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FULL PAPER

Using “iDose⁴” iterative reconstruction algorithm in adults’ chest–abdomen–pelvis CT examinations: effect on image quality in relation to patient radiation exposure

I ARAPAKIS, MD, E EFSTATHOPOULOS, PhD, V TSITSIA, BSc, S KORDOLAIMI, MSc, N ECONOMOPOULOS, MD, S ARGENTOS, MD, A PLOUSSI, MSc and E ALEXOPOULOU, MD, PhD

2nd Department of Radiology, Medical School, National and Kapodistrian University of Athens, Athens, Greece

Address correspondence to: Mr Ioannis Arapakis
E-mail: arapakisj@gmail.com

Objective: The aim of this study is to examine the effect of iDose⁴ hybrid iterative reconstruction algorithm (Philips Healthcare, Cleveland, OH) on radiation dose and image quality in chest–abdomen–pelvis (CAP) CT scanning of adult patients.

Methods: CAP CT examinations were performed on 99 patients with the use of the “old standard” protocol performing filtered back projection reconstruction algorithm (FBP protocol) and on 84 patients with the use of iDose⁴ protocol on a 64-multidetector CT. Patients were subdivided into three weight groups (Group 1, 41–60 kg; Group 2, 61–90 kg; and Group 3, >90 kg). Volume CT dose index and dose length product (DLP) were recorded, while effective dose was calculated from DLP measurements. Objective image noise, signal-to-noise

ratio and contrast-to-noise ratio were calculated. Two radiologists reviewed images to evaluate image quality.

Results: Compared with the FBP protocol, there was an overall 46.5% significant decrease in effective dose with the use of iDose⁴ protocol.

Conclusion: Objective image quality was higher in iDose⁴ images than in FBP images. Subjective image noise, sharpness, contrast and diagnostic confidence scores tended to be better for iDose⁴ protocol at the decreased radiation exposure level. Artefacts were minor for both protocols.

Advances in knowledge: Our results suggest that the iterative acquisition protocol provides great potential for reducing radiation exposure and maintaining or improving image quality in CAP CT examinations.

Chest–abdomen–pelvis (CAP) CT examination is the second most common CT examination after head CT¹ and is used to investigate manifestations of systemic diseases, infections or neoplasms (e.g. Hodgkin’s lymphoma), or generally it is used for diseases that indicate chest, and upper and lower abdomen abnormalities. It is an examination that can be repeated frequently to estimate whether the patient is responding to treatment or to detect relapsed disease. According to Hart et al,¹ CAP CT scanning makes the largest contribution to the collective dose (16%) in common CT examinations. Regarding patient radiation exposure, effective dose from CAP CT examinations ranges from 7 to 28 mSv.^{2–5} Owing to the high exposure and the frequency of CAP CT studies, there is increasing concern about patient exposure that recommends optimization and reduction of the radiation dose.

However, patient radiation exposure cannot be considered separately from diagnostic image quality. Dose reduction should be performed only under the condition that image

quality is equal to or better than a minimum acceptable threshold set by the radiologists. Immoderate exposure reduction can adversely affect image quality and reduce the visibility of lesions. Hence, there must be a trade-off between image quality and radiation dose for the optimization of CT protocol. Iterative reconstruction (IR) algorithms seem to have the potential of reducing CT patient radiation exposure without any significant loss in image quality.

iDose⁴ is a fourth-generation hybrid IR algorithm introduced by Philips Healthcare (Cleveland, OH). iDose⁴ provides an innovative solution in which iterative processing is performed in both the projection and image domains. The reconstruction algorithm starts first with projection data, where it identifies and corrects the noisiest CT measurements. Through an iterative diffusion process, the noisy data are penalized and edges are preserved. The next major component of the iDose⁴ algorithm deals with subtraction of the image noise while preserving the

Table 1. Patients' characteristics in different weight groups

Patient weight (kg)	Characteristics	Filtered back projection	iDose ⁴
41–60	No. of patients	20	20
	Age (years)	67.4 ± 14.1	64.8 ± 16.0
	Effective diameter (cm)	25.0 ± 2.0	25.6 ± 3.1
61–90	No. of patients	54	44
	Age (years)	62.7 ± 16.3	63.3 ± 14.4
	Effective diameter (cm)	30.0 ± 2.8	29.6 ± 2.4
≥90	No. of patients	25	20
	Age (years)	55.3 ± 16.4	59.1 ± 14.7
	Effective diameter (cm)	35.1 ± 3.0	35.8 ± 2.0

iDose⁴ has been obtained from Philips Healthcare, Cleveland, OH.

