Quantitative assessment of myocardial perfusion SPECT acquisition parameters

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INTRODUCTION:

The accurate noninvasive diagnosis and functional evaluation of coronary artery disease (CAD) is an important step in selecting the appropriate management strategy [1] . Molecular imaging techniques with high sensitivity, such as single photon emission computed tomography (SPECT) and positron emission tomography (PET) and structural imaging, such as CT and MRI, have long been used routinely as an aid to diagnosis and treatment assessment, and they are often used successively at various stages of the patient management pathway [2]. Myocardial perfusion imaging (MPI) is not only useful in the diagnosis of (CAD) but also helps in risk stratification and management of patients with known or suspected CAD.It gives information about perfusion, myocardial viability and function of the left ventricle (LV) [3].SPECT myocardial perfusion imaging (SPECT MPI) examination is an established method to assess blood circulation within LV myocardium and enables the quantification of myocardial wall dynamics. Such nuclear medicine imaging method relies on the utilization of a gamma camera and a radiopharmaceutical. Currently, 99mTc-sestamibi is the most used radiopharmaceutical in this procedure[4]. In myocardial perfusion SPECTfield this leads to the question whether the current established imaging methodologies still deliver the optimal image quality [5].To assess how different acquisition parameters might affect the image quality and quantitative result in SPECT imagessimulations and mathematical models are often used.These procedures indeed have high potential and deliver significant and satisfying results however inevitable uncertainties in system modeling are introduced.Quantitative parameters calculated in specialized software applications help to stratify the probability of developing angina or myocardial infraction even in asymptomatic patients [6].These parameters are determined by a number of factors namely. (i) single or multiple head gamma camera. (ii) rest or stress acquisition. (iii)andtype of acquisition protocol used. The SPECT acquisition parameters that may be altered are: orbit type,degrees of rotation, i.e. 180 or 360 degrees, type of rotation ‘continuous’ or ‘step and shoot’, speed of rotation or time per step,number of projections per detector as well asgating (R-wave synchronized acquisition) [7].

In the current study by using hybrid SPECT/CT (Symbia® -T2, Siemens Medical Solutions) and made-in-house cardiac phantom aimedto optimize acquisition parameters for SPECT cardiac imaging in term of time per projection , count per projection, number of projection , angle configuration between two detectors , rotation mode , orbit type andsingle or dual heads. The best suited protocol is then tested in clinical trials. In this work also, we quantify the effects of acquisition parameters on quantitation results by investigating cardiac image data, acquired with a cardiac phantom and a variety of different system setups.

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MATERIALS AND METHODS

Phantom study

The attenuation and scattering mediumphantom used for acquisition was cylindrical 20 cm diameter phantom (Data Spectrum, inc)utilized and acrylic glass cylinder with cardiac simulating. The cardiac insert consists of two chambers, simulating the left ventricular blood_ pool and the myocardial wall with a true wall thickness of 10_mm. The phantom consists of a commercially supplied cylindrical Perspex container. It has a cavity and three screw-filling plugs that can be filled and then sealed. The total fluid filling volume is about 4.0 liters. Acquisition parameters were set at 99m-Tc having gamma ray energy of 140 KeV, and acceptance window of 10%. The radioactive material used in the tests must be prepared and measured in a clean and well aerated area (Laminar flow). The cardiac insert phantom was loaded with 99m-Technetium adjusting the activity concentration about 5µCi/ml. The cardiac insert of the phantoms was positioned carefully to mimic the true cardiac position in humans. Within the rotational field of view, we acquired 20 SPECT acquisitions to evaluate the different parameters.

