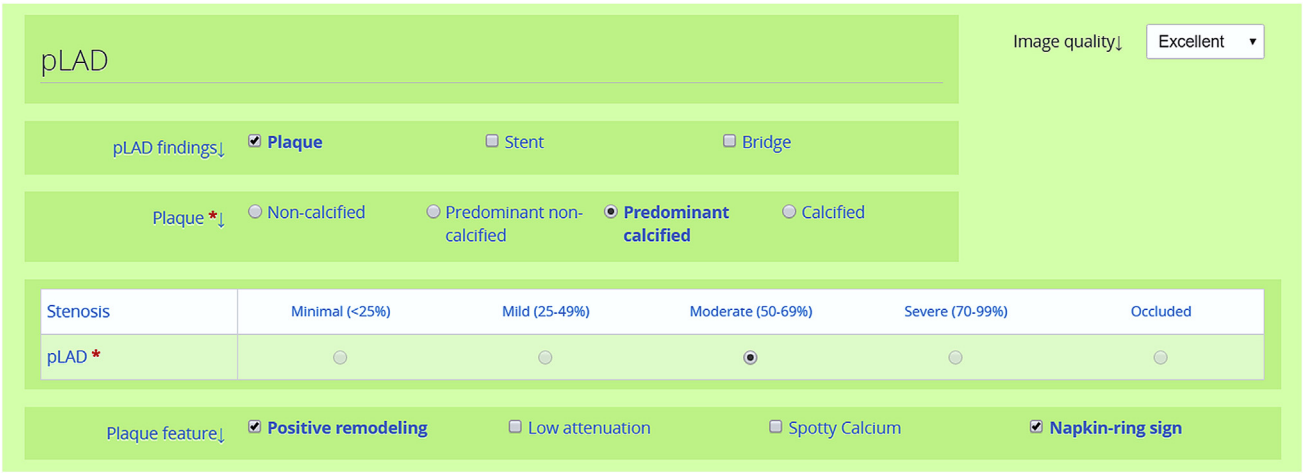

Fig. 1. Representative image of the applied structured reporting platform in clinical routine. The figure demonstrates how plaques were evaluated by the readers including plaque features and stenosis severity using single and multiple choice questions for all coronary segments. The platform includes all components of CAD-RADS assessment. Based on these conditional inputs the CAD-RADS score was automatically calculated (e.g. 3/V) that remain hidden to the readers. We compared the results of the automated score with the manual CAD-RADS classification.

apart from 0 vs 1 and 1 vs 2 or discrepancy in modifiers among all misclassified cases.

2.4. Factors increasing CAD-RADS misclassification rate

We hypothesized that CAD-RADS training, time of the day, clinical load and level of expertise could influence reader's performance when assessing CAD-RADS scores. At the beginning of the study we gave detailed instructions to all readers to ensure proper use of CAD-RADS and distributed the consensus document for reviewing. Readers were allowed and also encouraged to read the score system regularly or at any time during the study. Additionally, after the first 50 cases each reader received an individual training, which included a short review of CAD-RADS and case evaluations focusing on correcting common mistakes. We also assessed the association of clinical load (defined as $\geq$5 reports/day) and time of the day (in 6 h intervals) with reader's performance. We differentiated two groups of readers based on clinical experience (2 readers with 2 years vs 3 readers with 7 years' experience in reading coronary CTAs).

2.5. Statistical analysis

Continuous variables are presented as mean and standard deviation, whereas categorical parameters are presented as frequency with percentages. We compared reader's and the structured reporting platform's performance using the McNemar's test for modifiers and the Wilcoxon-rank sum test for stenosis categories. We assessed the effects of clinical load, clinical experience, individual training and diurnal rhythm on agreement by using Fisher exact test for modifiers and Mann-Whitney for stenosis categories. To create a continuous scale for data analysis of stenosis, we separated 4A and 4B into different severity categories. A p value < 0.05 was considered statistically significant. All calculations were performed using SPSS software (SPSS version 22; IBM Corp., Armonk, New York).

