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Low kilovolt “prospective ECG-triggering” vs. “retrospective ECG-gating” coronary CTA: comparison of image quality and radiation dose

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ABSTRACT

Background: To compare image quality and radiation doses of low kilovolt (kV) “prospective ECG-triggering” (PT) and standard “retrospective ECG-gating” (RG) coronary computed tomography (CT) angiography. ***Materials and Methods:*** A total of 101 consecutive patients (76 males, 25 females; mean age: 55.44 ± 8.28 years) with low-to-intermediate risk status for coronary artery disease and with a body mass index (BMI) of <30 kg/m^2 were prospectively included in the study. The images were acquired with a 64-detector (128-slice) CT using the tube current modulation technique. The PT CT technique (100 kV, heart rate [HR]<70) was applied in 59 patients, while the RG CT technique (120 kV, HR≥70-90) was applied in 42 patients. The study was approved by the ethics committee. All patients provided informed written consent. ***Results:*** No significant difference was found between age, sex and BMI of both groups ($p > 0.05$). The mean image quality score was 2.87 ± 0.25 for the low kV PT CT technique and 2.73 ± 0.31 for the RG CT technique, which was statistically significant ($p < 0.05$). No statistically significant difference was found between groups for signal-noise and contrast-noise ratios ($p > 0.05$). The mean effective dose was 1.43 ± 0.3 mSv for low kV PT CT technique and 8.20±2.36 mSv for the RG CT technique ($p < 0.001$). ***Conclusion:*** In the low kV PT CT technique, the radiation dose is significantly reduced without loss of image quality. This technique can reliably be used in patients with BMI<30 kg/m^2 and HR less than 70 bpm.

Keywords: *Prospective ECG-triggering; kilovolt; coronary CTA.*

INTRODUCTION

The role of coronary computed tomographic angiography (CCTA) in the diagnosis of coronary artery disease (CAD) has increased significantly due to its speed, accuracy and noninvasiveness (1-3). In a couple of meta analyses (3), it was shown that multi-detector computed tomography (MDCT) could be highly sensitive and specific for detecting CAD (97% sensitivity and 96% specificity). On the other hand, despite its noninvasive nature, high radiation doses in MDCT compared with conventional angiography, preclude its wider application (1,4,5). Thus, literature on CCTA mostly consists of studies related to reduced radiation doses (1,2,6).

“Retrospective electrocardiographically (ECG)-gated” (RG) CT is a widely used technique for image acquisition in CCTA (2). However, the major drawback of RG CCTA is the high radiation dose associated with the risk of cancer induction (5). Using “prospective ECG-triggering” (PT; “step-and-shot”) instead of retrospective ECG-gating coronary CT scanning provides another effective tool to reduce the radiation dose, especially in selected patients with reasonably low and stable HRs (1,2,4,7,8).

Another way of reducing the dose of CCTA is to reduce the kilovolts (kV) to decrease the tube voltage, which allows an increase in opacification of blood vessels due to an increase in the photoelectric effect and a decrease in

Compton scattering (5,8-11).

In CCTA, the aim is to obtain images of high diagnostic quality with minimum dose. In our study, we aimed to compare the RG CT technique (120 kV) with the PT CT technique applying a low kV (100 kV) for image quality and radiation dose. There is a limited number of studies in the literature using the low kV PT CT technique.

MATERIALS AND METHODS

Patients

In total, 101 patients with low or intermediate risk for CAD (76 males, 25 females; mean age: 55.44 ± 8.28 years) were prospectively included in the study. Exclusion criteria were renal dysfunction (serum creatinine level >1.5 mg/dl), hyperthyroidism, known hypersensitivity reaction to iodinated contrast agent, history of coronary artery bypass grafting, recent intake of metformin, arrhythmia and pregnancy. Inclusion criteria were a body mass index (BMI) of less than 30 kg/m^2, HR≤90 beats per minute (bpm) achieved after the administration of beta-blockers and a coronary calcium load of less than 400 Agatston Units. The study was approved by the institutional review board and written informed consent was obtained from each patient before the examination.