underlying edges associated with true anatomy or pathology. Following this, a selector chooses among noiseless structural models, and the model that best fits the local topology of the image volume is chosen. Once the best model is chosen, it is used to reduce the noise in the image volume.^{6,7}

The goal of the present study is to investigate the effect of the use of iDose⁴ protocol in adult CAP CT examinations on image quality and on patients' radiation exposure.

METHODS AND MATERIALS

Patient study

Our retrospective study consisted of 230 patients (62.20 ± 15.65 years) who underwent CAP CT examination between October 2010 and February 2013. All patients were adults and able to be placed in supine position with both arms elevated above the head and hold their breath for at least 10 s. General exclusive criteria were renal insufficiency and history of allergic reaction to iodine contrast material. Of the 230 diagnostically accepted examinations, 47 were excluded from the analysis since no contrast medium was injected. Therefore, a total of 183 patients (62.2 ± 15.4 years, 102 males/81 females) were included in the present study. All patients received 270–370 mg ml⁻¹ of iodine contrast material. Our study consisted of 2 cohorts: 99 patients (61.78 ± 15.9 years) underwent CAP CT examination with the routine acquisition protocol [filtered back projection (FBP) protocol] before the implementation of iDose⁴ algorithm, and 84 patients (62.6 ± 14.8

years) underwent CAP CT examination with the iterative acquisition protocol (iDose⁴ protocol), which occurred in March 2012.

CT data acquisition and image reconstruction

All CAP studies were performed on a 64-slice multidetector CT scanner (Brilliance; Philips Healthcare) using dose modulation technique. According to the department's protocol, all patients underwent CAP CT examination with a weight-based adjustment of exposure settings. Patients were categorized into three weight groups: 41–60 kg (Group 1), 61–90 kg (Group 2) and >90 kg (Group 3). Information on patients' demographic characteristics is presented in Table 1.

The FBP group was scanned with the routine exposure settings, while the iDose⁴ group was scanned with reduced exposure settings using two levels of hybrid IR algorithm. iDose⁴ Level 4 (L4; 50%/50% blend of IR/FBP) and Level 6 (L6; 70%/30% blend of IR/FBP) were chosen for the present study, leading theoretically to an image denoising of 29% and 45%, respectively, compared with FBP.^{6,7} All image data sets of the iDose⁴ group were reconstructed with both L4 and L6.

Scanning parameters including helical acquisition mode, 3 mm reconstructed slice thickness, standard filter and 64 × 0.625 mm detector configuration were kept constant for both FBP and iDose⁴ protocols. For iDose⁴ protocol, reduced tube current time product was selected according to the vendor's instructions. Data acquisition parameters are summarized in Table 2.

Table 2. Acquisition parameters

Patient weight (kg)	Characteristics	Filtered back projection	iDose ⁴
41–60	Voltage (kVp)	120	100
	Exposure (mAs)	74–182	63–119
61–90	Voltage (kVp)	120	120
	Exposure (mAs)	86–350	56–128
≥90	Voltage (kVp)	140	140
	Exposure (mAs)	137–362	62–167

iDose⁴ has been obtained from Philips Healthcare, Cleveland, OH.

Radiation exposure assessment

For radiation dose estimation, volume CT dose index (CTDI_{vol}) and dose length product (DLP) were recorded from the console of the CT scanner for all the CAP CT examinations. The effective dose (mSv) was estimated using DLP multiplied by a k conversion coefficient for the CAP region. The International Commission on Radiological Protection, publication no. 60⁸ and 103,⁹ do not provide k conversion factors for the CAP region. In the present study, for the estimation of effective dose, $k = 0.015 \text{ mSv mGy}^{-1} \text{ cm}^{-1}$ was used according to Christner et al.¹⁰ Effective dose is a well-established radiation exposure quantity, which is widely used

in CT dosimetry and therefore allows a direct comparison of our results with other published studies.