3. Results

3.1. Evaluation of CAD-RADS using structured reporting algorithm

In total, 500 consecutive coronary CTAs were included in the analysis (mean age 59.6 ± 12.5 years, 42.0% female gender and mean BMI 28.5 ± 5.0 kg/m^2). Patient characteristics and imaging parameters are summarized in Table 1. We detected total agreement between manual and automated CAD-RADS classification in 80.2% of the cases. The agreement in stenosis categories was 86.8%. In addition, we investigated the agreement in modifiers with the following results: 95.6% for V, 95.8% for N, 96.8% for S, and 99.4% for G. Distribution of modifiers was N: 15.0% vs 17.2%, S: 6.0% vs 9.2%, V: 11.8% vs 15.4%, G: 1.8% vs 2.4%, for manual vs automated, respectively ($p < 0.05$ for N, S, V and $p = 0.25$ for G). Readers forgot to assign S in 34.8% of all patients who had at least one stent, N in

Table 1
Patient characteristics.

	Study population (n = 500)
Demographics	
Age (years)	59.6 ± 12.5
Female gender, n (%)	210 (42.0)
BMI (kg/m^2)	28.5 ± 5.0
Blood pressure (Hgmm)	145 ± 19.7
Diamond-Forrester pretest probability	
Very low	28 (5.6)
Low	66 (13.2)
Intermediate	389 (77.8)
High	17 (3.4)
Cardiovascular risk factors, n (%)	
Hypertension	301 (60.2)
Diabetes mellitus	97 (19.4)
Dyslipidemia	207 (41.4)
Current smoker	77 (15.4)
Family history of premature CAD	144 (28.8)
Type of chest pain, n (%)	
Typical	24 (4.8)
Atypical	147 (29.4)
Aspecific	329 (65.8)
Imaging parameters	
DLP (mGy*cm)/effective dose (mSv)	358.4 ± 142/5.0 ± 2.0
Contrast agent (ml)	92.5 ± 10.8
Heart rate during scan (1/min)	62.1 ± 13.8
Use of Beta-Blockade, n(%)	368 (73.6)
Use of nitroglycerine, n(%)	494 (98.8)
Agatston score	205 ± 614
SSS	4.0 [1.0 to 9.0]
SIS	3 [1.0 to 5.0]

