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Comparison of Reconstructive Methods Using Different Filters to Study Cardiac Wall Motions in Gated Single Photon Emission Computerized Tomography

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Abstract: The aim of study is to comparison of two reconstructive methods using different filters to study the five cardiac wall motions via Gated single photon emission computerized tomography imaging was done through Gated SPECT (with a two-day protocol) and quantitative coronary angiography (QCA) on 25 patients (16 males, 9 females, mean ages, 54.08 year). Angiography was performed on patients about 1 to 5 days before scanning. Regional wall motion was determined through two methods: using Gated SPECT, FBP and OSEM reconstructive methods and changes in frequency and spectrum slope in Metz, Butterworth and Ramp, it creates 42 sets. Motion disorders were classified in four groups. This data was compared and evaluated to data which was gained from QCA method in which motion disorders were classified in to four groups, too. The result reveals that in order to study function of each WM, the accurate and precise method is as follows ($r = 0.7$): For antero-basal wall OSEM reconstructive method with Ramp 2-8 filter and FBP reconstructive method with Metz 5-9 and Butterworth 0.35-9 filters is an accurate method. Applying OSEM with Ramp 4-8 filter and FBP with Metz 4.5-9 and Butterworth 0.35-9 filters for postero-basal wall is a suit method. OSEM with Ramp 2-8 filter and FBP with Metz 4-9 and Butterworth 0.30-9 filters for antero-lateral is a sufficient method. For apex wall, OSEM with Ramp 4-8 filter and FBP with Metz 4.5-9 and Butterworth 0.35-3 filters is a reliable method. Finally, applying OSEM with Ramp 2-8 filter and FBP with Metz 4.5-9 and Butterworth 0.35-9 filters for diaphragmatic wall is an accurate method. Electrocardiographic Gated single photon emission computed tomography (EGS) supplies worthwhile functional data to cardiologists. Exercising two physical factors of reconstructive methods and filtration in Gated SPECT, significant information can be obtained about cardiac wall motions. It suggests using an appropriate reconstructive method and filtration for studying cardiac wall motions by non-invasive and economical Gated SPECT method supplies maximum results.

Key words: Wall motion, ECG-Gated myocardial perfusion SPECT, Quantitative coronary angiography, ^{99m}Tc-MIBI

INTRODUCTION

Although regional wall contractility can be quantified, it is more commonly assessed qualitatively. A normal contraction of the left ventricle should show uniform thickening and inward motion of the myocardium. A hypo-kinetic region demonstrates decreased thickening or inward motion compared with other regions. A kinetic region shows an absence of thickening and motion. A dyskinetic region shows an absence of thickening and paradoxical motion during systole and diastole. Some cases such as motionlessness or severe decrease of cardiac wall motion in infarction regions are observed in which no or little bloodstream exists in cardiac muscles. Therefore, identifying the severity and location of lesion plays a significant role in future treatments. Gated SPECT MPI (myocardial perfusion imaging) is a method, which helps a physician to dynamically study the wall motion of a patient's heart (Sciagra and Leoncini, 2005). Gated SPECT MPI is a diagnostic method (Suratkal *et al*., 2003), helping a physician in her/his decision-making on choosing her/his treatment process. This method has some advantages, such as diagnose coronary thrombosis, reveal coronary vessels diseases, estimate severity of ischemia, categorize a patient's risk of getting sick and also categorize illness symptoms.