Objective image analysis

For each CT image series, image noise, contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) were evaluated. Circular regions of interest (ROIs) were placed in the muscle (1 cm^2), the pulmonary artery (1.5 cm^2), the liver (2 cm^2) and the abdominal aorta (0.5 cm^2) to measure the CT values (in Hounsfield units). The ROIs were placed by one radiologist (IA with 5 years experience in chest-abdominal imaging) who was blinded to all

Figure 1. Axial (i) chest and (ii) abdomen-pelvis multidetector CT images obtained with (a) filtered back projection, (b) iDose⁴ (Philips Healthcare, Cleveland, OH) Level 4 and (c) iDose⁴ Level 6. Regions of interest were drawn on the pulmonary artery, muscle, liver and abdominal aorta. SD, standard deviation.

scanning parameters. Window settings (window level and window width) were consistent in all images that were evaluated. Specifically, the window width was 350 HU and the length was 40 HU. The pulmonary artery ROIs were placed at the level of the pulmonary artery division, the muscle ROIs were placed at the latissimus dorsi muscle, and the liver and abdominal aorta ROIs were positioned at the level of the origin of the superior mesenteric artery. ROIs were placed in identical positions for all image series (Figure 1). All CT attenuation value measurements were performed in three contiguous slices, and the mean CT attenuation value and the standard deviation (SD) were recorded. Image noise was determined as the SD of the attenuation value (in Hounsfield units). The SNR and CNR were calculated using the following formulas:

$$\text{SNR} = \frac{\text{HU}_o}{\text{SD}_o} \quad (1)$$

where HU_o is the mean attenuation value and SD_o is the SD in the ROI.

$$\text{CNR} = \frac{\text{HU}_o - \text{HU}_m}{\sqrt{\text{SD}_o^2 + \text{SD}_m^2}} \quad (2)$$

where $\text{HU}_{o,m}$ and $\text{SD}_{o,m}$ are the mean attenuation value and mean SD for the organ of interest and muscle, respectively.

Subjective image analysis

Subjective image noise, sharpness, contrast, diagnostic confidence and artefacts were evaluated independently by two radiologists with experience in CAP CT examinations (EA with 23 years' experience and NE with 25 years' experience) using a five-point scale (Table 3). The readers assessed the chest and the abdomen–pelvis region separately. The evaluation of the image quality was performed on a picture archiving and communication system diagnostic workstation (EISO; Eizo® Nanao Technologies Inc., Cypress, CA). The radiologists provided clinical diagnosis for all patients before image quality evaluation.

Statistical analysis

Statistical analysis was performed using SPSS® v. 21.0 statistical software (SPSS Inc., Chicago, IL). For all studies, a p -value of ≤ 0.05 was defined as statistically significant. Continuous variables are expressed as mean $\pm$ SD.

Overall differences in baseline demographic characteristics and exposure quantities among FBP and iDose⁴ protocols were calculated using the one-way analysis of variance test. To compare objective image noise, SNR and CNR for the two protocols, a Student's paired t -test was performed. Subjective image data were compared using the Wilcoxon signed rank test. Interobserver agreement for the two radiologists was assessed using Cohen's weighted κ analysis. The following κ values were used to signify agreement: $\kappa = 0.00$ –0.21, poor agreement; $\kappa = 0.21$ –0.40, fair agreement; $\kappa = 0.41$ –0.60, moderate agreement; $\kappa = 0.61$ –0.80, good agreement; and $\kappa = 0.81$ –1.0, excellent agreement.

RESULTS

Patient population

There was no statistical difference between FBP and iDose⁴ groups in terms of age ($p = 0.770$) and effective diameter ($p = 0.643$).

Radiation exposure assessment

The overall effective dose was calculated to be 12.9 ± 3.2 mSv (range, 4.4–33.5 mSv) for FBP and 7.1 ± 1.5 mSv (range, 0.9–17.2 mSv) for iDose⁴ protocol. Radiation exposure quantities for FBP and iDose⁴ protocols are listed in Table 4. The results show that iDose⁴ allows an overall reduction of 45.4% in the CTDIvol, 46.2% in DLP and 46.5% in effective dose compared with the FBP protocol. All differences in CTDIvol, DLP and effective dose were statistically significant between the two protocols ($p < 0.0001$). In patients with a weight < 60 kg, the mean effective dose reduction was 55.9%, while in patients with a weight > 90 kg it was 45.9% using iDose⁴.

