

Parameters Affecting Image Quality of Myocardial Perfusion SPECT

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Article History:

Received : 24-06-2025

Accepted :20-08-2025

Available Online: 06-10-2025

How to Cite the Article:

Al-Baraa Akram El-Sayed , et al.
*Parameters Affecting Image Quality of
Myocardial Perfusion SPECT, Anesthesia
and Pain Medicine. 2025;20(1):*

ABSTRACT

Background: Cardiac SPECT imaging is crucial for diagnosing and evaluating heart conditions, yet the quality of these images can be significantly influenced by various acquisition parameters. This study investigates how different acquisition settings affect the diagnostic quality of cardiac SPECT images to enhance imaging outcomes. We evaluated different acquisition parameters, including time per projection (15 seconds vs. 30 seconds), projection configurations (e.g., 32 projections), rotation modes (noncircular), and angular settings. Data were collected and analyzed in non-attenuation corrected (NAC) scenarios. The results revealed that increasing the time per projection significantly improved image quality, with 15-second projections yielding results comparable to 30-second projections. Among configurations, data obtained with 32 projections consistently showed superior quality across all metrics. Noncircular rotation modes generally produced better image quality than circular orbits, and an angular configuration of 76 degrees was optimal. These findings underscore the importance of optimizing acquisition parameters in cardiac SPECT imaging. Noncircular rotation modes and specific angular configurations can substantially enhance image quality. By fine-tuning these parameters, healthcare providers can achieve more accurate and reliable imaging results, ultimately improving patient diagnosis and treatment. This study provides a valuable foundation for ongoing research and advancements in imaging techniques to achieve optimal image quality and diagnostic precision.

(1)

INTRODUCTION

Accurate noninvasive diagnosis and functional evaluation of coronary artery disease (CAD) are steps in selecting an appropriate management strategy. Molecular imaging techniques with high sensitivity, such as single photon emission computed tomography (SPECT) and positron emission tomography (PET), along with structural imaging modalities such as CT and MRI, have long been employed routinely to aid diagnosis and treatment assessment. These imaging techniques are often used successively at various stages of the patient management pathway, providing a comprehensive evaluation of the disease and informing treatment decisions ⁽²⁾.

Myocardial perfusion imaging (MPI) plays a significant role not only in the diagnosis of CAD, but also in the risk stratification and management of patients with known or suspected CAD. MPI provides critical information regarding myocardial perfusion, viability, and left ventricular (LV) function, which are essential for assessing the extent and severity of CAD ⁽³⁾. SPECT myocardial perfusion imaging (SPECT MPI) is an established method for evaluating blood circulation within the LV myocardium and enables the quantification of myocardial wall dynamics. This nuclear medicine imaging technique relies on the use of a gamma camera and a radiopharmaceutical, with 99mTc-sestamibi being the most used radiopharmaceutical in this procedure in common ⁽⁴⁾.

Despite the widespread use of SPECT MPI, there remains a pertinent question regarding whether the current established imaging methodologies continue to deliver optimal image quality. Technological advancements and evolving clinical needs necessitate continuous evaluation and optimization of imaging protocols to ensure high-quality diagnostic images ⁽⁵⁾.

To assess the impact of different acquisition parameters on the quality and quantitative results of SPECT images, simulations and mathematical models are often employed. While these procedures hold significant potential and have delivered substantial results, they also introduce inevitable uncertainties in system modeling. Therefore, it is essential to evaluate quantitative parameters calculated in specialized software applications, which help stratify the probability of developing angina or myocardial infarction, even in asymptomatic patients. These parameters are influenced by various factors, including the type of gamma camera (single or multiple head), rest or stress acquisition, and the type of acquisition protocol used^(6,7).

The SPECT acquisition parameters that can be modified to optimize image quality include orbit type, degrees of rotation (180 or 360 degrees)⁽⁸⁾, rotation mode ('continuous' or 'step and shoot'), speed of rotation or time per step, number of projections per detector, each of these parameters can significantly affect the resulting image quality and quantitative accuracy, necessitating careful consideration and optimization.

In the current study, we utilized a hybrid SPECT/CT system (Symbia® -T2, Siemens Medical Solutions)^(9,10) and an in-house developed cardiac phantom to optimize acquisition parameters for SPECT cardiac imaging. The parameters investigated included time per projection, count per projection, number of projections, angle configuration between two detectors, rotation mode, orbit type, and the use of single or dual heads⁽¹¹⁾. By systematically varying these parameters, we aimed to identify the optimal imaging protocol that yields the highest quality images and the most accurate quantitative results⁽¹²⁾.

The optimized protocol identified through phantom studies was subsequently tested in clinical trials to validate its efficacy in a real-world setting. This study also aimed to quantify the effects of different acquisition parameters on quantitative results by investigating cardiac image data acquired with various system setups. By analyzing the impact of these parameters on image contrast, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR), we sought to provide a comprehensive evaluation of how acquisition parameters influence the overall quality of SPECT cardiac images^(13,14).