MDCT scanning protocol and reconstruction

CT was performed on a 64-detector (128-slice) CT system (Definition AS+, Siemens Healthcare, Forchheim, Germany). The PT CT technique (100 kV, before breath hold HR< 70) was applied in 59 patients, while, the RG CT technique (120 kV, before breath hold HR ≥ 70-90) was applied in 42 patients. Using the 128-slice CT system for both groups, collimation was 64 × 0.6 mm, which resulted in 128 reconstructed slices per gantry rotation using a z-flying focal spot technique. A nonionic contrast medium (370 mg I/ml) was infused through an 18-G intravenous antecubital catheter at 5.5 ml/s, followed by 50 ml of saline at 5.5 ml/s, which was injected in the antecubital vein for contrast enhanced CT coronary angiography. The injection was performed with a dual-head power injector (Stellant; Medrad, Indianola, Penn). Next, 1.1 ml/kg of iodinated contrast material was applied. For timing purposes, a bolus tracking technique was used with the region-of-interest placed in the ascending aorta, applying a threshold of 120 Hounsfield units and adding an additional delay before CT data acquisition of 7 s. The patients were instructed to hold their breath after mild inspiration. In patients with a HR of ≥70 and with no contraindications, such as chronic obstructive pulmonary disease, asthma, AV block or systolic blood pressure <100 mmHg, 50 mg of oral beta-blocker an hour before the scan was administered. If HR was not below 70 bpm, intravenous beta-blocker (2 mg metoprolol [BelocTM, Schering]; every 3-5 minutes up to a maximal dose of 6 mg) was applied. All patients received 0.6 mg of nitroglycerin sublingually 3 minutes prior to scanning to dilate the coronary arteries.

Contrast enhanced CT images were reconstructed with a field of view of 200 mm, slice thickness of 0.6 mm. For the PT CT group, datasets were reconstructed at 70% of the RR interval, i.e., at the mid-diastolic phase of the cardiac cycle. For RG CT group, datasets were reconstructed in the mid-diastole and end-systole phases, using a motion-mapping algorithm (BestPhase, Siemens Healthcare, Forchheim, Germany).

Assessment of image quality

All images were transferred to a dedicated postprocessing workstation (Leonardo, Siemens Medical Solutions), and analyzed using interactive oblique multiplanar reformations (MPR) and curved-MPR (Syngo Circulation, Siemens). CT image quality was assessed as a double step procedure qualitatively and quantitatively. The reader was unaware of the patients' history and the results of any previous examinations.

Qualitative evaluation involved image quality analysis on a per vessel and per segment basis (left main coronary artery [LM], left anterior descending coronary artery [LAD], left circumflex coronary artery [LCX], and right coronary artery [RCA]) according to a 4-point scale (0-3 score):

insufficient image quality; multiple segments of a coronary artery are nondiagnostic because of severe motion artifacts or noise-related blurring, fair vessel opacification, and structural discontinuity.

1. **insufficient image quality**; a single segment of a coronary artery is nondiagnostic because of severe motion artifacts or noise-related blurring, fair vessel opacification, and structural discontinuity.
2. **moderate but sufficient image quality**; multiple segments of a coronary artery are diagnostic because of mild to moderate motion artifacts or noise-related blurring, good vessel opacification, and no structural discontinuity.
3. **excellent image quality**; multiple segments of a coronary artery are diagnostic because of no motion artifact or noise-related blurring, excellent vessel opacification, and no structural discontinuity.

The image quality score for each single coronary artery was assessed, and subsequently, the mean image quality score of each patient was calculated by using the following formula:

(LM score+LAD score+LCX score+RCA score)/4).

For quantitative evaluation, intraluminal CT attenuation, contrast "enhancement" (intraluminal CT attenuation–perivascular fat tissue attenuation), image-noise, signal-noise ratios (SNRs) and contrast-noise ratios (CNRs) were calculated at the aortic root and proximal coronary arteries according to previously described methods (1,12,13). The following measurements were performed on axial source images (figure 1):

Figure 1. A. Axial CT image (0,6 mm slice thickness), placement of the ROI for measuring the CT attenuation value of the main left coronary artery and perivascular fat tissue is demonstrated. **B.** Axial CT image, placement of the ROI for measuring the CT attenuation value of the aortic root is seen.

