Original Article

Reevaluation of Computed Tomography-Based Attenuation Correction on Myocardial Perfusion Imaging Compared With Coronary Angiography Findings

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ABSTRACT

Background: Noninvasive diagnostic methods for coronary artery disease (CAD) are a health priority. Coronary angiography (CA) is currently the gold-standard method for diagnosing CAD. Myocardial perfusion imaging (MPI) is used to diagnose CAD as well. This study aimed to reevaluate the effects of computed tomography (CT)-based attenuation correction on MPI results compared with CA findings.

Methods: This cross-sectional study enrolled 293 patients referred to Rajaie Cardiovascular Medical and Research Center. The study population underwent MPI with CT-based attenuation correction and CA to diagnose CAD within 3 months.

Results: In the right coronary artery (RCA) territory, CT-based attenuation correction led to a significant decrease in MPI sensitivity in men and an increase in specificity in all the patients except those with a normal body mass index. In the left circumflex coronary artery (LC_X) territory, a significant reduction in sensitivity was noted just in overweight patients, while specificity improved merely in men. In the left anterior descending artery (LAD) territory, none of the diagnostic parameters changed significantly with attenuation correction.

Conclusions: Performing CT-based attenuation correction significantly enhanced diagnostic specificity and worsened sensitivity in the RCA and LC_X territories. The advantage of CT-based attenuation correction is more pronounced in patients with a normal body mass index and women. ***(Iranian Heart Journal 2023; 24(3): 15-23)***

KEYWORDS: Computed tomography, Myocardial perfusion imaging, Coronary artery disease, Attenuation correction

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Received: January 19, 2022 **Accepted:** May 10, 2022

Coronary artery disease (CAD) remains one of the leading causes of morbidity and mortality in adults [1] and is the third relevant disease in developing and developed countries. [1, 3, 4] The mortality rate of CAD in Iran is reported to be 35%. [5, 6] Coronary angiography (CA) is the gold-standard method to diagnose CAD. Myocardial perfusion imaging (MPI) has been a useful tool to assess perfusion for the past few decades.[7] It is a noninvasive method for diagnostic testing, risk assessment, and management. [8]

The most common use of cardiac perfusion scans is in patients with an intermediate probability of CAD. The sensitivity and specificity of single-photon emission computed tomography (SPECT) MPI for detecting significant stenosis are 87% and 89%, respectively. [9] Nonetheless, the specificity of this method is reduced by the effect of artifacts. One of these artifacts is diaphragmatic and soft-tissue attenuation. Count reduction in the left ventricular inferior wall is seen naturally in perfusion images in both sexes. The most common cause of this phenomenon is the attenuation of photons by the left hemidiaphragm and to a lesser extent by the right ventricle. [10]

Another phenomenon that leads to the sub-optimization of MPI results is the attenuation of photons by an overlying soft tissue, especially in women and by the breast, which is more problematic in the anterior wall of the heart. [11]

Several ways exist to mitigate the problem of photon attenuation, including scanning in the prone position, using gating parameters such as wall thickening and motion, and finally using attenuation correction by an external source such as a radioactive source (eg, gadolinium 153), computed tomography (CT), and magnetic resonance imaging. [12] Each of these methods, however, has its limitations.

The concept of attenuation correction is to compensate for the phenomenon whereby photons emitted from the myocardium are absorbed into the patient’s body by a combination of photoelectric and Compton scatters instead of being counted by the gamma camera, reducing counts density. The amount of reduction in count depends on the tissue volume and the density of the region. [13] This count reduction is seen in both stress and rest images as a fixed defect and mimics the infarct view. If the relative position of the weakening tissue shifts between stress and rest phases, it can mimic the appearance of reversibility and ischemia.

One way to correct diaphragmatic attenuation with a view to differentiating perfusion defects from artifacts is to use an X-ray source (eg, CT). There are, however, limitations to the use of this method such as high costs, radiation exposure, and misregistration between emission (perfusion) and transmission (CT) images. On the other hand, the photons emitted from the subdiaphragmatic structures may intensify after correction and interfere with the evaluation of the left ventricular inferior wall (overcorrection). Solving these problems necessitates quality control. [14]

Given the limitations in CT-based attenuation correction, inconsistent findings published regarding the effectiveness of this method, and feedback on the discrepancy between MPI (with attenuation correction) and CA results, we sought to evaluate the effects of this method on the diagnostic accuracy of myocardial perfusion scans.

