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Assessment of Gated Single Photon Emission Computerized Tomography Cardiac Wall Motion by Using Different Reconstruction Methods and Filters in Comparison with Quantitative Coronary Angiography

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The aim of this study was to check which of reconstruction (FBP and OSEM) methods and which of (Butterworth, Metz and Ramp) filters with which frequency and order for filtration manner in ECG Gated SPECT (single photon emission computerized tomography) is more coincident with Wall Motion in quantitative coronary angiography methods. In this study, cardiac wall motion of 25 patients (16 males, 9 females, mean ages, 54.08 y) who had an angiography five days before the scanning referred for evaluation of coronary artery disease underwent ^{99m}Tc-tetrofosmin gated SPECT in comparison with quantitative coronary angiography. LV ejection fraction (LVEF), end-systolic volume (ESV) and end-diastolic volume (EDV) from EGS were compared with QCA. Then quantitative regional wall motion was assessed in these patients with both methods. The sampling is continuous and the study was experimental. Motion disorders are classified in four categories: normal = 0, mild = 1, moderate = 2 and severe = 3. For defining the cardiac wall motion, using FBP and OSEM methods in ECG Gated SPECT and by changing the frequency cut-off and order in Butterworth, Metz and ramp filters, found 42 different states that checked them with quantitative coronary angiography findings. LV end-diastolic, LV end-systolic volumes and LV ejection fraction were analyzed with dedicated software. Correlations were excellent between QCA and EGS ($r \sim 0.8$). FBP with ramp filter before the reconstruction, with Metz filter and Order = 9 and FWHM = 5 after the construction in Gated SPECT method have a coincidence with quantitative coronary angiography. By using both physical methods, reconstruction and filtration in Gated SPECT and comparing the cardiac wall motion parameters in Gated SPECT with quantitative coronary angiography, usage of non-invasive Gated SPECT method instead of invasive coronary angiography in some cases is recommended. EGS was in proper agreement with QCA for quantification of cardiac WM. Global and regional LV function and LV volumes can be adequately assessed with EGS. EGS has a robust evidence base, including the support of numerous clinical guidelines and is considered a clinically acceptable method to evaluate cardiac wall motion. Gated SPECT studies allow simultaneous assessment of perfusion and function in a single-injection, single-acquisition sequence.

Key words: Gated spect, quantitative coronary angiography, cardiac wall motion, reconstruction methods

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INTRODUCTION

Among the 58 million deaths in the world in 2005, non-communicable diseases were estimated to account for 35 million. Among the non-communicable diseases, cardiovascular diseases are the leading cause of death, responsible for 30% of all deaths-or about 17.5 million people in 2005. Risk stratification in coronary artery disease is based on estimates of myocardial ischemia (Sciagra and Leoncini, 2005) and left ventricular systolic function (Wahba *et al*., 2001; Candell-Riera *et al*., 2004). Precise and reliable assessment of left ventricular function and dimensions is prognostically important in cardiac patients. Endo-cardiac wall motion can be difficult to assess accurately in patients with previous ischemic heart disease, as passive tethering or gross movement of the heart may complicate it (Giubbini *et al*., 2004). Wall motion, therefore, becomes the most accurate measure of local systolic function.

Ventricular wall motion is generally defined as the displacement of the intersection of a wall edge and an axis of the cardiac coordinate system. One of the methods used in heart imaging is angiography in which cardiac factors are quantitatively shown by using modern software called quantitative coronary angiography (Sharir *et al*., 2000a). Quantitative coronary angiography is a precise method aimed at evaluating coronary stenosis and quality of cardiac wall motion while measuring coronary arteries diameter and ejection fraction. On the other hand, being invasive and uneconomical (Khan and Jacobs, 2003; Sockalingam *et al*., 2005; Gur *et al*., 2006) can be the defects of this angiography method. Recent studies have demonstrated that gated Single Photon Emission Computerized Tomography (SPECT) can evaluate ventricular systolic function in addition to myocardial perfusion imaging (Wahba *et al*., 2001). In ECG Gated SPECT, EGS, method in addition to three mentioned items that can be evaluated and measured by QCA, wall motion at the before of systole and diastole evaluated and measured as well.