- Aortic root: A round-shaped region of interest (ROI) (4 cm^2) was placed within the ascending aorta.
- Coronary arteries: Two round ROIs (as large as possible, 0.03–0.06 cm^2) were placed within two main coronary arteries, the LM and the RCA, proximally. Plaques were excluded from the ROI.
- Perivascular fatty tissue: A ROI (0.07 cm^2) was placed within the perivascular fatty tissue.

Measurement of the radiation dose

The dose–length product (DLP) was obtained from the patient protocol of the system. This method has been shown to be reasonably robust and consistent at estimating the effective dose. The effective dose is derived from the product of the dose–length product and a conversion coefficient for the anatomical region examined, i.e., 0.017 mSv mGy^{-1} cm^{-1} for the chest. In addition, parameters for the volume CT dose index (CTDI) were obtained from each CT examination protocol.

Statistical analysis

Qualitative and quantitative values, radiation dose and image quality of both groups were compared. Statistical analyses were performed using SPSS version 23 software (SPSS Inc, Chicago, IL). Continuous variables were expressed as the mean±standard deviation (SD), and categorical variables were expressed as frequencies or percentages. Nominal variables of both groups were compared using the Chi-square test and Fisher's exact test if appropriate. Student's t-test for independent samples was used to compare all continuous variables that were distributed normally, such as average age, attenuation and CTDI, excluding those that were compared by the non-parametric Mann–Whitney test, such as average HR, BMI, SNR, CNR and DLP. A p-value of less than 0.05 indicated a statistically significant difference.

RESULTS

PT CT and RG CT techniques were successfully performed in 101 patients. Adverse reactions to the beta-blocker, such as bradycardia or bronchospasm, and to the sublingual nitrate, such as tachycardia or a clinically relevant drop in blood pressure, were not observed. The demographics, general clinical information and Agatston scores of the patient groups are shown in table 1. No significant differences between age (54.8 ± 8.8 vs 56.0 ± 7.6 years; p = 0.65), gender (p = 0.45) and BMI (26.7 ± 2.5 kg/m^2 vs 26.8 ± 1.9 kg/m^2; p = 0.79) were found in both groups. Mean heart rate for the PT CT technique was 61.84 ± 5.87 bpm, while it was 74.07 ± 7.02 bpm for the RG CT technique ($p < 0.001$). Heart rate values less than 70 in some patients imaged with the RG CT technique were due to HR decrease following breath holding.

Mean image quality scores were 2.87 ± 0.25 and 2.73 ± 0.31 for the low kV PT CT and RG CT techniques, respectively (table 2). The difference was statistically significant ($p < 0.05$).

Quantitative image quality assessment results are shown in table 3. Intraluminal CT attenuation, contrast enhancement and noise values were higher in the PT CT technique compared to values obtained with the RG CT technique. There was a statistically significant difference between intraluminal CT attenuation, contrast enhancement and noise values of coronary arteries ($p < 0.001$), while no difference was found between SNRs and CNRs of both scanning protocol groups ($p > 0.05$). Due to the higher values of CT attenuation, contrast enhancement and image noise in the low kV PT CT technique, the SNRs and CNRs did not differ in comparison with the RG CT technique in the proximal coronary arteries.

The mean DLP was 85 ± 18.06 mGy.cm (range 45-128 mGy.cm) and 484.19 ± 139.64 mGy.cm (range 236-822 mGy.cm) for the low kV PT CT technique and RG CT technique, respectively. The mean effective dose for the PT CT technique was 1.43 ± 0.3 mSv compared with 8.20 ± 2.36 mSv for the RG CT technique (figure 2). The mean CTDIvol was 6.45 ± 1.17 mGy (range 3.25-8.61 mGy) and 31.4 ± 7.73 mGy (range 19.06-48.17 mGy) for the low kV PT CT technique and the RG CT technique, respectively ($p<0.001$) (table 4). The patient dose was 5.73 times lower for the low kV PT CT technique which corresponds to a radiation dose reduction of 82.6% achieved by lowering the tube voltage to 100 kV. There were 4 subjects in the low kV PT CT group who received a dose less than 1.0 mSv.

Images obtained with the lowest dose in the low kilovolt PT CT technique and images obtained with the RG CT technique for comparative image quality assessment are illustrated in figures 3 and 4, respectively.

Table 1. Demographic features and Agatston score.