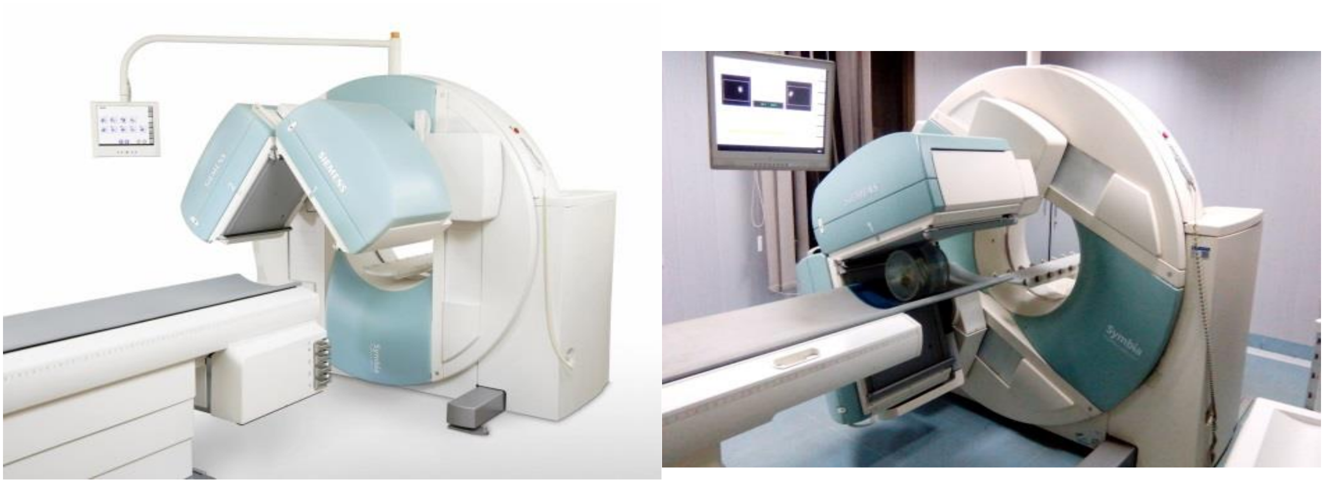

Figure (1): hybrid SPECT/CT (Symbia® -T2, Siemens Medical Solutions) and experimental setup.

Imaging Instrumentation

The nuclear medicine imaging system was used for data acquisition was a dual-headed SPECT-CT hybrid camera (Symbia®-T2, Siemens Medical Solutions) comprising a 90° , 76° and 180° angle configuration system and an image processing software was esoft. Each detector has 53.3x38.7 cm (21x15.25 in) rectangular field of view (FOV) and diagonal FOV 65.9 cm (25.9 in) of a 9.5 mm-thick NaI(Tl) crystal.

The low energy collimator was used in this work: Low Energy All Purpose (LEAP). The sensitivity of LEAP collimator is (330 cpm/uCi) and the geometric resolution is 8.3mm at 10cm.

1. Data Acquisition

The scan orbit range of the phantom extended from 45°left posterior oblique to 45°right anterior oblique where the detectors followed the human body in a non-circular orbit(except in rotation circular type) to minimize the distance to the object.

These data sets served as high level starting point for further processing. The cardiac image acquired by using different acquisition parameters such as time per projection , number of projections , total count, type of rotation , mode of acquisition, detectors configuration angle and single or dual detectors . In this range high-count projections in one-degree angular steps were acquired with fixed 128x128 matrix size and zoom 1.00 (full field of view) as the following:

• Cardiac phantom positioning: supine, Matrix: 128x128, Zoom: 1.0, Pixel size: 4.8 mm, Voxel size: 4.8 × 4.8 × 1 mm, Orbit: 180°, Energy window: 140 keV ± 15%, Collimator: Low Energy All Purpose (LEAP) parallel holes, Detectors: Both detectors or single detector, Number of projections: 16, 32and 64, Time per projections : 10, 15, 20,25 and 30sec, Detectorsconfiguration:76° and 90° geometry, Orbit: non-circular and circular and Acquisition mode: step-and-shoot, step-and-shoot continuous and continuous.

i.Number of projection (NOP).

The effect of the number of acquired projection on the Cardiac SPECT images was evaluated. The Cardiac phantom had been imaged three times using fixed parameters in both acquisition and reconstruction. The only difference was the number of projection per scan. In this parameter 16, 32and 64 views were used per acquired image.

ii.Time per projection (Scan time):

The time per projection changed from 10 to 30 seconds (10, 15, 20, 25, and 30 sec).The effect of time per projection on Cardiac images was applied by used fixed parameters for both acquisition and reconstruction.

iii.Acquisition mode (mode of rotation).