METHODS

Study Population

The present cross-sectional study enrolled 293 patients referred to the Nuclear Medicine Department between May 2017 and October 2019. Ninety-three patients were excluded due to overcorrection in attenuation-corrected images and muscle bridging. Two hundred cases, composed of 46 women and 154 men, remained for the final analysis. The patients underwent MPI with attenuation correction and CA within 3 months.

Inclusion Criteria

All patients who were referred to the department of nuclear medicine for CAD evaluation between May 2017 and October 2019 and who underwent MPI with CT and CA within 3 months were eligible for inclusion in the current study.

Exclusion Criteria

Patients with excess subdiaphragmatic visceral activity, motion during the acquisition, overcorrection in attenuation-corrected images, or muscle bridging in CA were excluded from the study.

Data Collection

Data collection featured the use of a questionnaire containing the patients' demographic information, including age, sex, height, and weight; past medical history, including a history of hypertension, diabetes, and hyperlipidemia, and their respective duration; medications; a history of smoking; and information of the last echocardiography and electrocardiography.

All the patients underwent MPI SPECT based on a 2-day stress-rest protocol with Tc-99m Sestamibi. Acquisitions were performed with a Symbia T2 and Symbia T6 (Siemens Healthcare) dual-head gamma camera, equipped with low-energy–high-resolution collimators. Attenuation correction was performed only on stress images. For SPECT image reconstruction and analysis, non-corrected and CT-AC image data were reconstructed using the ordered subset expectation maximization (OSEM) algorithm.

MPI was reported via the visual method by 2 experienced nuclear medicine specialists, blinded to the result of the angiography, in 2 ways: with and without attenuation correction. Thereafter, the MPI and angiography results were compared. A luminal diameter narrowing of more than 70% was considered significant CAD. [15]

Statistical Analysis

The statistical analyses were performed with IBM SPSS Statistics 22 for Windows (IBM Inc, Armonk, NY). The fitness of interval data to normal distribution was assessed via the one-sample Kolmogorov-Smirnov test. The data were described as mean ± standard deviation or the median (the interquartile range) for interval variables and frequencies (percentages) for categorical variables. Comparison between subgroups was performed via the Student *t* or the Mann-Whitney *U* test for interval and the χ^2 test for categorical variables. The diagnostic accuracy of the tests was reported using sensitivity, specificity, negative predictive values (NPVs), and positive predictive values (PPVs) with their 95% confidence intervals (95% CIs) and compared using the Pearson χ^2 test. A *P* value of less than 0.05 was considered statistically significant.

Ethics

MPI was performed with clinical indications and at the discretion of the patients' cardiologist. Written consent was obtained from all the patients for MPI in the nuclear medicine department. The patients' information was confidential, and no additional costs were imposed on the study population. The study protocol was approved by the ethics committee of the university (No. 15395).

RESULTS

The study population consisted of 293 patients: 239 men (81.5%) and 54 women (18.5%). Eighty-eight cases could not be interpreted due to overcorrection in attenuation-corrected images (fig 1), and 5 patients were excluded due to muscle bridging on CA. The final analysis was conducted on 200 patients on the basis of the study's inclusion and exclusion criteria.