	Low kV PT CT technique (59 patients)	RG CT technique (42 patients)	*P* value
Age (y)*	54.8±8.8 (39-77)	56.0±7.6 (44-72)	0.65
Gender (men/women)	46/13	30/12	0.45
BMI (kg/m^2) *	26.7±2.5 (20.9-29.8)	26.8±1.9 (23.1-29.5)	0.79
HR (bpm)*	61.8±5.8 (51-69)	74±7.0 (57-83)	<0.001
HR variability*	2.4± 2.1 (0.9–8.8)	2.9± 2.7 (1.2–10)	0.253
Diabetes mellitus (n,%)	8 (13.5%)	10 (23%)	0.184
Hypertension (systolic pressure< 140mm Hg) (n,%)	26 (44%)	25 (59.5%)	0.125
Elevated serum cholesterol (>200mg/dl) (n,%)	25 (42.3%)	22 (52.3%)	0.320
Smoking (10 pack/years) (n,%)	23 (38.9%)	25 (59.5%)	0.041
Positive family history (n,%)	29 (49.1%)	20 (47.6%)	0.879
Agatston score*	40.53±77.43 (0-255.4)	48.11±86.70 (0-383.4)	0.686

BMI= body mass index. HR=Heart rate; *Data are the mean±SD; numbers in parentheses are the range.

Table 2. Comparison of the resulting coronary image quality.

	Low kV PT CT Technique	RG CT Technique	*P* value
	mean±SD (min:max)	mean±SD (min:max)	
LM	2.98±0.13 (2:3)	3±0 (3:3)	0.385
LAD	2.86(1:3)	2.78±0.41 (2:3)	0.155
LCX	2.81±0.47 (1:3)	2.54±0.67 (1:3)	0.02
RCA	2.84±0.36 (2:3)	2.61±0.69 (0:3)	0.89
Mean image quality score	2.87±0.25 (1.75:3)	2.73±0.31 (1.75:3)	0.003

Table 4. Radiation dose.

	Low kV PT CT Technique	RG CT Technique	*P* value
	mean±SD (min:max)	mean±SD (min:max)	
DLP (mGy.cm)	85±18 (45:128)	484.19±139.63 (236:822)	<0.001
Effective dose (mSv)	1.43±0.3 (0.76:2.1)	8.2±2.36 (4:13.9)	<0.001
CTDI (mGy)	6.45±1.17 (3.25:8.61)	31.42±7.73 (19.06:48.17)	<0.001

Table 3. Quantitative image quality parameters.

	Low kV PT CT Technique	RG CT Technique	*P* value
	mean±SD	mean±SD	
CT attenuation (HU)			
Aortic root	505.9±77.9	384.3±70.9	<0.001
LM	506.6±85.4	386.7±71.7	<0.001
RCA	501±90.4	362.4±69.9	<0.001
Perivascular fat tissue	-66±27.7	-67.1±24.7	0.723
Contrast enhancement (HU)			
Aortic root	571±83.7	450.6±78.6	<0.001
LM	572.2±92.2	450.9±83.6	<0.001
RCA	559.2±96.9	429.5±73.1	<0.001
Image noise (SD of HU)			
Aortic root	37.8±7.5	27.7±5.2	<0.001
LM	34.9±12.3	26.9±8.2	<0.001
RCA	38.9±12.6	29±7.8	<0.001
Perivascular fat tissue	38.7±15.2	31.1±11	0.009
SNR			
Aortic root	13.6±3.3	14.2±3.9	0.526
LM	15.8±5	15.3±4.7	0.537
RCA	13.5±4.3	13±3.3	0.684
Perivascular fat tissue	1.9±1	2.3±1.4	0.058
CNR			
Aortic root	15.5±3.9	16.7±4.5	0.168
LM	18.2±5.7	17.8±5.2	0.669
RCA	15.5±4.7	15.6±3.8	0.778