To study the effect of the acquisition mode on the cardiac SPECT images;, three modes of gantry rotation was applied namely step & shot, step & shot/cont and continuous applied to the phantom, and another cardiac image in a fixed state were obtained. This protocol was applied to the phantom three times within the acquisition.

iv.Rotation type.

v.Gamma camera is equipped by two different options of obit distance such as circular where the detector radius is fixed at a certain value from the center in addition to noncircular orbit in which the detector radius is modified to minimize the dead distance of the detector from patient body surface.

vi.Detectors configuration.

The angle configuration between two detectors in this study (76° and 90°) were applied on the cardiac images in two acquisitions to detect the effect of image quality and quantitation values.

vii.Single or dual detectors.

The image acquired by using Single or dual detectors in this work, so two acquisition cardiac images applied with fixed another parameters.

viii.Image processing and reconstruction.

The images were iteratively reconstructed with the aid of the software flash™ for cardiac from Siemens Medical Solutions, a recently introduced algorithm for cardiac images reconstruction OSEM (ordered subset expectation maximization) 3D with collimator and detector response compensation ("Flash3D") by using 4 iteration and 2 subset. Iterative methodwas used for reconstruction of the tomographic data; Butterworth filter (cut-off Nyquist frequency 0.4 cycle/cm, order 5) was also used.Quantitative analysis on functional parameters was performed using Quantitative perfusion SPECT (QPS) 2012 program (Cedars-Sinai Medical Center, Los Angeles, CA, USA) [8].

ix.Quantitative analysis

For a quantitative analysis of the image data, specific to the cardiac phantom, was developed with the aim to facilitate the characterization of the performance of an imaging system. It provides the user with a set of quality control images as well as quantitative measures.The processes reconstructed reoriented and transversal cardiac SPECT data and calculates diagnostically important metrics like perfusion,lesion contrast and attenuation performance.This work focused on myocardium perfusion cavity ratio, signal to noise ratio (SNR) and contrast to noise ratio (CNR)of the cardiac wall.The definition of the SNR is the mean value of the perfusion values in the mid regions of the myocardium normalized to the standard deviation of cavity:

$$\text{SNR} = \frac{\text{Mean value(myocardium } wall)}{\text{standard deviation of cavity}} \qquad (1)$$

$$\text{While the CNR} = \frac{\text{Mean Myocardium} - \text{Mean Cavity}}{\text{standard deviation of cavity}} \qquad (2)$$

x.Observing Study

The observer study used a graphical user interface showing the user a series of short axis images. The images were displayed zoomed (5 times the original matrix size) using cubic interpolation and shown with color table (warm metal). The short axis slices were created by reorientation of the reconstructed volume and extraction of a 3 slices in the center of series slice then drown region around the slices.

RESULTS:

Time of projection: Time of projection showed variable results in terms of the attenuation correction (AC) and non-attenuation correction (NAC) within the various figures of merit measured for image quality. 15 sec and 30 sec provided comparable results when data were not corrected for attenuation while 30 sec per projection yielded the best results when AC was implemented. The signal to noise retio (SNR) measurements were the best in 25 sec/projection in case of NAC but 30 sec was again the best in AC data set and better than 25 sec by only 3%. contrast to noise ratio(CNR) calculations was the highest when 25 sec/projection was used while 30 sec/projection was the best in case of AC and provided an improvement of 9% when compared to 25 sec/projection.

No of projections : Number of projection is also one of the acquisition parameters that influence image quality. In figure 1, it is obvious that increasing the number of projections serve to improve signal to noise (SNR) ratio and contrast to noise ratio (CNR) especially in data corrected for attenuation correction, but less remarkable improvement in myocardial/cavity ratio (in both attenuation and non-attenuation correction data set). Data acquisition with 64 projections achieved the best results in all quantitative metrics measured.

Acquisition Mode: Mode of acquisition results demonstrated that S&S continuous and continuous rotation had the best myocardial/cavity contrast in comparison to the conventional S&S acquisition mode in both NAC and AC. In terms of SNR, continuous rotation has better results in NAC but S&S

continuous was the best in AC data. However, continuous rotation showed superior CNR results in NAC data but step and shot was the best mode followed by S&S continuous in AC reconstructed images.