Objective image assessment

Image noise, SNR and CNR values for the two protocols are summarized in Table 5. iDose⁴ images show significantly lower

Table 3. Grading scale for subjective image quality evaluation

Image characteristics	1	2	3	4	5
Noise	Minimal or no noise	No significant noise	Noisy diagnostic	Significant noise—affects diagnosis	High level noise—non-diagnostic
Sharpness	Excellent sharpness	Good sharpness	Moderate sharpness	Poor sharpness—bad visibility	Zero visibility—non-diagnostic
Contrast	Excellent contrast	Very good contrast	Good contrast	Poor contrast—unsatisfactory visualization	Non-diagnostic—image similar to the use of no contrast
Diagnostic confidence	Completely confidence	High confidence	Good confidence	Poor confidence	No diagnostic confidence—unacceptable
Artefacts	No artefacts	Insignificant artefacts	Minor artefacts	Major artefacts—diagnosis still possible	Artefacts affecting diagnostic information
Blotchy appearance	Absent	Mild	Moderate	Significant—diagnosis still possible	Intense—affecting diagnosis

Table 4. Radiation exposure quantities for filtered back projection (FBP) and iDose⁴ protocols for the three weight groups

Patient weight (kg)	Characteristics	FBP	iDose ⁴	Reduction (%)
41–60	CTDIvol (mGy)	8.0 ± 3.3	3.5 ± 0.8	56.2
	DLP (mGy cm)	484.4 ± 114.3	212.9 ± 65.9	56.0
	Effective dose (mSv)	6.8 ± 1.6	3.0 ± 0.9	55.9
61–90	CTDIvol (mGy)	9.9 ± 2.3	6.1 ± 1.4	38.4
	DLP (mGy cm)	710.1 ± 179.1	422.4 ± 96.2	40.5
	Effective dose (mSv)	9.9 ± 2.5	5.9 ± 1.3	40.4
≥90	CTDIvol (mGy)	23.6 ± 6.4	12.8 ± 2.4	45.8
	DLP (mGy cm)	1724.6 ± 446.3	938.3 ± 172.5	45.6
	Effective dose (mSv)	24.2 ± 6.2	13.1 ± 2.4	45.9
Overall	CTDIvol (mGy)	13.0 ± 3.5	7.1 ± 1.5	45.4
	DLP (mGy cm)	920.7 ± 233.5	495.5 ± 107.2	46.2
	Effective dose (mSv)	12.9 ± 3.2	6.9 ± 1.6	46.5

CTDIvol, volume CT dose index; DLP, dose length product.

iDose⁴ has been obtained from Philips Healthcare, Cleveland, OH.

Data shown as mean ± standard deviation.

image noise ($p < 0.0001$) than FBP images. The image noise of the pulmonary artery, liver and abdominal aorta was reduced by 16–20% between FBP and iDose⁴ L4 and by 33.5–42.2% between FBP and iDose⁴ L6. Statistically significant differences ($p < 0.0001$) were also observed between the two levels of iDose⁴. SNR and CNR were greater ($p < 0.0001$) under the iDose⁴ protocol. Significantly higher SNR and CNR ($p < 0.0001$) were also observed between iDose⁴ L4 and iDose⁴ L6. Compared with the FBP protocol, the SNR was increased by 28.1–42.2% with iDose⁴ L4 and 59.6–80.7% with iDose⁴ L6 for the three ROIs. Contrary to FBP protocol, CNR in the pulmonary artery and abdominal aorta was higher by a factor of 39.2% and 52.3%, respectively, using iDose⁴ L4 and 75% and 92.3%, respectively, with iDose⁴ L6.