The advantage of EGS (Go *et al*., 2004; Berman *et al*., 2007) is being a non-invasive and economical method. Cardiac wall motion factor can be measured by both EGS and QCA methods. In EGS, physical factors such as filtration (Butterworth, Ramp and Metz) with varied cutoff frequencies and orders can be used followed by FBP (filter back projection) and OSEM (ordered-subsets expectation maximization image) reconstruction.

In this study, wall motion data derived from QCA method (as a standard) was used as a source to certify EGS method. Physical factors of filtration and reconstruction are also modified and the best method of reconstruction is selected. Similarly, the most suitable filter is chosen from mentioned filters with suitable frequency and cutoff frequencies and order and finally the results of EGS and QCA are compared.

MATERIALS AND METHODS

To determine wall motion using of the EGS and QCA, 25 patients (16 males and 9 females, mean ages, 54.08 y) who had an angiography five days before scanning was tested by EGS in comparison with QCA in Rajee Hospital Nuclear Medicine Department, Tehran, 2007. The sampling is continuous and the study was semi-experimental.

To collect and classify the data, a questionnaire is designed to put the data in different stages. The individuals in the study were questioned about the causes of danger and other causes effective in the emergence of coronary diseases such as their occupation.

Myocardial perfusion SPECT was performed sixty minutes after injection of 20 mCi of ^{99m}Tc-MIBI, with a fat meal taken by the patient after tracer application (Sharir *et al*., 2001). Data were acquired with a dual-head camera equipped with SMV detectors (DST-Xli, France). The size of the detector is 540×400 mm (used for 45 to 560 KeV) having the thickness of 3.8 inch, 84 hexagonal photomultiplier tube (PMT) and 8 circular PMT. The inherent resolution = 6.5 mm, power of energy resolution = less than 10% and the software = AXL (4.2.1 version). In this gated acquisition, a three-lead ECG provided the R wave trigger to the acquisition computer, with 2 successive R wave peaks on the ECG defining a cardiac cycle. Counts from each phase of the cardiac cycle were associated with a temporal frame within the computer. Gating of myocardial perfusion was performed at 8 frames per R-R interval per projection. The acquired data were then reconstructed and displayed in a cinematic or multi frames format, allowing the reader to assess wall motion in all areas of the myocardium, including the left and right ventricles. Radionuclide used in this study was ^{99m}Tc. It was a two-day injection protocol with ^{99m}Tc. The twenty-mCi injection boosts the system's sensitivity and consequently the image quality (Suratkal *et al*., 2003).

A matrix size of 64×64 pixels and a pixel size of 5.25×5.25 mm were used. A 360° circular orbit and a step-and-shoot imaging protocol (20 stops, 20 seconds per stop) were used for image acquisition. A total of 60 (20×3 heads) projections were acquired for each image set.

The images were reoriented according to the LV axes. Modern reconstruction and review software is used to reorient the transverse thoracic slices into cardiac short-axis slices (Yanagisawa and Maru, 2001). Several validated algorithms are used to analyze these data (Cooke *et al*., 1994; Germano *et al*., 2000; Sharir *et al*., 2000b; Liu *et al*., 2005). These programs segment out the left ventricle, determine the apical and basal limits and then contour the endo-cardiac and epi-cardiac surfaces. These data were analyzed for regional myocardial wall motion and LV volumes using Quantitative Gated SPECT, Cedars-Sinai Medical Center (Hida *et al*., 2003).

All images were modified using FBP and OSEM methods with different filters and then changed into three-dimensional images by Vision Software (Herath and Sharp, 1976; Haddad and Porenta, 1998; Adachi *et al*., 2000). In FBP, Metz (Gilland *et al*., 1988) and Butterworth (Adachi *et al*., 2000) filters and in OSEM method, Ramp (Haddad and Porenta, 1998) filter and consequently 42 different sets (15 for Butterworth, 15 for Metz and 12 for Ramp filters) were used (Lalush and Tsui, 2000; Hambye *et al*., 2004).

In Butterworth filter, 15 different sets are obtained by the change of cutoff frequency (0.25, 0.3, 0.35, 0.4 and 0.45) and order parameters of 3, 6, 9. For Metz filter, 15 sets are achieved by the change of FWHM (4, 4.5, 5, 5.5 and 6) and order of 3, 6 and 9.