Furthermore, using a special algorithm, plenty of information can be obtained about cardiac functional parameters. Depending on the filtration type, images can be sharper. This will change the image and its data. It is

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manifested that there is a correlation between regional wall motion abnormalities and severe perfusion defects (Johnson *et al*., 1997). In this study, the assessment of the five cardiac wall motions: postero-basal, antero-basal, apex, diaphragmatic and antero-lateral including the local wall motion of each wall have been considered. With the assistance of a special algorithm, in a short processing time, EGS method can produce reliable data of global and regional parameters of cardiac function (Sharir *et al*., 2001; Maruyama *et al*., 2002; Lima *et al*., 2003; Hida *et al*., 2003; Murashita *et al*., 2003; Giubbini *et al*., 2004). EGS can assess and measure the thickening of wall in systole and diastole. The ECG-Gated myocardial perfusion SPECT using special softwares can produce reliable and significant data and also can measure ejection fraction, regional wall motion and cardiac volumes. Non-invasive EGS imaging is a quick and economical method (Levine *et al*., 1999). QCA is another method for observing dynamic wall motion in which cardiac factors by using advance software can be shown quantitatively (Sharir *et al*., 2000a). This method is known as a precise method for qualitative study of WM, for estimating coronary structure/stricture and measuring cardiac WM (Sharir *et al*., 2000b; Wahba *et al*., 2001; Candell-Riera *et al*., 2004; Sockalingam *et al*., 2005; Sciagra and Leoncini, 2005; Gur *et al*., 2006; Alfeeli *et al*., 2007; Berman *et al*., 2007). The WM data gained by QCA, is used as a reference to validate EGS method. As a result, the accuracy of functional parameters acquired by EGS will be assessed.

The objective of this study is examining functions of FBP (Filter Back Projection) and OSEM (Ordered-Subsets Expectation Maximization) reconstructive methods using Metz, Ramp and Butterworth filters to study the five cardiac wall motions via Gated SPECT method.

MATERIALS AND METHODS

This is a cross-sectional study and a predictive research with continuous sampling done in Department of Nuclear Medicine, Shahid Rajaee Heart Hospital, Tehran, Iran, 2007.

Study group: EGS was performed on twenty-five patients (16 males, 9 females with the age range of 40-68 and mean age, 54.08 year) according to two-day protocol and gating in stress phase. They all had an angiography five days in advance and none of them had a history of infarction. In addition, they were not under revascularization at interval between angiography and MPI.

Exercise protocol: Patients did the exercise test with treadmill and Bruce protocol while the use of Beta-blockers and Nitrates was cut off. For 85% of patients the end of the time were target heart rate, the exercise ECG>2 mm ST segment depression on, or typical ischemic chest pain. In 15% of the rest, positive exercise ECG and typical exercise-induced angina and the rate of maximum target determined the end of the exercise time.

Radionuclide protocol: Two-day Gated SPECT protocol was performed with ^{99m}Tc-MIBI. With respect to the weight of patients 15-22 mCi dose of ^{99m}Tc-MIBI was injected intravenously. This amount of radioactive with increasing the excess numeration would increase the quality of images. All imaging was done 5 to 30 min after stopping exercise.

The SPECT imaging protocol: A dual-head camera SPECT equipped with SMV detectors and DST-XLi made by France located in Shahid Rajaee heart hospital, was used in this study. The size of the detector is 540×400 mm (used for 45 to 560 KeV) with 3.8 inch thickness and having 84 hexagonal photomultiplier tube (PMT) and eight circular PMT. The inherent power of resolution = 6.5 mm and the power of energy resolution = less than 10% and has AXL (4.2.1 version) software. Collimator is of high resolution and low energy. For image acquisition, a 20% acceptance window around the 140 KeV image peak was used, a 64×64×16 matrix was utilized for all studies. Stress acquisitions were gated at eight frames/cycle, with 100% beat acceptance. Detectors were supplied with a cardiac image (in 40 sec) in quadrant circular orbit; for each six grades, one image was captured.

During this time, each detector provided 16 frames of heart. Hence, two detectors provided 32 frames from diverse angles of heart. Imaging began in semicircle, moving from oblique anterior 45 degrees to oblique posterior 135 degrees. The high rate of counting in ^{99m}Tc-MIBI allows to uses Gated SPECT technique, which is used for estimating cardiac perfusion and function coincidently (Fakhri *et al*., 2000; Go *et al*., 2004; Berman *et al*., 2007). In general, using this method the pattern of bloodstream in heart at high activity or rest, wall motion and ejection fraction of ventricular, can be generally and locally delineated. The projection data sets were pre-filtered using studied filters.