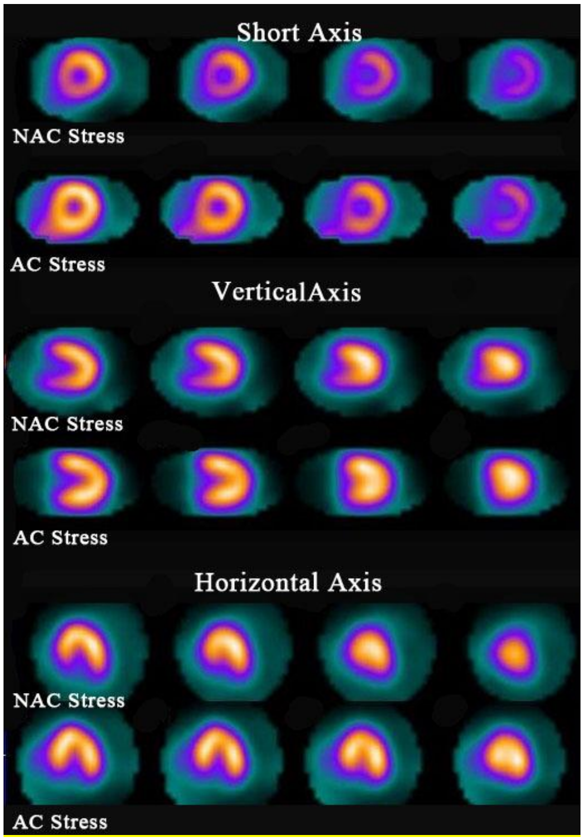

Figure 1: The image shows overcorrection in CT-based attenuation correction.
AC: Attenuation-corrected; NAC: Non–attenuation-corrected

Considering the importance of the issue, the 2 excluded groups were also compared. The group excluded due to overcorrection had statistically significantly fewer female patients (*P* = 0.006), lower body mass index (BMI) (*P* =0.022), and lower weight (*P* =0.022). However, the 2 excluded groups were not statistically significantly different in terms of height and age (*P* =0.37 and *P* =0.24, respectively) (Table 1). The Mann-Whitney *U* test was employed to compare age, height, weight, and BMI.
The patients' MPI (200 patients) was reported by 2 experienced nuclear medicine specialists, blinded to the information regarding history, angiography findings, and outcomes with and without attenuation correction. Additionally, 20 patients were randomly selected and reported twice by each specialist.
According to the obtained Kappa values, there was no significant difference between the reports of the 2 specialists and the results of MPI reported by a reader at the first and second rounds (inter and intraobserver agreement).
Sensitivity, specificity, PPV, NPV, and 95% CI were calculated by comparing the results of MPI and CA in vascular territories.
An improvement in specificity and exacerbation in sensitivity were observed in all 3 territories with the use of attenuation correction. Nonetheless, significant improvements and exacerbations were noted in the right coronary artery (RCA) and left circumflex coronary artery (LCx) regions (*P* <0.05).
A comparison of the results between the 2 sexes in different coronary artery territories showed that the decreased sensitivity in the RCA and LC_X territories was significant just in men. In the RCA territory, a significant increase in specificity was noted in both sexes, whereas in the LC_X territory, it was limited to men. In the left anterior descending artery (LAD) territory with attenuation correction, none of the diagnostic parameters changed significantly in both sexes (Table 3).
Afterward, the sensitivity, specificity, PPV, and NPV of MPI were calculated in individuals with a normal BMI, overweight, and obesity with 95% CIs, respectively (Table 4). In the RCA territory, all the groups exhibited a statistically significant enhancement in specificity and exacerbation in sensitivity. The exception was a decrease in sensitivity in the normal BMI group. In the LCx territory, there was a significant decline in sensitivity, limited to the overweight group. In the LAD territory with attenuation correction, none of the diagnostic parameters changed significantly in all 3 groups.

Table 1: Demographic characteristics of the patients included in the study and a comparison of BMI, height, weight, and age between the 2 excluded groups and the group entered into the final analysis

	Total Number of Patients	Patients Excluded due to Muscle Bridging	Patients Excluded due to Overcorrection	Patients Remaining in the Study
Men	239 (81.5%)	5 (100%)	80 (90.9%)	154 (77%)
Women	54 (18.5%)	0 (0%)	8 (9.1%)	46 (23%)
	P value		0.006	
Total	293	5	88	200
Body mass index	Normal range		34.1%	20.2%
	Overweight		36.4%	42%
	Obese		29.5%	37.8%
	Mean		27.3 (24.3-30.4)	28.8 (25.7-31.7)
	P value		0.022	
Weight	Mean		80 (70-90)	84 (73-93)
	P value		0.033	
Height	Mean		170 (160-178)	170 (160-176)
	P value		0.379	
Age	Mean		59.7±10	58.2±10
	P value		0.242	

Table 2: Sensitivity, specificity, PPV, and NPV of MPI with and without AC compared with coronary angiography