In Ramp filter 12 different sets are studied and they are gained by the changes of iteration (2, 3 and 4) and subsets parameters of 4, 8, 12 and 16.

In QCA, GE Med AI 1000 Angio system was used (Revision B, No. 2002377-031) that was the same software as SPECT which was used with the capability to identify the end of systole and diastole, aimed for achieving the cardiac wall motion qualitatively in 5 sections of antero-basal, infero-basal, apex, diaphragmatic and antero-lateral. Cardiac wall motion data is saved by terminal option in card-wall program and can be compared with 5 sections of the above-mentioned sections. Wall motion for each segment was also scored using a 0-3 scale (above 50% = 0 or normal, 40-50% = 1 or mild, 20-40% = 2 or moderate and for less then 20% = 3 or severe). Quantitatively, cardiac wall motion in 42 different sets mentioned above is scored by using QCA method. Statistical analyses were performed with SPSS 14 software. Differences of values between motions of five-myocardium wall from two methods were assessed using Kendall's TAU-B test.

Finally the best filter and method was chosen and the cardiac wall motion in the 5 mentioned sections and the 42 filter sets are compared with the 5 acquired sections in QCA.

RESULTS

During the study period, 25 patients were referred to ^{99m}Tc-MIBI gated SPECT. There were no documented data suggesting any change in clinical status of the patients during the time interval between EGS and quantitative coronary angiography. Clinical characteristics of patients were shown in Table 1.

Table 1: Patients' clinical characteristics and risk factors in this study

Case study (N = 25)	Values
Mean ages(years)	54.08±8.6
Male	16 (64%)
Female	9 (36%)
Risk factors	
Hypertension	13 (52%)
Diabetes mellitus	10 (40%)
Cholesterol	20 (80%)
Smoking	11 (44%)
Triglycerides	20 (80%)
Genetic (Hereditary)	3 (12%)
BMI (>25)	4 (56%)

Table 2: Result for Metz filter with FBP reconstruction method in EGS for the assessment of antero-basal cardiac wall in comparison with QCA

Metz filter FBP	Cases					
	Included		Excluded		Total	
M (FWHM-Order)	N	%	N	%	N	%
M4_3	21	84.0	4	16.0	25	100.0
M4_6	22	88.0	3	12.0	25	100.0
M4_9	23	92.0	2	8.0	25	100.0
M4.5_3	24	92.0	2	8.0	25	100.0
M4.5_6	22	88.0	3	12.0	25	100.0
M4.5_9	23	92.0	2	8.0	25	100.0
M5_3	20	80.0	5	20.0	25	100.0
M5_6	22	88.0	3	12.0	25	100.0
M5_9	23	92.0	2	8.0	25	100.0
M5.5_3	21	84.0	4	16.0	25	100.0
M5.5_6	20	80.0	5	20.0	25	100.0
M5.5_9	22	88.0	3	12.0	25	100.0
M6_3	21	84.0	4	16.0	25	100.0
M6_6	22	88.0	3	12.0	25	100.0
M6_9	22	88.0	3	12.0	25	100.0

To assess and test the validity of left ventricle functions (wall motion, ejection fraction, end of systole and diastole) contrast left ventriculography and radionuclide angiocardiography was used (Scanlon *et al*., 1999). In this method, cardiac wall motion was also divided into different parts and the walls were scored from 0 to 3 (normal = 0, mild = 1, moderate = 2 and severe = 3).

In EGS the FBP method with Metz filter, FWHM = 5, with order = 9 was one of the best. There was a satisfactory coincidence between EGS and QCA (percent match: 92%) in the assessment of antero-basal cardiac wall motion (r = 0.96) as indicated in Table 2.

As shown in Table 3, the acquired figures of correlation are permanently, more than 0.7 indicating that the two discussed groups are related and correlative. The relationship of the compassions are so close to 1 and over 0.7 therefore, an excellent correlation is among the compared groups. For instance, the table of calculated items with Metz filter compared with angiography method for calculation of WM is presented.