OSEM method: Applying Ramp filter in the method gained fifteen different sets. For using Ramp filter twelve sets were assessed. These sets were obtained by changing two subsets and iteration parameters. Iteration changes included: 2, 3 and 4 and subsets changes included: 4, 8, 12 and 16. In this method, the multiple of two parameters affected the images.

FBP method: Metz and Butterworth filters were used in FBP method from which 30 sets were acquired (15 sets for Butterworth and 15 sets for Metz). For using Butterworth, 15 different sets were used which were gained from changes in cutoff frequency and slope spectrum. The changes of cutoff frequency included: 0.25, 0.30, 0.35, 0.40 and 0.45. Changes of order included: 3, 6 and 9. In Butterworth filter the radical changes is caused by cutoff frequency. As the cutoff frequency is in lower amount, the images are uniform. On the contrary, the higher the number of orders, more uniform the images. Consequently, an optimal parameter is chosen to reconstruct the images by this filter.

Fifteen different sets were applied in Metz filter which changes were caused by changing on FWHM and order parameters. The changes of FWHM are as follows: 4, 4.5, 5, 5.5 and 6. The changes of order included 3, 6 and 9. The effect of FWHM on images is like the higher the number of parameters, the more uniform are the images. Similarly, order has the same effect. Consequently, an optimal parameter is obtained by combining these two parameters in reconstructing the images using this filter.

Angio-imaging: AI 1000 (General Electric Medical System, USA) was used for angiography under windows 2000. In QCA, WM can be acquired by Revision B, No. 2002377-031 software which acts similar to SPECT software for edge detection action. Information on WM recorded by terminal menu in card-wall program and the WM of five regions: antero-basal, postero-basal, apex, diaphragmatic and antero-lateral were analyzed by Compare program. The motion of each region was illustrated in this program in percentage. In this program, the information of patients and WM mentioned in 42 sets was scored and recorded quantitatively. Moreover, WM in five mentioned regions were scored and evaluated by QCA software.

Scan interpretation: The patients' images were converted to three-dimensional images and reconstructed by OSEM and FBP methods (Yanagisawa and Maru, 2001). Metz and Butterworth filters were used in FBP method and Ramp filter was used in OSEM method which 42 sets were gained (15 for Butterworth, 15 for Metz and 12 for Ramp) (Hambye *et al*., 2004; Berman *et al*., 2007). In this process, Region of Interest (ROI) was delineated around the heart in different views (frames) and wedges in such a way that the center of heart could be observed (Liu *et al*., 2005). Therefore, thoracic cross-sectional slices reoriented to short axis slices by modern reconstructive method and special software (Germano *et al*., 2000; Sharir *et al*., 2000b). A reliable algorithm which used by others was used to analyze the data (Sharir *et al*., 2000a; Candell-Riera *et al*., 2004). Through using this program the border of basal and apical regions in left ventricular can be calculated and the distance between endocardial and epicardial was also identified. Distinguishing endocardial borders in the end-systole and end-diastole can assess the local motion. Then the possibility of studying dynamic WM was provided. The end levels of systole and diastole were estimated according to Simpson. After comparing this data with basic data of a healthy heart, they enable user to define lesion precisely. Regional disorders and cardiac volumes can also be obtained from the mentioned data.

By changing the physical parameters of data process, such as filtration, by Butterworth and Metz and Ramp by cutoff frequency and different degree with OSEM and FBP reconstructive methods, different results can be acquired (Haddad and Porenta, 1998; Adachi *et al*., 2000; Yanagisawa and Maru, 2001). Motion disorders were classified in four scales (0 = normal, 1 = mild hypokinesia, 2 = moderate to severe hypokinesia and 3 = akinesis or dyskinesia). Such data was obtained and compared by the data gained via QCA method. Hence, the best choice was gained by selecting the optimal method.