Rotation Mode: Rotation mode whether circular or noncircular was also investigated and showed that the myocardial/cavity contrast ratio was higher in noncircular than circular orbit in both NAC and AC. In terms of SNR, noncircular data also showed better results than circular rotation especially for NAC data whereas circular orbit was much better in AC than noncircular orbit. CNR measurements showed better results in noncircular orbit whereas comparable results of circular vs. noncircular was observed when AC was applied.

Detector configuration: Detector configuration angle (90degree vs. 76 degree) revealed comparable results in both myocardial/cavity contrast ratio when both NAC and AC were applied. In terms of SNR and CNR, the 76o detector geometry provided better results than 90o in NAC data set whereas the reverse was true in data corrected for attenuation.

Detector Heads: The number of detector heads also showed remarkable results in favour of using one head instead of two detector heads in terms of myocardial/cavity ratio and CNR in both NAC and AC data sets. However, the SNR of the two detectors was slightly better than that of one detector in AC reconstructed images but lower than when NAC was applied.

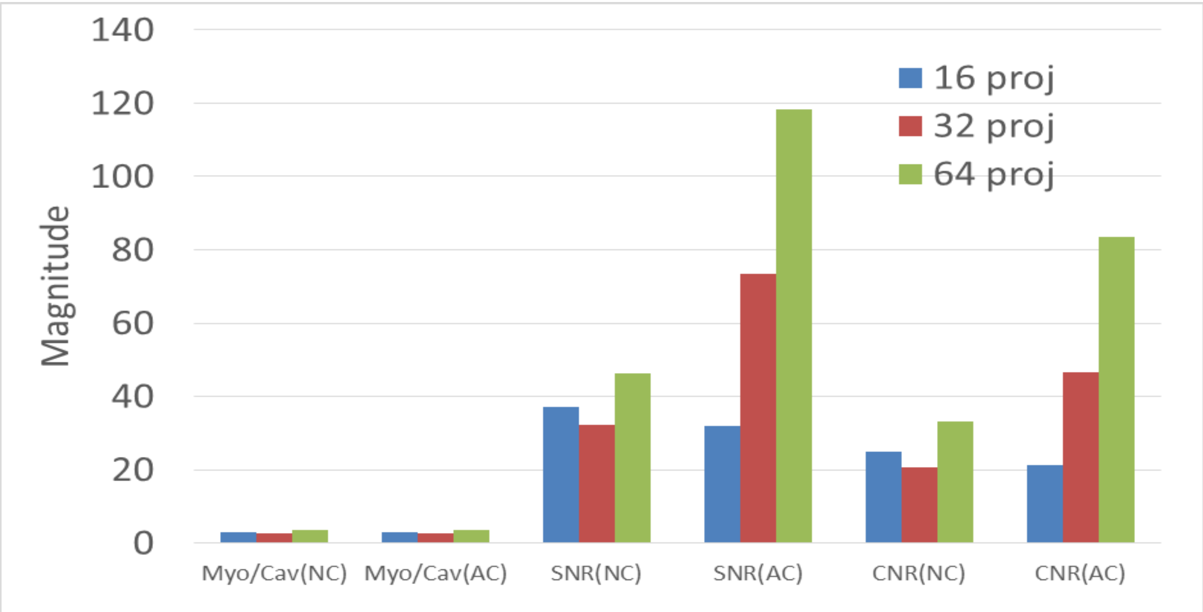

Figure 1. The influence of number of projections on SNR, CNR as well as myocardial/cavity ratio.