Table 3: Results of four Metz filters with FBP reconstruction method in EGS for the assessment of antero-basal cardiac wall

Metz M (FWHM-order)	Correlation	p-value
M4-9	0.89	p<0.001
M4.5-9	0.88	p<0.001
M5-9	0.96	p<0.001
M5.5-9	0.88	p<0.001

Table 4: Results of Metz filters with FBP reconstruction method in EGS in the assessment of overall wall motion (five cardiac wall motions) in comparison with QCA

M(FWHM-Order)	N (case)	Minimum	Maximum	Mean±SD
M4_3	25	2.00	5.00	4.08±0.86
M4_6	25	3.00	5.00	4.44±0.65
M4_9	25	3.00	5.00	4.64±0.56
M4.5_3	25	3.00	5.00	4.12±0.78
M4.5_6	25	3.00	5.00	4.28±0.79
M4.5_9	25	3.00	5.00	4.72±0.54
M5_3	25	2.00	5.00	3.92±0.95
M5_6	25	3.00	5.00	4.52±0.65
M5_9	25	3.00	5.00	4.56±0.58
M5.5_3	25	2.00	5.00	3.96±0.97
M5.5_6	25	3.00	5.00	4.12±0.72
M5.5_9	25	3.00	5.00	4.76±0.52
M6_3	25	3.00	5.00	4.24±0.72
M6_6	25	2.00	5.00	4.20±0.86
M6_9	25	2.00	5.00	4.20±0.95

Table 5: Results of four Ramp filters with OSEM reconstruction method in EGS for the assessment of antero-basal cardiac wall

Ramp filter R (iteration-subsets)	Correlation	p-value
R2-8	0.96	p<0.001
R3-8	0.95	p<0.001
R2-12	0.89	p<0.001

Table 6: Results of four Butterworth filters with FBP reconstruction method in EGS for the assessment of antero-basal cardiac wall

Butterworth B (cutoff-order)	Correlation	p-value
B0.25-3	0.87	p<0.001
B0.35-3	0.95	p<0.001
B0.35-9	0.90	p<0.001
B0.40-3	0.96	p<0.001

In order to have an overall comparison between EF and WM, all the acquired 42 different sets were studied and the correlation of wall motions that were achieved by Gated-SPECT using varied methods and parameters was compared with those wall motions obtained by angiography. The classification was done from the lowest to the highest correlation. This analysis was similarly repeated for ejection fraction study. The best and more accurate Metz filter that could be used for assessment EF and WM from EGS in comparison with QCA are shown in Table 4.

The statistical indexes acquired from Kendall's TAU-B test indicates that the best achieved states after the coincidence of cardiac wall motions obtained from SPECT method with 42 filter states and the two reconstruction methods in 25 studied cases are as follows when compared with QCA method:

Metz filter, correlation ~ 0.9, Percent match ~ 92%
Butterworth filter, correlation ~0.8, Percent match~ 88%

In this study, EGS method along with image-base and count-base algorithm was used.

In addition to common data reconstruction, Metz filters are used with various orders to reconstruct data via FBP method.

In addition, for Ramp filter, correlation ~0.8% match~ 84%. Analysis was similarly repeated for ejection fraction study. The best and more accurate Ramp filters with OSEM reconstruction method used for assessment EF and WM that the results were shown in Table 5. Also Table 6 indicated results of 4 Butterworth filters with FBP reconstruction method in EGS for the assessment of antero-basal cardiac wall.

DISCUSSION

In this study, the usefulness of EGS in the assessment of wall motion by using different reconstruction methods and filters in comparison with QCA was demonstrated. There was a very good agreement between EGS and QCA with ^{99m}Tc-MIBI using Kendall's TAU-B Test. Among the achieved results of Quantitative Angiography and Gated SPECT, the best correlation and percent match for each cardiac wall motion was computed as follows in Fig. 1: Metz 5-9, with the FBP reconstruction method. In EGS has 92% match in antero-basal ($r = 0.96$), 92% in antero-lateral ($r = 0.89$), 88% in apical ($r = 0.83$), 92% in diaphragmatic ($r = 0.94$) and 92% in postero-basal ($r = 0.84$).

Although most cardiac imaging modalities display cardiac anatomy, radionuclide imaging of the heart acquires information about myocardial perfusion, cardiac wall motion and ventricular blood-pool dynamics for the evaluation of coronary artery disease and myocardial function. EGS has made it possible to view ventricular perfusion in any plane, to map the function of the entire left ventricular myocardium into single images, to render gated three-dimensional myocardial surfaces and to estimate chamber volumes (Stollfuss *et al*., 1999).