Territory	Ischemia in MPI		Ischemia in Angiography*		Diagnostic Accuracy **			
			Yes	No	Index	AC (95% CI)	NAC (95% CI)	*P* value
RCA	AC	Yes	25	7	Sensitivity	42.4% (29.6-55.9)	86.4% (75.0-93.9)	<0.001
		No	34	131	Specificity	94.9% (89.8-97.9)	47.1% (38.5-55.7)	<0.001
	NAC	Yes	51	73	PPV	78.1% (62.0-88.6)	41.1% (36.6-45.2)	<0.001
		No	8	65	NPV	79.4% (75.5-82.7)	89.0% (80.6-94.0)	0.072
LCx	AC	Yes	16	9	Sensitivity	32.7% (19.9-47.5)	61.2% (46.2-74.8)	0.005
		No	33	139	Specificity	93.9% (88.7-97.1)	86.5% (79.9-91.5)	0.031
	NAC	Yes	30	20	PPV	64.0% (45.6-79.0)	60.0% (48.5-70.4)	0.737
		No	19	128	NPV	80.8% (77.5-83.7)	87.1% (82.4-90.5)	0.131
LAD	AC	Yes	53	26	Sensitivity	66.3% (54.8-76.4)	76.3% (65.4-85.0)	0.162
		No	27	91	Specificity	77.8% (69.1-84.9)	69.2% (60.0-77.4)	0.139
	NAC	Yes	63	34	PPV	77.1% (70.9-80.3)	62.9% (55.7-69.5)	0.562
		No	17	83	NPV	67.1% (58.3-74.7)	81.0% (73.8-86.5)	0.484

* The results are presented as frequencies.
** All the indices are presented with a 95% CI.
AC, Attenuation-corrected; NAC, Non–attenuation-corrected; MPI, Myocardial perfusion imaging; NPV, Negative predictive value; PPV, Positive predictive value; CI, Confidence interval; LAD, Left anterior descending artery; RCA, Right coronary artery; LCx, Left circumflex artery

Table 3: Sensitivity, specificity, PPV, and NPV of MPI with and without AC compared with coronary angiography in men and women

	Men				Women			
	PPV	NPV	Specificity	Sensitivity	PPV	NPV	Specificity	Sensitivity
RCA NAC	43.4% (38.3-48.6)	87.0% (76.6-93.2)	45.6% (35.7-55.7)	86.0% (73.2-94.1)	33.3% (24.5-43.4)	95.0% (74.4-99.2)	54.3% (36.6-71.1)	88.9% (51.7-99.7)
RCA AC	78.6% (61.3-89.4)	77.6% (72.9-81.6)	94.2% (87.7-97.8)	44.0% (29.9-58.7)	75.0% (41.9-92.5)	91.7% (81.3-96.5)	94.3% (80.8-99.3)	66.7% (29.-92.5)
P value in RCA	0.001	0.144	<0.001	<0.001	<0.001	0.643	<0.001	0.257
LCx NAC	69.2% (55.7-80.0)	86.0% (80.5-90.0)	89.1% (81.7-94.2)	62.8% (46.7-77.0)	50.0% (29.0-70.9)	97.1% (84.5-99.5)	86.8% (71.9-95.5)	83.3% (35.8-99.5)
LCx AC	78.9% (56.8-91.4)	79.1% (75.2-82.5)	96.4% (90.9-99.0)	34.9% (21.0-50.9)	33.3% (10.38-68.3)	89.5% (82.6-93.8)	89.5% (75.2-97.0)	33.3% (4.3-77.7)
P value in LCx	0.437	0.159	0.038	0.01	0.515	0.206	0.0723	0.079
LAD NAC	65.9% (58.1-72.7)	80.3% (71.3-86.9)	67.1% (56.0-76.8)	79.4% (67.88-88.2)	60.0%	89.7%	81.3%	75.0%
LAD AC	66.7% (57.2-74.9)	72.4% (65.0-78.7)	74.1% (63.4-83.0)	64.7% (52.1-75.9)	63.6% (38.3-83.1)	84.8% (73.9-91.7)	87.5% (71.0-96.4)	58.3% (27.6-84.3)
P value in LAD	0.917	0.25	0.330	0.056	0.851	0.573	0.491	0.386

AC, Attenuation-corrected; NAC, Non–attenuation-corrected; MPI, Myocardial perfusion imaging; NPV, Negative predictive value; PPV, Positive predictive value; CI, Confidence interval; LAD, Left anterior descending artery; RCA, Right coronary artery; LCx, Left circumflex artery