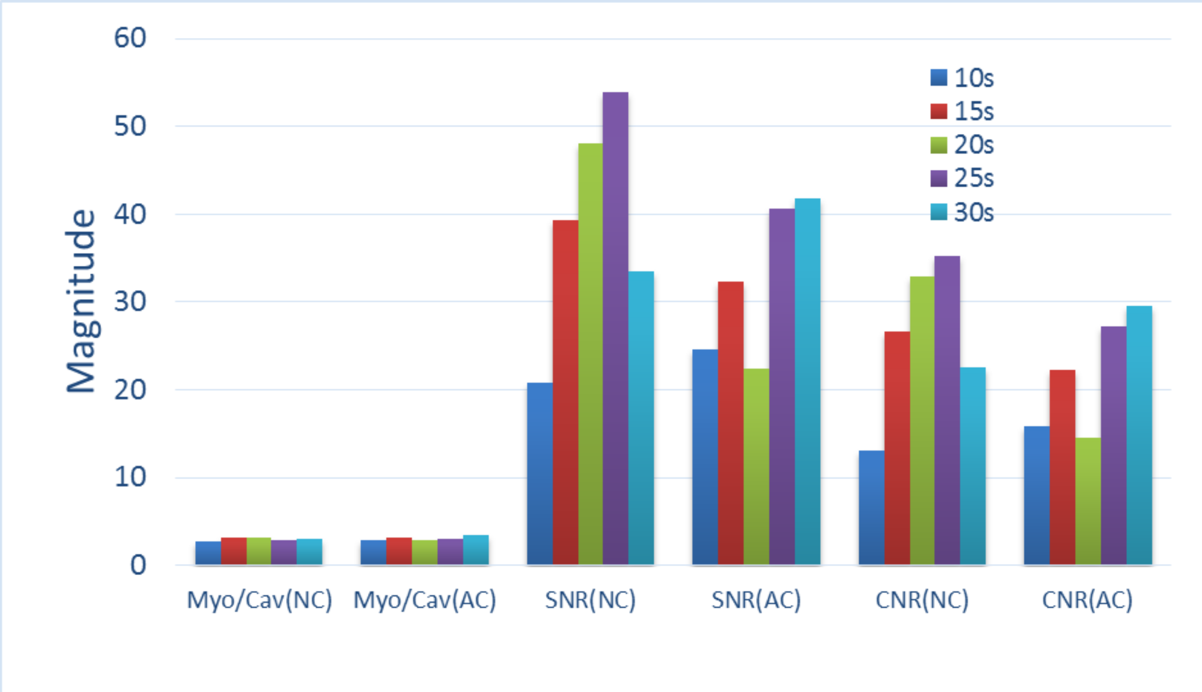

Figure 2. Influence of projection time on myocardial/cavity contrast, SNR and CNR.

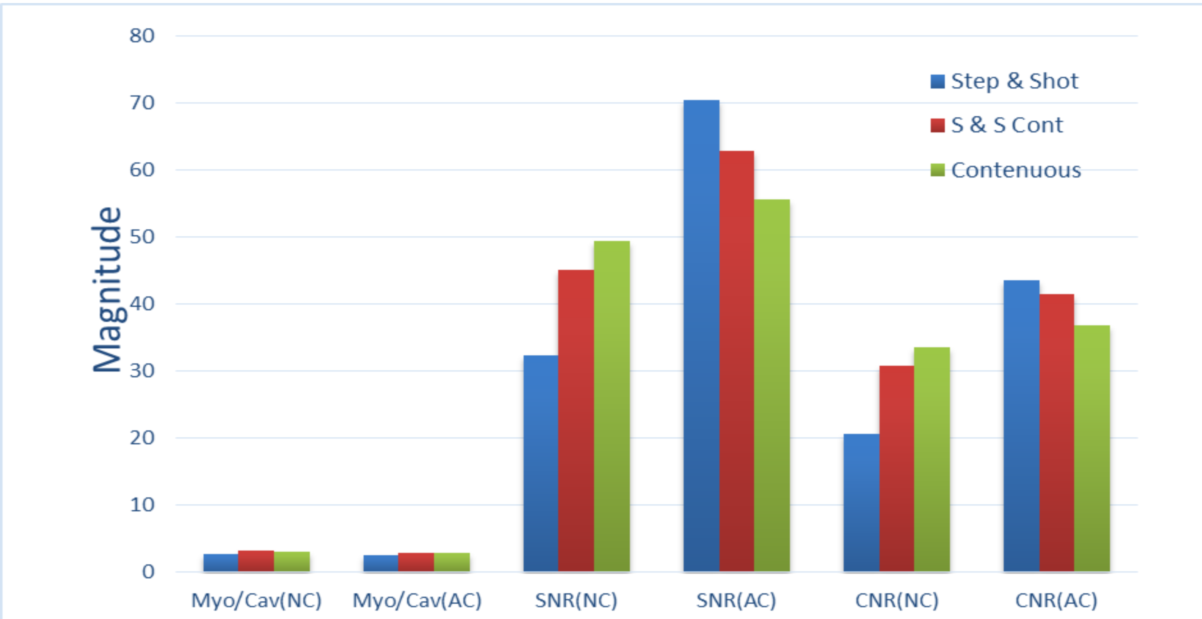

Figure 3. Mode of acquisition and its impact on cavity contrast, myocardial SNR and myocardial CNR.