Diagnostic accuracy was slightly better for gated MIBI. Possible reasons for this difference could be attributed to improved image contrast and resolution of ^{99m}Tc-MIBI, its shorter physical half time and different biologic characteristics (Suratkal *et al*., 2003; Sharir *et al*., 2000a).

This study demonstrated that the reorientation algorithm and the interpolation method significantly affect the accuracy of quantitative image analysis in myocardial SPECT perfusion imaging (Haddad and Porenta, 1998).

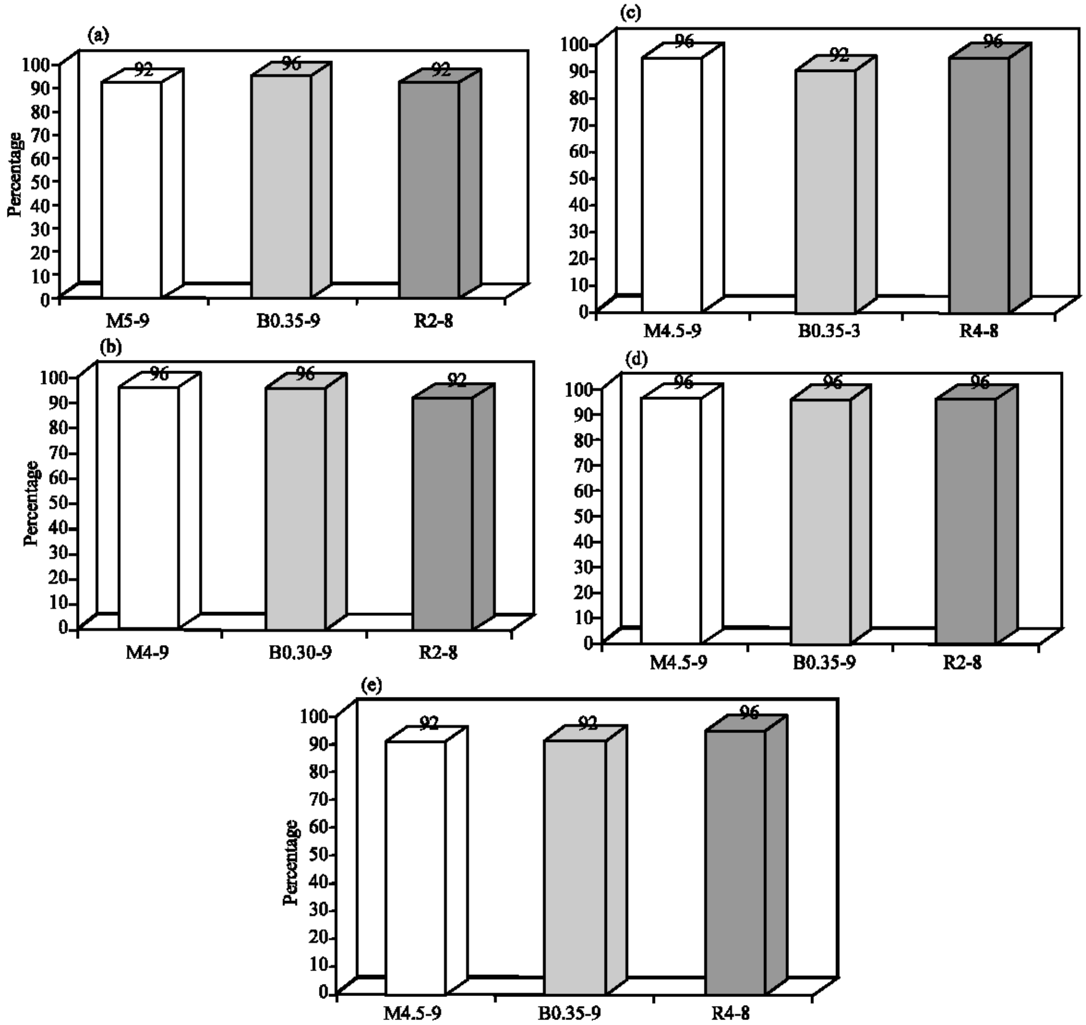

Fig. 1: Ranking of filters with two reconstruction methods that are used in EGS, for assessment of five-wall motions in comparison with QCA, (a) Antero-Basal, (b) Antero-Lateral, (c) Apex, (d) Diaphragmatic and (e) Postero-Basal

There are also some advantages, however, for post reconstruction filtering. One advantage of post reconstruction processing for recovery of resolution is that spatial resolution (MTF) varies much less across a given tomographic slice than it does with distance away from the face of a collimator in planar images.