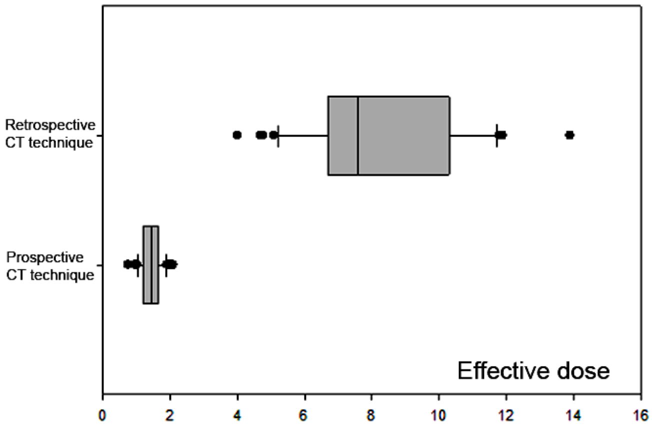

Figure 2. Box plot showing comparison of the low kV PT CT technique and RG CT technique. Values of the two groups were significantly different for effective dose (p<0.001). The line within the box represents the median value.

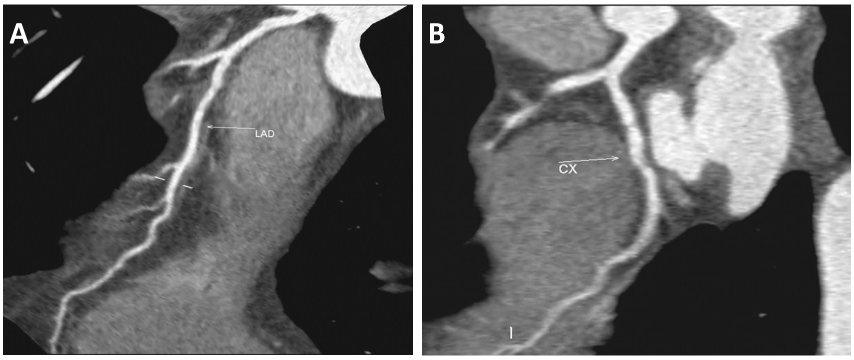

Figure 3. Prospective ECG-triggering coronary CT angiography **A.** Curved multiplanar reformations the left main and LAD coronary artery show no motion artifact or noise related blurring, excellent vessel opacification, and no structural discontinuity (image quality score 3). **B.** Curved multiplanar reformation of the LCX coronary artery show minor motion artifact or noise-related blurring, good vessel opacification, and no structural discontinuity (image quality score of 2).

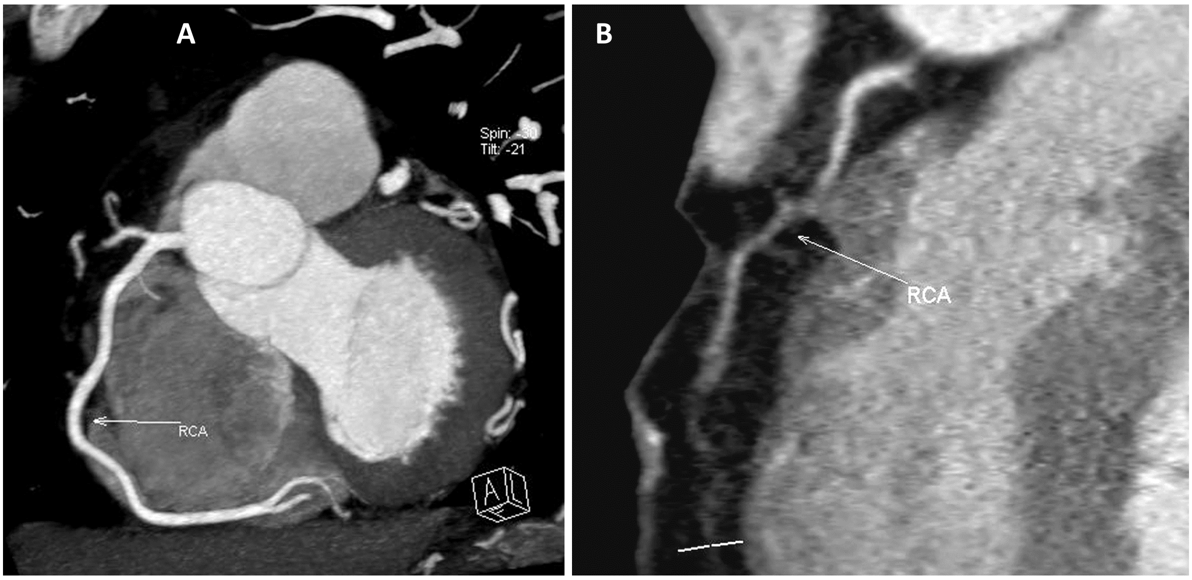

Figure 4. Retrospective ECG-triggering coronary CT angiography **A.** Excellent image quality B. Insufficient image quality, multiple segments of RCA are nondiagnostic due to high HR (83 bpm).