Table 4: Sensitivity, specificity, PPV, and NPV of MPI with and without AC compared with coronary angiography in patients with normal BMI, overweight, and obesity

	Normal BMI				Overweight				Obese			
	PPV	NPV	Sensitivity	Specificity	PPV	NPV	Sensitivity	Specificity	PPV	NPV	Sensitivity	Specificity
RCA NAC	35.0% (24.0-47.7)	88.2% (67.8-96.3)	77.8% (39.9-97.1)	53.6% (33.8-72.4)	46.2% (39.5-52.9)	92.0% (74.5-97.8)	92.3% (74.8-99.0)	45.1% (31.1-59.6)	31.7% (24.3-40.1)	86.7% (72.5-94.1)	76.5% (50.1-93.1)	48.1% (34.3-62.1)
RCA AC	71.4% (36.7-91.4)	86.7% (75.6-93.1)	55.6% (21.2-86.3)	92.9% (76.5-99.1)	76.5% (54.0-89.9)	78.3% (70.9-84.2)	50.0% (29.9-70.0)	92.2% (81.1-97.8)	75.0% (39.9-93.1)	82.5% (76.8-87.0)	35.3% (14.2-61.6)	96.3% (87.2-99.5)
P value	0.095	0.877	0.317	0.001	0.03	0.132	0.001	<0.001	0.022	0.613	0.016	<0.001
LCx NAC	70.% (42.7-87.9)	88.9% (75.4-95.4)	70.0% (34.7-93.3)	88.9% (70.8-97.6)	61.1% (41.2-77.8)	83.1% (75.5-88.5)	52.4% (29.7-74.2)	87.5% (75.9-94.2)	58.8% (40.1-75.2)	94.4% (86.2-97.8)	76.9% (46.1-94.9)	87.9% (76.7-94.9)
LCx AC	80.0% (33.5-96.9)	81.3% (72.2-87.8)	40.0% (12.1-73.7)	96.3% (81.0-99.9)	57.1% (24.5-84.5)	75.7% (71.5-79.4)	19.0% (5.4-41.9)	94.6% (85.1-98.8)	60.0% (33.0-82.0)	88.5% (82.2-92.7)	46.2% (19.2-74.8)	93.1% (83.2-98.0)
P value	0.68	0.418	0.299	0.178	0.856	0.308	0.024	0.185	0.952	0.261	0.107	0.342
LAD NAC	86.7% (62.9-96.1)	81.8% (65.3-91.4)	76.5% (50.1-93.1)	90.0% (68.3-98.7)	69.2% (57.4-78.9)	81.6% (69.0-89.7)	79.4% (62.1-91.3)	72.1% (56.3-84.6)	45.7% (35.4-56.3)	86.1% (73.6-93.2)	76.2% (52.8-91.7)	62.0% (47.1-75.3)
LAD AC	90.0% (55.8-98.4)	70.4% (58.6-79.8)	52.9% (27.8-77.0)	95.0% (75.1-99.8)	70.6% (57.2-81.1)	76.7% (65.6-85.)	70.6% (52.5-84.9)	76.7% (61.3-88.2)	44.0% (30.0-58.9)	78.3% (69-85.3)	52.4% (29.7-74.2)	72.0% (57.5-83.7)
P value	0. 802	0.534	0.151	0.548	0.9	0.594	0.401	0.621	0.85	0.362	0.107	0.288

AC, Attenuation-corrected; NAC, Non–attenuation-corrected; MPI, Myocardial perfusion imaging; NPV, Negative predictive value; PPV, Positive predictive value; CI, Confidence interval; LAD, Left anterior descending artery; RCA, Right coronary artery; LCx, Left circumflex artery

DISCUSSION

In the present study, we aimed to reevaluate the diagnostic value of MPI with CT-based attenuation correction.

In the RCA territory, CT-based attenuation correction led to a significant decrease in MPI sensitivity in men and a significant increase in specificity in all patients except those with a normal BMI. In the LCx territory, a significant reduction in sensitivity was noted just in overweight patients, while specificity improved merely in men. In the LAD territory, none of the diagnostic parameters changed significantly with attenuation correction.