Subjective image assessment

Subjective image quality scores are provided in Table 6. None of the images was ranked as unacceptable. All subjective parameters including image noise, sharpness, contrast, diagnostic confidence and artefacts were superior with iDose⁴ to FBP protocol. In comparison with FBP protocol, image noise was statistically significantly lower using iDose⁴ L6 in both the chest and abdomen–pelvis regions. A significant difference in image noise was also observed between the two levels of iDose⁴ in the chest region. Sharpness and diagnostic confidence tended to be better with iDose⁴ protocol, and a significant difference was observed between FBP and iDose⁴ L6 in the chest and abdomen–pelvis regions. iDose⁴ images had a higher contrast than FBP,

Table 5. Objective image assessment for filtered back projection (FBP) and iDose⁴ protocols

Image characteristics and target organs	FBP protocol	iDose ⁴ protocol	
		Level 4	Level 6
Noise			
Pulmonary artery	13.6 ± 2.6	11.4 ± 1.4	8.9 ± 1.3
Liver	17.9 ± 2.9	15.0 ± 1.8	11.9 ± 1.6
Abdominal aorta	22.7 ± 3.8	18.1 ± 2.9	14.1 ± 2.6
SNR			
Pulmonary artery	13.5 ± 3.2	19.2 ± 5.2	24.4 ± 6.8
Liver	5.7 ± 1.6	7.3 ± 2.0	9.1 ± 2.6
Abdominal aorta	8.2 ± 2.5	11.2 ± 3.4	14.6 ± 4.7
CNR			
Pulmonary artery	6.5 ± 2.2	9.9 ± 3.7	12.5 ± 4.7
Abdominal aorta	2.8 ± 1.9	3.9 ± 2.5	4.9 ± 3.2

CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio.

iDose⁴ has been obtained from Philips Healthcare, Cleveland, OH.

Data shown as mean ± standard deviation.

Table 6. Subjective image assessment for filtered back projection (FBP) and iDose⁴ protocols and *p*-values

Image characteristics	FBP protocol	Protocol		<i>p</i> -value		
		L4	L6	FBP <i>vs</i> L4	FBP <i>vs</i> L6	L4 <i>vs</i> L6
Noise						
Chest	2.2 ± 0.4	1.6 ± 0.4	1.2 ± 0.3	0.111	0.000	0.023
Abdomen–pelvis	2.7 ± 0.5	2.1 ± 0.4	1.6 ± 0.5	0.078	0.010	0.251
Sharpness						
Chest	2.1 ± 0.3	1.8 ± 0.5	1.6 ± 0.5	0.430	0.021	0.235
Abdomen–pelvis	2.4 ± 0.5	2.0 ± 0.5	1.7 ± 0.5	0.149	0.007	0.390
Contrast						
Chest	1.9 ± 0.4	1.6 ± 0.5	1.6 ± 0.5	0.240	0.118	0.030
Abdomen–pelvis	2.1 ± 0.5	1.5 ± 0.5	1.4 ± 0.5	0.003	0.000	0.084
Overall image quality						
Chest	2.1 ± 0.2	1.7 ± 0.3	1.5 ± 0.3	0.000	0.000	0.000
Abdomen–pelvis	2.4 ± 0.4	1.8 ± 0.3	1.6 ± 0.3	0.000	0.000	0.000
Diagnostic confidence						
Chest	2.0 ± 0.2	1.8 ± 0.3	1.5 ± 0.5	0.873	0.005	0.036
Abdomen–pelvis	2.2 ± 0.4	1.9 ± 0.4	1.7 ± 0.5	0.755	0.033	0.399
Artefacts						
Chest	2.0 ± 0.7	1.9 ± 0.5	1.7 ± 0.5	0.146	0.903	0.775
Abdomen–pelvis	1.4 ± 0.8	1.7 ± 0.7	1.6 ± 0.6	0.000	0.001	0.393
Blotchy pixelated image						
Chest	1.0 ± 0.0	1.0 ± 0.2	1.3 ± 0.4	0.001	0.000	0.000
Abdomen–pelvis	1.0 ± 0.0	1.2 ± 0.4	2.0 ± 0.4	0.002	0.000	0.000

L4, iDose⁴ Level 4; L6, iDose⁴ Level 6.

iDose⁴ has been obtained from Philips Healthcare, Cleveland, OH.

Data shown as mean ± standard deviation.

and a statistically significant difference was observed between FBP and iDose⁴ L6 in the abdomen–pelvis region. Overall image quality was significantly superior under iDose⁴ to that under FBP protocol. The differences in the artefacts were insignificant in the chest region between the two groups. However, more artefacts were observed in the abdomen–pelvis region for the iDose⁴ protocol. In all cases the artefacts were scored as minor. iDose⁴ L6 images showed a mild blotchy appearance in the abdomen–pelvis region, but this artefact did not affect the diagnostic information. The interobserver agreement between the two radiologists varied from fair-to-good agreement ($\kappa = 0.22$ – 0.71).