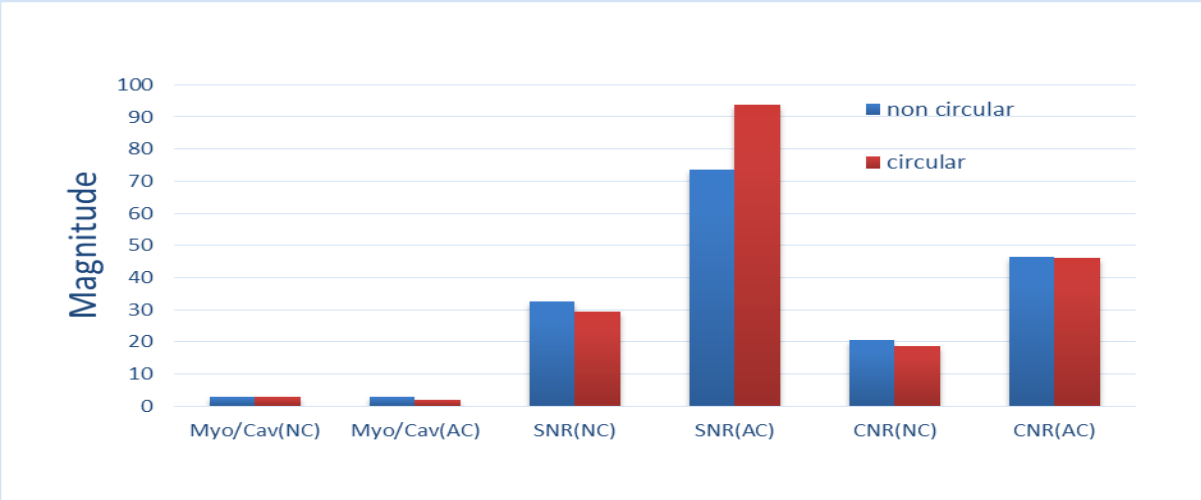

Figure 4. Circular vs. noncircular orbit and myocardial/cavity, SNR and CNR measurements.