The mean BMI and weight were significantly lower in our 2 excluded groups than in our group of patients entered into the final analysis; there was, however, no significant difference in height and age. Our examination of the effects of attenuation correction on diagnostic parameters by sex showed that decreased sensitivity, increased specificity, and PPV were significant in men in the RCA territory. We also found a significant decrease in sensitivity and an increase in specificity in the LCx territory. In the LAD territory, none of the changes were significant. These changes were significant in women in the RCA territory for increased specificity and PPV. None of the changes were statistically meaningful in the LCx and LAD territories in women. As a result of hypersensitivity in the RCA, sensitivity and specificity in the LC_X were significant in men only.

In a study by Xin et al, [16] who used CT-based attenuation correction, all the patients underwent CA for up to 6 months after MPI. A significant improvement in specificity and exacerbation in sensitivity were observed only in patients with a minimum BMI of 24. In our study, specificity improvement in the RCA territory with attenuation correction occurred in all BMI groups (including normal BMI), and decreased sensitivity in the RCA territory was noted in overweight and obese patients. We also showed that decreased sensitivity was significant in the LCx territory of overweight patients. It should be borne in mind that according to Chinese guidelines, a minimum BMI of 24 is considered overweight, whereas this category in Europe and the United States, as well as our study, is defined as a BMI of greater than 25. Similar to our study, the diagnostic specificity of CAD detection with attenuation correction was significantly higher in the RCA territory. Xin and colleagues reported that the diagnostic specificity of CAD with attenuation correction was significantly higher than non-attenuation correction only in men. In our study, specificity was higher in the RCA territory in both sexes and the LCx territory only in men.

Raza et al [17] investigated the effects of attenuation correction with CT on the sensitivity, specificity, and accuracy of MPI in 102 patients. Attenuation correction resulted in an increase in specificity in all 3 territories, but the increase was significant only in the RCA territory. In our study, the increase in specificity was significant in the LCx territory in addition to the RCA territory. Similar to the previous study, all the patients underwent CA for up to 6 months after MPI.

Sharma et al [18] showed that MPI with attenuation correction was markedly less sensitive in the RCA territory, which chimes in with our study. One of the limitations of their study was its small sample size (171 persons) by comparison with our study. Sharma and colleagues concluded that although the blindness of the interpretation makes it more valid, the fact that this method is different from routine practice can affect the reader’s interpretation. Their conclusion is concordant with the present study.

A semiquantitative study by Huang et al [19] showed that CT-based attenuation correction in the anterior wall lessened specificity. In contrast, we found that in both sexes, CT-based attenuation correction boosted specificity in the LAD territory, although its impact was not significant. A notable difference between our studies is that we did not utilize quantitative analysis. Huang and colleagues concluded that this technique was more effective in men than in women.

In another semiquantitative study, performed by Tonge et al, [20] a significant fall in perfusion defect scores was observed in the inferior wall score with attenuation correction just in men. Once again, a difference of note between our investigations is that we did not make use of quantitative analysis.

We observed that 30% (88 patients) of our study population had overcorrection in attenuation-corrected images with no obvious subdiaphragmatic activity in non–attenuation-corrected images. This could be a disadvantage of CT-based attenuation correction. Still, it is worthy of note that had we employed scatter correction software, we might have obtained different results. Further studies are, therefore, warranted.

Limitations

The high prevalence of overcorrected images was a limitation of our study. Nevertheless, this limitation should be interpreted in light of the fact that we did not draw upon scatter correction.

CONCLUSIONS

Performing CT-based attenuation correction significantly augments diagnostic specificity and worsens sensitivity in the RCA and LCx territories. The advantage of using CT-based attenuation correction is more prominent in patients with a normal BMI and women.

New Knowledge Gained

Given the relatively low sensitivity of attenuation-corrected images in the RCA and LCx territories, we recommend that MPI reporters pay special heed to the pretest probability of CAD and keep the use of non–attenuation-corrected images or prone images in mind in order to decrease false-negative results in these territories.

Availability of Data and Materials

The datasets used in this study are available from the first author and corresponding author upon reasonable request.

Acknowledgments

We thank the staff members of the Nuclear Medicine Department of Rajaie Cardiovascular Medical and Research Center for their collaboration in imaging.

Disclosure

None of the authors of this paper has a financial or personal relationship with other people or organizations that could inappropriately influence or bias the content of the paper.

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