Statistical analysis: In Butterworth filter (Adachi *et al*., 2000) fifteen sets were used for each wall (order: 3, 6 and 9 and cutoff: 0.25, 0.30, 0.35.0.40 and 0.45). In Metz filter (King *et al*., 1988) also used fifteen sets for each wall (Order: 3, 6 and 9 and FWHM: 4, 4.5, 5, 5.5 and 6) and in Ramp filter (Haddad and Porenta, 1998) twelve different sets for each wall were obtained. Subsets: 4, 8, 12 and 16 and iteration: 2, 3 and 4). Finally data of WM gained by SPECT in 42 filter sets and FBP and OSEM reconstructive methods were compared to the achieved semi-quantitative results of WM by QCA. After evaluating the coincidence of the acquired figures, excellent correlation was observed among the WM figures by Gated SPECT and QCA methods for each wall motion.

RESULTS

In this study, 25 patients were referred to ^{99m}Tc-MIBI gated SPECT. There was 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 summarized in Table 1.

The total wall motion score based on these two projections: RAO projection the anterior wall, apex and the inferior wall are visualized. The regional wall motions are thus clearly assessable. ECHO projection (four-

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

Characteristics	Values
Case study (N = 25)	
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: Physical parameters for the suggested filters considering each of the reconstructive and filtration methods

Wall motion /Filters	Antero-basal	Antero-lateral	Apex	Diaphragmatic	Postero-basal
Metz	5-9	4-9	4.5-9	4.5-9	4.5-9
Ramp	2-8	2-8	4-8	2-8	4-8
Butterworth	0.35-9	0.30-9	0.35-3	0.35-9	0.35-9

Table 3: The coincidence percentage for the three filters, Ramp, Metz and Butterworth, with various parameters in the five cardiac WMs

Wall motion /Filters	Antero-basal	Antero-lateral	Apex	Diaphragmatic	Postero-basal
Metz (%)	92	96	96	96	92
Ramp (%)	92	92	96	96	96
Butterworth (%)	96	96	92	96	92

chamber view): septum, apex and the lateral wall are visualized. All segments show normal WM as indicated by the motion of the endocardial edge between end-systole and end-diastole. WM is utilized as a measurement parameter for cardiac functions aimed at diagnosing cardiac illnesses, trends of a patient's recovery or improvement and diagnosing various myocardial diseases. By assessing the five cardiac WMs with function of organs, the viability of cardiac muscle after infarction is determined and after surgery, pursuing how the treatment is responded and evaluating the function of improved tissues will be available.

The motion of five regions: Antero-basal, antero-basal, apex, diaphragmatic and antero-lateral was evaluated under 42 sets. Thus, the coincidence between degrees of wall motion gained in cardiac perfusion scan by gated methods in different parameters was compared to degrees gained by angiography. So, as to estimate the coincidence of the acquired figures of the two methods, the Kendall's TAU-B was used and classified based on the amount of coincidence. The results revealed that a logical and powerful correlation exists among groups. The results in Table 2 and 3 show that for studying antero-basal wall, OSEM reconstructive method with Ramp 2-8 (matching percentage = 92% and correlation = 0.96) and FBP reconstructive method with Metz 5-9 (matching percentage = 92% and correlation = 0.96) and with Butterworth filters 0.35-9 (mp = 96% and r = 0.90). For studying postero-basal wall, OSEM with Ramp 4-8 (mp = 96% and r = 0.84) and FBP with Metz 4.5-9 (mp = 92% and r = 0.98) and with Butterworth filters 0.35-9 (mp = 92% and r = 0.84). For studying antero-lateral wall, OSEM with Ramp 2-8 (mp = 92% and r = 0.89) and FBP with Metz 4-9 (mp = 96% and r = 0.94) and with Butterworth 0.30-9 filters (mp = 96% and r = 0.94). For studying apex wall, OSEM with Ramp 4-8 (mp = 96% and r =0.94) and FBP with Metz 4.5-9 (mp = 96% and r = 0.94) and with Butterworth 0.35-3 filters (mp = 92% and r = 0.91). For studying diaphragmatic wall, OSEM with Ramp 2-8 (mp = 96% and r = 0.92) and FBP with Metz 4.5-9 (mp = 96% and r = 0.97) and with Butterworth 0.35-9 (mp = 96% and r = 0.97). The best physical parameters for the suggested filters considering each of the reconstructive and filtration methods are shown in Table 2. The coincidence percentage of the three filters, Ramp, Metz and Butterworth, with various parameters in five cardiac WMs is compared and results are shown in Table 3.