DISCUSSION

Cardiac CT is a reliable and accurate modality for the diagnosis or exclusion of CAD, although its high radiation dose. Radiation doses reported in the literature vary a great deal depending on the scan parameter settings and different generations of CT scanners (14,15). Scanner geometry, tube voltage, tube current, scan range, ECG-gating (prospective versus retrospective), slice thickness, overlap and pitch (for helical scanning), and shielding are factors influencing the overall radiation dose.

To our knowledge, the present study demonstrates the lowest effective doses reported and is the first to demonstrate the diagnostic performance of the prospective ECG- triggering CCTA with low kV technique. We found that a significant decrease in radiation dose reaching almost 82.6% (mean 1.43 ± 0.3 mSv) is attainable with the PT CT technique without any decrease in image quality.

In 2006, Hsieh *et al.* (16) first described a step-and-shoot protocol with prospective ECG- triggering for imaging CAD. They claimed that the patient dose could be reduced by at least 50% when compared to the standard retrospective ECG-gating protocol, without compromising image quality. Studies have shown that the prospective ECG-triggering offers a diagnostic image quality of the coronary arteries (17). The radiation dose can be reduced substantially, and in some series, average doses as low as 2.1 mSv have been reported (1,5). Achenbach *et al.* (11) have reported a mean effective dose as low as 0.87 mSv using the dual source CT and PT CT technique with high pitch values (3.2-3.4).

The main limitation of the PT CT technique is that image quality is dependent on the HR, HR variability and BMI (18). HR can be decreased with intravenous beta-blockers in patients without any contraindications. It is reported that 5-15 mg intravenous beta-blocker can be used for HR control (12). This is the reason why the inclusion criteria for the patients scanned with the PT CT technique in our study were a lack of arrhythmia, HR below 70 bpm (with or without beta-blockers) and BMI of 30 kg/m^2.

The radiation dose can be further reduced with a reduction of the tube voltage. In general, the dose is proportional to the square of the kilo -voltage in the setting of a constant tube current. Therefore, reducing the tube voltage has a greater effect on the reduction of the radiation dose than reducing the tube current (19). Stolzmann *et al.* (9) studied the image quality and radiation dose with dual source CT by using different protocols. The results showed no significant difference in image quality between the 100 kV and 120 kV protocols, but a significant reduction of radiation dose was achieved with the 100 kV protocols (1.2 ± 0.2 mSv) compared with the 120 kV protocols (2.6 ± 0.5 mSv). However, in their study, 100 kV was applied in patients with a BMI of 25 kg/m^2 or less. Gopal et al (17) compared prospective ECG-triggering and retrospective ECG-gating protocols with different kV groups. Their results showed that a radiation dose reduction of up to 90% was achieved with 100 kV (1.93 ± 0.84 mSv) compared to the conventional prospective ECG-triggering at 120 kV. However, in their study, 100 kV was used in patients under 85 kg. Another study similar to ours was done by Feng *et al.* (20) using a 128 detector CT, alhough in their study, the mean radiation dose was 2.71 mSv for the prospective ECG-triggering group and the mean BMI of patients was 24.67 kg/m^2. Hence, combining prospective ECG-triggering with a low kV protocol would be the most effective approach to minimize radiation dose.

There are some limitations in our study. First, we only evaluated image quality and not diagnostic accuracy, e.g., for the detection of coronary artery stenosis. It is not known whether sensitivity and specificity for stenosis detection would differ for the scanning protocols, since most patients did not undergo additional invasive coronary angiography. Second, no patients with HR >70 bpm were included in the PT CT technique. Therefore, we did not assess the quality of the low kV PT CT technique in patients with a high HR.

In conclusion, PT CT can be performed with low kV in patients with a regular heartbeat, HR <70 bpm and BMI <30 kg/m^2. High image quality with minimal radiation dose can be achieved with this technique.

Conflicts of interest: *Declared none.*

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