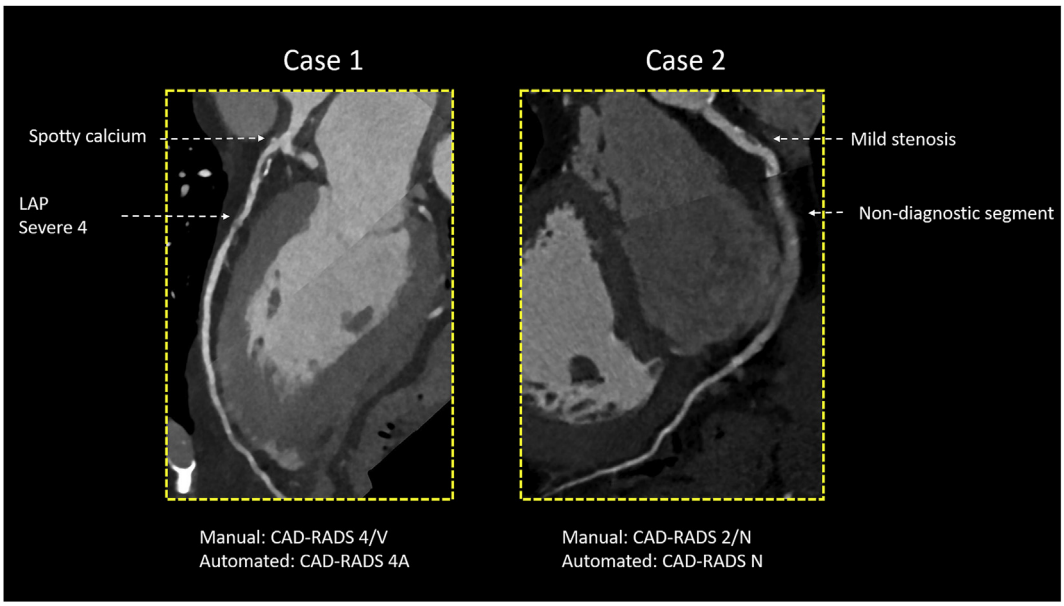

Fig. 2. Pitfalls in CAD-RADS classification that might lead to reporting inconsistency and altered patient management. On the left panel, case 1 is a representative example for plaque vulnerability assessment in CAD-RADS. The reader misclassified this case and assigned V (Vulnerability), although high-risk plaque features were present in two clearly distinct plaques along the proximal and mid segment of the left anterior descending artery (LAD). The CAD-RADS classification requires minimum two high-risk plaque features to be present in a single lesion to apply modifier V. Also, reader forgot to assign A or B to describe lesion severity. Severe lesion in the LAD was marked as 4/V by the reader, whereas the automated tool correctly assigned a CAD-RADS score 4A. The right panel represents another common mistake in classification (case 2). A predominantly non-calcified plaque leading to a mild stenosis was detected in the proximal right coronary artery (RCA), followed by a step artifact and severe motion artifacts on the mid-RCA. Reader assigned a non-existing category (2/N), whereas the automated tool correctly assigned N without stating the stenosis grade.

12.8% of studies with non-diagnostic coronary segments, V in 23.4% of patients with vulnerable plaques and G in 25.0% among patients with bypass grafts. Importantly, 4.6% of all cases were falsely classified by the readers into non-existing CAD-RADS categories that included 0/N, 1/N 2/N and the stenosis category 4 without assigning A or B (Fig. 2). Details of CAD-RADS assessment for stenosis categories and modifiers are shown in Table 2, whereas most common mistakes are summarized in Table 3. Stenosis of 4B (indicating the presence of left main stenosis greater than 50% or three-vessel obstructive CAD) was misclassified in four cases to 4A (0.8%). Discrepancy between the manual and automated classification could have led to changes in patient management recommendations in 13.2% of cases and 15.6% of cases when including discrepancy of the modifier V.

The total time to prepare the structured reports using the software tool was 38.1 (IQR 21.1–66.5) minutes, which includes the entry of anamnestic data, clinical parameters, anthropometrics, acquisition parameters, indication for coronary CTA, calcium scoring results and the assessment of coronary arteries.

3.2. Factors influencing CAD-RADS misclassification

We detected significantly higher agreement of the modifier "V" after the individual training (first vs. second 250 cases, $p = 0.047$). The agreement of other modifiers and stenosis categories did not show any significant improvement ($p > 0.05$ for all). Time of the day and clinical load (as assessed by ≥ 5 reports on a given day) did not significantly influence reader's performance ($p > 0.05$ for all). Less experienced readers (2-year experience in coronary CTA) had a higher total agreement with the automated classification as compared to more experienced readers (years' experience in coronary CTA) 87.0% vs 78.0%, respectively ($p = 0.011$). Also, non-existing CAD-RADS categories were more frequent among more experienced readers as compared to the less experienced clinicians (6.3% vs 2.0%, respectively, $p = 0.02$).

4. Discussion

The utilization of structured reporting platforms in reading and reporting of coronary CTA findings allows automatically derived CAD-RADS classification, which substantially reduces human error and thus improves data integrity. CAD-RADS categories were misclassified by clinicians in approximately one fifth of the patients.

The implementation of the CAD-RADS multidisciplinary consensus document represents an important step to achieve uniform and consistent coronary CTA reporting using a standardized and simplified terminology. Similar data systems exist in breast, prostate and lung imaging, and studies have verified their ability of standardizing patient management in a practical way.[15–18] Both image interpretation and subsequent reporting can inflict errors in CAD assessment and thus lead to altered clinical decision making. Clinical experience and training of readers ensures the adequate assessment of lesion severity and high-risk plaque morphology and thus reduces interpretation inconsistency. The use

Table 2
Distribution of CAD-RADS based on manual versus automated classification.

	Manual	Automated	p value
Stenosis, (n,%)			0.008
0	87 (17.4)	90 (18.0)	
1	122 (24.4)	114 (22.8)	
2	100 (20.0)	93 (18.6)	
3	58 (11.6)	61 (12.2)	
4A	32 (6.4)	49 (9.8)	
4B	3 (0.6)	5 (1.0)	
5	19 (3.8)	25 (5.0)	
Non-existing	23 (4.6)	0 (0.0)	
N, (n,%)	75 (15.0)	86 (17.2)	0.027
S, (n,%)	30 (6.0)	46 (9.2)	<0.001
V, (n,%)	59 (11.8)	77 (15.4)	0.001
G, (n,%)	9 (1.8)	12 (2.4)	0.250

Table 3
Top 5 errors in manual CAD-RADS classification (N = 500).