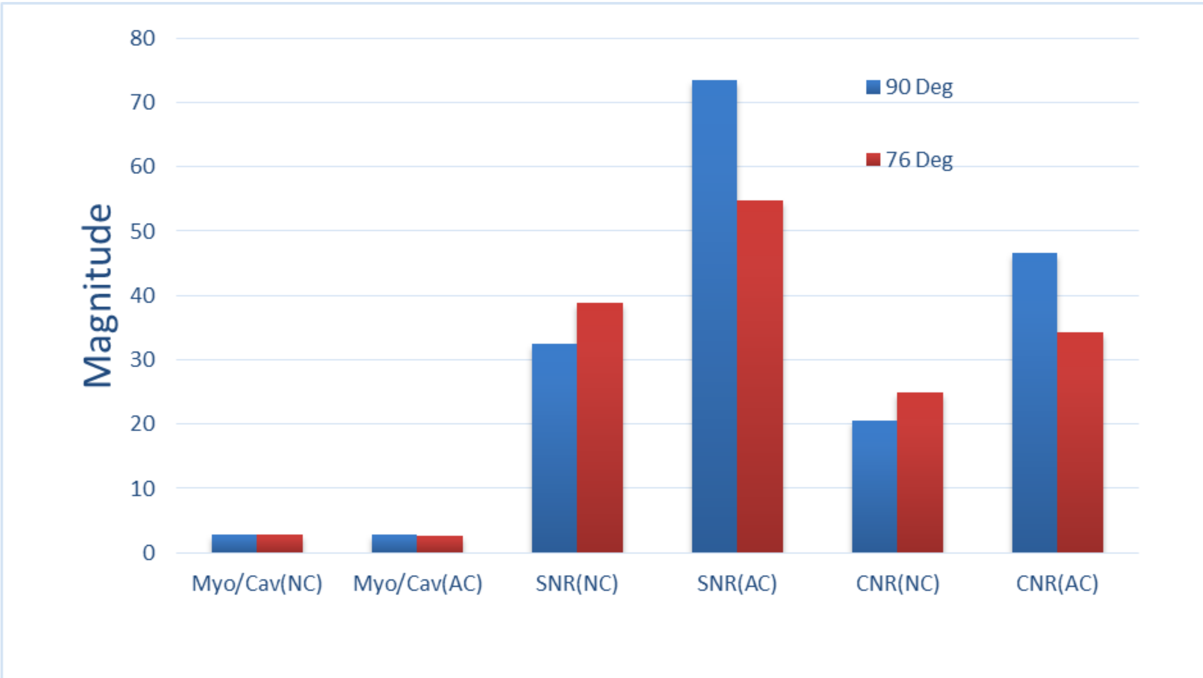

Figure 5. Detector angle configuration and its impact on myocardial/cavity ratio, SNR and CNR calaculations.

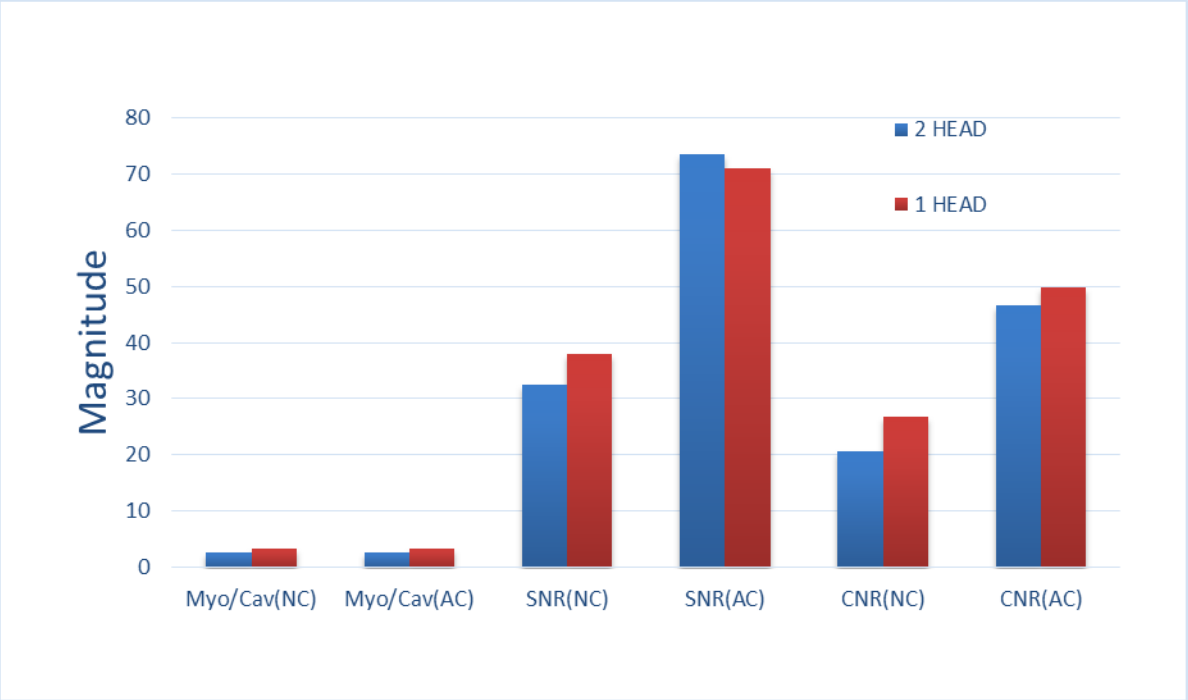

Figure 6. The impact of number of detectors on myocardial/cavity contrast, SNR and CNR measurements.

DISCUSSION:

Recent advances in detector technology and gamma camera performance characteristics would have a direct impact on detection task and diagnostic performance of the scanning systems. Image quality and quantitative accuracy of myocardial perfusion studies are determined by many factors mainly acquisition and reconstruction parameters in addition to other biological or body habitus variations. In this study, we sought to assess the impact of quite important acquisition parameters including total number of projections, time of projection, acquisition mode, acquisition orbit, configuration angle and number of detectors heads on image quality of myocardial perfusion SPECT images.