The Metz filter is a combination of deconvolution and smoothing filters. Most SPECT filter functions allow the user to control the degree of high frequency suppression by choosing a cut-off frequency, or similar filter parameter, which determines where the filter rolls off to zero gain. The location of this cut-off frequency determines how the filter will affect both image noise and resolution. Low cut-off frequencies provide good noise suppression, but they can blur the image. Higher cut-off frequencies can preserve resolution, but often suppress noise insufficiently. An optimum cut-off frequency should exist for a particular filter function which compromises the trade-off between noise suppression and spatial resolution degradation. This optimum will depend on factors such as the detector response function, the spatial frequencies of the object and the count density of the image (Gilland *et al*., 1988).

LIMITATIONS OF THE STUDY

There are some limitations of this study, which need to be addressed. Firstly, for the efficient use of multi-dim reconstruction program, construction of three-dimensional images and choice of an appropriate sample for a research, some essential points need to be considered. Detect the abnormal size of the heart when compared with a normal heart, or the existence of an irritating activity in the digestive system, will cause a defect in boundary of cardiac image.

The Vision 6 Software has been used in the process of preparation of three-dimensional images. Therefore, the software will not be able to compute the proper figure of ejection fraction and cardiac wall motions. The only possible solution which can be suggested for these patients is the use of filters that improve the image so that the system can identify the boundary of the cardiac image. The problem with this solution was creating a fake change in figures of ejection fraction and cardiac wall motions and for these patients a correction needs to be made to the results of ejection fraction and cardiac wall motions.

Another point of this study is that the imaging results using Gated method can be demolished due to creation of artifact and therefore the exactness of what is acquired through this method reduces. Generally, the reduction in image quality is caused by collimator response, scatter and photon attenuation having a negative effect on contrast and resolution of the images. Therefore, since in nuclear medicine data is received counts in to detectors any sorts of omission in photons leads to omission of diagnostic data (Gilland *et al*., 1988; Fakhri *et al*., 2000).

Thirdly, comparison of wall motion analysis and ejection fraction calculations of gated data with echocardiography was not addressed in this study. It will be of interest to search for a correlation between these modalities. Recent data by Nichols *et al.* (2000) indicated that ejection fraction values calculated by echocardiography and gated SPECT showed good correlation and agreement (Maruyama *et al*., 2002; Murashita *et al*., 2000; Lima *et al*., 2003; Mahrholdt *et al*., 2005).

Fourthly, patients with previous myocardial infarction and multi-vessel disease were not evaluated in this study.

Finally, in imaging with Gated SPECT method, the patient's ECG enters the system and the R-R distance is divided. Consequently, the patient's motions artifact is omitted. The reason is that if the patient has any movements, the patient's ECG will change in a way that the R-R distance will be impossible to be computed and it makes the Gated SPECT images have a better resolution compared with normal SPECT images. Unfortunately, due to not having a fixed R-R interval, in patients with cardiac arrhythmia (Alfeeli *et al*., 2007), Gated SPECT method is not possible.

Different processing algorithms make possible to perform a reproducible and reliable assessment of left ventricular (LV) function, which has been extensively various reference (Sciagra and Leoncini, 2005).

CONCLUSION

Using both physical methods, reconstruction and filtration in Gated SPECT and comparing the cardiac wall motion parameters in Gated SPECT with quantitative coronary angiography, both methods showed close correlation with each other and FBP method with 5-9 Metz filter produce brilliants results for analysis of cardiac wall motions. This study has shown high correlation between QCA and EGS method in estimation of five cardiac wall motions. Overall, it is recommended to a use non-invasive and economical Gated SPECT method rather than an invasive coronary angiography for the assessment of ventricular wall motion and actual ability to pump blood.

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