Discrepancy	N (%)
Stenosis category	44 (8.8)
Missing V	18 (3.6)
Missing S	16 (3.2)
4 without A or B	19 (3.8)
0/N or 1/n or 2/N	4 (0.8)

of CAD-RADS could result in improved reproducibility for image interpretation although this has not yet been tested. Reporting inconsistency is associated with non-standardized reporting and inconsistent use of nomenclature and classification schemes. The implementation of CAD-RADS in the clinical routine requires proper training in coronary CTA and standardized clinical reporting. Importantly, CAD-RADS classification might be influenced by reporting inconsistency despite proper image interpretation. Our study design provides a unique opportunity to assess this inconsistency. We have identified several potential pitfalls that could hinder the primary aim of CAD-RADS, namely, to provide consistent CTA reports in a standardized fashion. We demonstrated that approximately one fifth of the patients were misclassified by the readers during reporting. Total agreement between manual and automated classification was 80.2%. Lowest agreement was found for two high-risk feature positive plaques, denoted by modifier V. This could possibly alter patient management and also lead to lower data integrity for research purposes. In addition, we demonstrated that human error might influence further management and decision making up to 16% of the patients, including errors in plaque vulnerability assessment. Although clinicians should still evaluate the patient's individual risk status in addition to the CAD-RADS recommendation in clinical decision making.

Structured reporting tools in cardiac imaging have been predominantly implemented to improve data integrity and to establish large databases for research purposes, education and patient care.[19–23] The implementation of automated CAD-RADS calculations in structured reporting platforms has been previously proposed by experts in the field.[5,24] Structured reporting algorithms that are capable of calculating CAD-RADS scores are needed to avoid simple mistakes in classification. Our work suggests that structured reporting platforms could improve clinical workflow by assisting clinicians in reporting and at the same time significantly reducing errors due to human factors, such as inattention, clinical overload or lack in knowledge. Consequently, effective communication of coronary CTA results and adequate clinical decision making can be established. Importantly, our study demonstrated that the misclassifications were not caused by the limitations of the common CAD-RADS lexicon, they can rather be attributed to human error. The results of our study could therefore help to develop training programs and software platforms to support the widespread adoption of CAD-RADS based coronary CTA interpretation.

We aimed to further elucidate the role of various factors that might be associated with CAD-RADS misclassification. Interestingly, more experienced readers had more errors in classifying the patients, which is also reflected in the higher number of non-existing CAD-RADS categories. This suggests that consistent CAD-RADS reporting is more influenced by factors that determine individual attention span rather than clinical experience. Nonetheless, we strongly encourage regular training of clinicians to ensure the proper use of CAD-RADS. We detected significant improvement in the agreement of modifier V as a result of training after the first half of the study (50 cases per reader). Importantly, the agreement for other modifiers (N, S and G) was similar throughout the whole study suggesting that these are not related to knowledge in classification but rather to inattention. Attention span is an important determinant of reader's performance and it might be influenced by the clinical workload or by the time of the day. Therefore, we also evaluated the effect of these factors on misclassification rates. However, we found that clinical load reflected by the number of reports or time of the day did not influence reader's performance.

We acknowledge the limitations of our study. Although such study might not contain all the different CAD-RADS categories, we are confident that our current study reflects real life experience and the studied patient population represents a wide spectrum of CAD. Further limitation in classification originates from the inability of CAD-RADS classification to address all complex scenarios in coronary imaging, such as various coronary anomalies, presence of stents on the native vessels which were treated by CABG or the exact specification of the run-off vessels in case of CABG. We implemented a relatively short training after 50 cases that included case evaluations and revisiting the CAD-RADS consensus document. A more intensive training might have led to improved reader performance for all aspects of CAD-RADS classification. Also, a control group of patients with non-structured reporting were not evaluated in current study. We assume that such comparison would show an even larger misclassification rate as compared to the structured reporting platform, as further studies demonstrated the high inconsistency and ambiguity associated with free text reporting.

Even though automated CAD-RADS classification uses data filled in by the readers, it performs better in determining the CAD-RADS category than the clinical readers by preventing human errors. Structured reporting platforms with automated score calculations might improve data quality and support clinical decision making.

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