DISCUSSION

In this article we evaluate patient radiation exposure in relation to image quality with the application of iDose⁴ IR algorithm in CAP CT examinations. Our study results demonstrate that iDose⁴ protocol permits a 46.5% overall reduction in effective dose while improving image quality compared with FBP protocol. In comparison to FBP, objective and subjective measurements were superior in all regions with the iDose⁴ protocol.

The two readers found that all of 183 CAP CT examinations were diagnostically acceptable. Objective image noise was reduced from 16% to 20% using iDose⁴ L4 and from 33% to 38% using iDose⁴ L6. CNR was higher in iDose⁴ images than FBP, from 39% to 52% for iDose⁴ L4 and from 75% to 92% for iDose⁴ L6, respectively. Subjective image noise, sharpness, contrast and diagnostic confidence tended to be better under the iDose⁴ protocol than the FBP protocol. More artefacts were observed in iDose⁴ images owing to the lower settings that were used. In the chest region, the majority of artefacts were due to the contrast material and beam hardening effect contributed from bone for both protocols. In the abdomen region, most artefacts were caused by Gastrografin® contrast material; however, the artefacts were graded as minor. In iDose⁴ L6 images, mainly in the abdomen–pelvis region, the readers noticed a blotchy and pixelated image texture, which did not affect the diagnostic acceptability. Previous reports have also shown that IR images appear as a blotchy pixelated texture, especially in higher levels of blending.^{11–14}

For the three weight groups, the effective dose reduction was 55.9% for Group 1, 40.4% for Group 2 and 45.9% for Group 3 using

iDose⁴ protocol compared with FBP. As a result, the greatest dose reduction (55.9%) was recorded in patients with lower weights (Group 1). This observation might prove useful for the dose reduction strategy in paediatric patients; however, further investigation should be conducted to draw the safest conclusions. Prakash et al,¹² in a weight-based abdominal CT examination determined that the highest dose reduction corresponds to the group with the lowest weight, which is consistent with our results. In a weight-adjusted chest CT study, the same group¹⁵ shows a constant decrease in effective dose (approximately 27%) for the different weight groups. Sagara et al¹⁶ showed that the average CTDIvol dose reduction was 66% for patients with a body mass index (BMI) of <20 and 23% for patients with a BMI of ≥25.

To the best of our knowledge, this is the first report that assesses the use of iDose⁴ algorithm in CAP CT examinations. In the literature, several studies on chest, abdomen or abdomen and pelvis CT scanning have shown that iterative algorithms clearly outweigh the standard FBP and demonstrate a significant dose decrease by 25–70%, noise reduction from 8% to 45% and superior subjective image quality.^{17–20} In a recent study of trauma patients who underwent CAP CT examination, Maxfield et al²¹ showed that the ASiR™ algorithm (GE Healthcare, Waukesha, MI) led to nearly a 20% dose reduction with no significant difference in image quality before and after ASiR use. One abdominal CT study with the use of iDose⁴ Level 5 was reported by Namimoto et al.²² The article concluded that the CTDIvol was reduced by 41%, and the contrast and overall image quality were

better using iDose⁴ than FBP protocol. In an article for paediatric patients, Ardley et al²³ found that iDose⁴ Level 6 can provide a 92% dose reduction in chest CT examinations.

One limitation of our study is that the data for the dose comparison between iDose⁴ and FBP protocols were obtained from two different patient populations. Nevertheless, no significant difference in patients' age and effective diameter between the two reconstruction sets was observed. Additionally, to obtain reliable conclusions for the radiation exposure in relation to image quality, FBP and iDose⁴ protocols must be *ex ante* optimized. In the present study, as demonstrated by our results, iDose⁴ settings need more optimization. Published data for iterative algorithms could be useful for better understanding of the application of iterative algorithms in clinical practice.

CONCLUSION

The present study shows that iDose⁴ protocol allows a 46% reduction in effective dose in adult CAP CT examinations while improving image quality. The results demonstrate that even further dose reduction can be safely achieved for CAP CT examinations using iDose⁴ technique.

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