DISCUSSION

This study demonstrated the usefulness of EGS in the assessment of wall motion by using different reconstruction methods and filters in comparison with QCA. There was a good agreement between EGS and QCA with ^{99m}Tc-MIBI with using Kendall's TAU-B test. The motion of five regions: antero-basal, antero-basal, apex, diaphragmatic and antero-lateral was evaluated under two physical factors (42 filter sets and two reconstruction methods). Thus, the coincidence between degrees of wall motion gained in cardiac perfusion scan by gated methods in different parameters was compared to degrees gained by QCA. Among the achieved results of QCA and Gated SPECT, the best correlation and percent match for each cardiac wall motion was computed as shown in Fig. 1-3.

The Metz filter is a combination of deconvolution and smoothing filters (King *et al*., 1988). 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

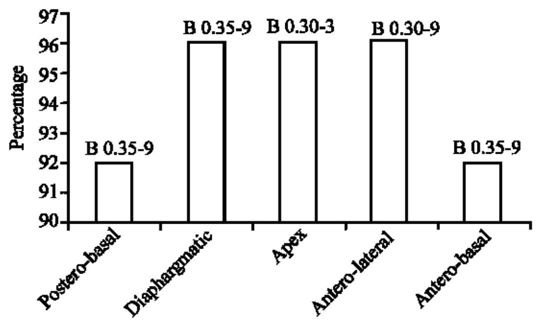

Fig. 1: The highest coincidence percentage of acquired figures via EGS method with FBP reconstructive method and Metz filter for the five selected cardiac WMs vs. WM obtained figures using QCA method

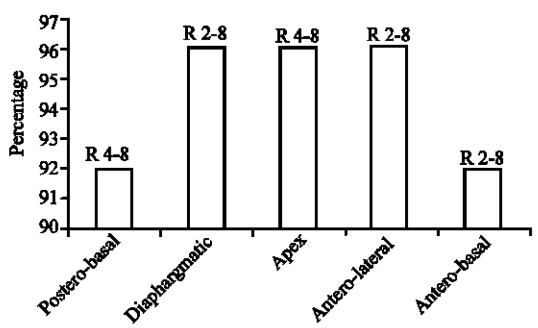

Fig. 2: The highest coincidence percentage of acquired figures via EGS method with FBP reconstructive method and Butterworth filter for the five selected cardiac WMs vs. WM obtained figures using QCA method

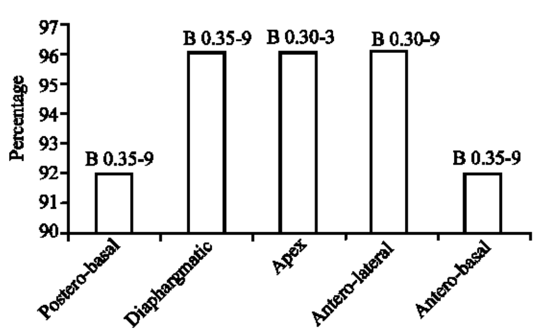

Fig. 3: The highest coincidence percentage of acquired figures via EGS method with OSEM method and Ramp filter for the five selected cardiac WMs vs. WM obtained figures using QCA method

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).

The 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 (King *et al*., 1988). This study demonstrates that the reorientation algorithm and the interpolation method significantly affect the accuracy of quantitative image analysis in myocardial SPECT perfusion imaging.