Image quality of nuclear imaging relies to large extent on sufficient count statistics and those parameters that achieve that goal are certainly desired. However, this fact often comes at the expense of higher injected dose or prolonged acquisition time. Both reactions would have their negative impact on radiation effective dose and patient comfort and also increased likelihood of motion artifacts respectively.

Attenuation correction is also a crucial factors that significantly influence image quality and diagnostic accuracy [9]. Therefore, our aim was to look at the differences and changes that come out when applying attenuation correction and also when it is not applied.

Time of projection is one of the factors that could improve the statistical quality of the scan as it permit for collecting more counting as the acquisitions runs. The default value of 25 sec per projection was found superior and provide an improvement in image quality in terms of myocardial/cavity as well as SNR and CNR. Using 30 sec per projection was found also superior in some aspects but this will significantly increase the acquisition time[10].

Number of projection is also one of the acquisition parameters that influence image quality. Again, it serve in providing an opportunity to collect more counts in a given study. It has shown that 64 projections has improved myocardial/cavity contrast ratio in addition to superior SNR and CNR in both data sets, AC and NAC. However, when combining this outcome with 25 sec/projection the total acquisition time will significantly be increased. So we seek to use slightly time less time per projection (i.e 20 sec) so that a little compromise in imaging time can be realized[11].

Mode of acquisition results demonstrated that S&S continuous and continuous rotation had the best myocardial/cavity contrast in comparison to the conventional S&S acquisition mode in both NAC and AC. In terms of SNR, continuous rotation has better results in NAC but S&S continuous was the best in AC data. However, continuous rotation showed superior CNR results in NAC data but step and shot was the best mode followed by S&S continuous in AC reconstructed images[12].

Rotation mode whether circular or noncircular was also investigated and showed that the myocardial/cavity contrast ratio was higher in noncircular than circular orbit in both NAC and AC. This is clearly due to the fact that the former helps in reducing the effect of collimator detector resolution loss and hence and improvement of myocardial wall contrast. In terms of SNR, noncircular data showed better results than circular rotation especially for NAC data whereas circular orbit was much better in AC than noncircular orbit as the SNR is a metric that is sensitive to the acquired count statistics and AC serve to achieve that goal. CNR measurements showed better results in noncircular orbit whereas comparable results of circular vs. noncircular was observed when AC was applied. This finding supports the fact that the AC can play a major role in the detection task[13].

When different detector configuration angle (90 degree vs. 76 degree) was applied, comparable results in myocardial/cavity contrast ratio (with both NAC and AC) was obtained as the two modes don't have preferential attitude to improve count statistics. In terms of SNR and CNR, the 76 degree detector geometry provided a better results than 90 degree in NAC data set whereas the reverse was true in data corrected for attenuation due to the implementation of the Flash resolution recovery [14.15].

The number of detector heads also showed remarkable results in favour of using one head instead of two detector heads in terms of myocardial/cavity ratio and CNR in both NAC and AC data sets. However, the SNR of the two detectors was slightly better than that of one detector in AC reconstructed images but lower than when NAC was applied. Again this is to the fact of using collimator characteristic information during the Flash 3D iterative reconstruction[14.15].

Our results demonstrated the impact of various acquisition parameters on useful image quality indicators such as myocardial/cavity, SNR and CNR ratio. The study recommends the use of large number projection angles (eg. 64) without too extension of the acquisition time and probably 20 sec is a good compromise. Using one detector head is preferred but this might not be in favour of study count statistics if the same time to be used similar to two detector system. It could be an advantage in systems with one single head configuration but this also comes at the expense of increased acquisition time. The detector configuration angle of 76 degree was superior in most of the image quality indices measured and hence we recommend further clinical studies to support this finding. The acquisition mode of step&shot continuous revealed better results when compared to other modes and thus our plan is to extend the evaluation in patient studies in comparison to other approaches. Noncircular orbit provided superior results when resolution recovery was not activated and hence we recommend to use it if means are not available to correct collimator detector distance.

One might see that using the above recommendations for data acquisition in myocardial perfusion SPECT imaging is not feasible or not applicable in some imaging systems. This can be resolved by performing an on-site validation studies to ensure optimal image quality realization taking our results as benchmarking in study design. Our study therefore warrants the use of the above recommendations in clinical trials for further verifications and individual imaging protocol validation.

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