The proposed cardiac wall motion analysis method uses epicardial and endocardial boundaries that were obtained from long axis slices for each time gate. An alternative approach is to use the 3-D reconstructed SPECT images from all the time gates simultaneously in the determination of epicardial and endocardial boundaries. Spatial and temporal smoothing could be performed as part of such an analysis in order to diminish noise-related artifacts.

The motions of systole and diastole were examined under the name of WM (Sciagra and Leoncini, 2005). It is clear that, wall deficiencies such as Ischemia or Infarction create disorder in normal cardiac wall motion. Therefore, with respect to the significance of correct diagnosis of motion degrees, a highly accurate method is desired (Sharir *et al*., 2001; Maruyama *et al*., 2002; Lima *et al*., 2003; Hida *et al*., 2003; Murashita *et al*., 2003; Giubbini *et al*., 2004). This study also shows that the reconstructive method and the kind of filtration alongside the decrease in noise and also enhancement of image resolution, increasing the numeration aimed at decreasing the casual errors, omitting of yelp in crude images, rational increase in the power of smoothing images, increasing the signal to noise ratio, improving the resolution power and increasing sharpness, all can significantly play a positive role in the accuracy and correctness of the outcome.

The results showed that the lower the product of S×I the more uniform the images. However, the uniformity of images gained by OSEM were identical to the images obtained by the saved filtered/filtration method. This caused the accuracy of the system in distinguishing the borders of cardiac images taken from diverse views to decrease; consequently, WM lacks the necessary accuracy. In the OSEM, the higher the subset numbers the longer the process and the more noise of reconstructed images. The numbers of views of each subset will be essential in determining the required number of iterations aimed at estimating the regional quantities such as WMs.

Limitations of the study: There are some limitations in this study, which need to be addressed as follows:

Firstly, 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.

Secondly, 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. 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 into 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.

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

Fifthly, due to not having a fixed R-R interval, in patients with cardiac arrhythmia; Gated SPECT method is not possible.

Finally, the use of Gated SPECT can neutralize the negative effects of artifacts. The degree of WM, gained by EGS, is independent to the ventricular position. Since the images were captured in 180 degrees around the heart, they are highly accurate. Whatever seems to be problematic is the changes in filtration for processing data related to each of the five walls, that with regard to advanced technology in medical instruments, the changes of filtration parameters and selection of reconstructive method would be possible. With a little care, the operator can easily use the appropriate filter for evaluating the motion, extent and severity of lesion in particular wall worthwhile supplementary method with regard to cardiac wall under observation. It suggested that for evaluating the five WMs, the special filter related to that wall should be used and for reconstructing images in order to study the blood perfusion of cardiac muscules, another appropriate filter ought to be used. This method causes the accuracy in both methods to rise, due to the fact that the appropriate filter for such aim has been distinguished. The only drawback of this method is its being time-consuming due to the need for a repetition of image reconstruction.

CONCLUSION

By choosing the appropriate filtration parameter and reconstructive method, the exact assessment of postero-basal, antero-basal, apex, diaphragmatic and antero-lateral walls can be calculated in a patient's heart. For studying antero-basal wall, OSEM reconstructive method with Ramp filter 2-8, for studying postero-basal wall, FBP and Metz filter 4.5-9, for studying antero-lateral wall, FBP reconstructive method with Metz filter 4-9, for studying apex wall, FBP reconstructive method with Metz filter 4.5-9, for studying diaphragmatic wall, FBP reconstructive method with Metz filter 4.5-9, may create the best accuracy and exactness for functional WM parameter; hence they are the best choices ($p<0.001$). Using of optimal method and filter for specific wall will certainly increase the accuracy of the study. By applying two physical factors related to reconstructive and filtration methods in EGS, which is a non-invasive, economical and quick method for estimating WM, this method may be used as a supplementary method to gain more data, besides other methods such as QCA and echocardiography.

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