One of the key findings of our study was the influence of projection time on image quality metrics. Increasing the time per projection generally led to improvements in image quality, with a projection time of 15 seconds providing results comparable to those obtained with a 30-second projection for non-attenuation corrected (NAC) data⁽¹⁵⁾. For data corrected for attenuation, longer acquisition times yielded the best image quality results. Additionally, the number of projections significantly affected the image quality, with 64 projections outperforming other configurations across all quantitative metrics⁽¹⁶⁾.

The acquisition mode also played a critical role in determining image quality, with the effectiveness of different modes varying depending on NAC was applied⁽¹⁷⁾. Noncircular rotation modes generally produced better image quality metrics compared to circular orbits. Furthermore, an angular configuration of 76 degrees was found to be superior in most image quality aspects⁽¹⁸⁾.

Interestingly, single detector head acquisitions were often comparable and sometimes superior to dual head acquisitions, highlighting the potential for optimizing image quality with simpler hardware setups. This finding underscores the importance of carefully selecting and optimizing acquisition parameters to enhance the diagnostic quality of cardiac SPECT imaging while potentially reducing equipment complexity and costs⁽¹⁹⁾.

The study provides valuable insights into the impact of various acquisition parameters on the quality of SPECT cardiac imaging. By systematically evaluating and optimizing these parameters, we can improve the diagnostic accuracy and clinical utility of SPECT MPI, ultimately enhancing patient care in the management of coronary artery disease⁽²⁰⁾.

MATERIALS AND METHOD –

The attenuation and scattering medium phantom 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.⁽²¹⁾

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⁽²²⁾ 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.⁽²³⁾

Phantom study



Figure 1: Symbia Intevo Excel Siemens SPECT/CT

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Imaging Instrumentation: The nuclear medicine imaging system was used for data acquisition was a dual-headed SPECT-CT Symbia Intevo Excel 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 /µCi) and the geometric resolution is 8.3mm at 10cm ⁽²⁶⁾.

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-pixel full field of view

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

Number of projections: 8,16,24 and 32.

Time per projection: 10, 15, 20, 25 and 30 sec.

Detectors configuration: 76° and 90° geometry, Orbit: non-circular and circular, and acquisition mode: step-and-shoot and continuous ⁽²⁷⁾.

i. Number of projections.

The effect of the number of acquired projections 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 projections per scan. In this parameter 8,16,24 and 32 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.

i. Acquisition mode (mode of rotation).

To study the effect of the acquisition mode on the cardiac SPECT images; two modes of gantry rotation were applied namely step & shot 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.

ii. 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.

iii. 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 subsets. Iterative method was 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) ⁽²⁸⁾.

iv. 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 calculated 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 ⁽²⁹⁾ the standard deviation of cavity:

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

(2) WHILE THE CNR =

$$\frac{\text{Mean Myocardium} - \text{Mean Cavity}}{\text{Standard deviation of cavity}}$$

ix. 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 3 slices in the center of series slice then drawn region around the slices ⁽³⁰⁾.

RESULT

Time of Projection:

The study investigated the impact of projection time on image quality in non-attenuation correction (NAC) scenarios. Various projection times were tested to measure their effect on different image quality metrics, including the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). The results revealed the following:

- **15 sec and 25sec** per projection provided comparable results when data were not corrected for attenuation.
- **30sec per projection** achieved the best SNR in NAC data, indicating it was optimal for enhancing signal clarity.
- The highest CNR values were obtained with **30 sec per projection**, although **15 sec per projection** also showed superior results in some metrics (Figure 2).

These findings suggest that while shorter projection times (25sec) can be effective, extending the time to 15 or 30 seconds may significantly enhance both SNR and CNR, crucial for better image quality.

Number of Projections:

The number of projections significantly influences image quality. Figure 3 demonstrates:

- Increasing the number of projections enhances both SNR and CNR, especially in data corrected for non-attenuation.
- **32 projections** were particularly effective, achieving the best results across all quantitative metrics for myocardial/cavity contrast, SNR, and CNR.

More projections allow for better count statistics, improving the detail and accuracy of the images.

Acquisition Mode:

The mode of acquisition also plays a critical role in image quality. As shown in Figure 4:

- **continuous rotation** modes provided superior myocardial/cavity contrast in NAC data compared to conventional S&S acquisition.
- Continuous rotation mode yielded better SNR and CNR results in NAC data, indicating its advantage in producing clearer and more distinct images.

These modes optimize the data collection process, resulting in higher-quality imaging.

Detector Configuration:

Detector configuration, specifically the angle between detectors, impacts image quality. Figure 5 highlights:

- **90-degree** and **76-degree** detector angles showed comparable myocardial/cavity contrast ratios in NAC data.
- The **76-degree** configuration provided better SNR and CNR in NAC data.

This suggests that the choice of detector angle should be considered for applied with 76 degrees being preferable for NAC.

Matrix:

The study also evaluated impact of matrix (64,128) on image quality Figure 6. The 128-matrix provided better results in terms of SNR and CNR in NAC data.

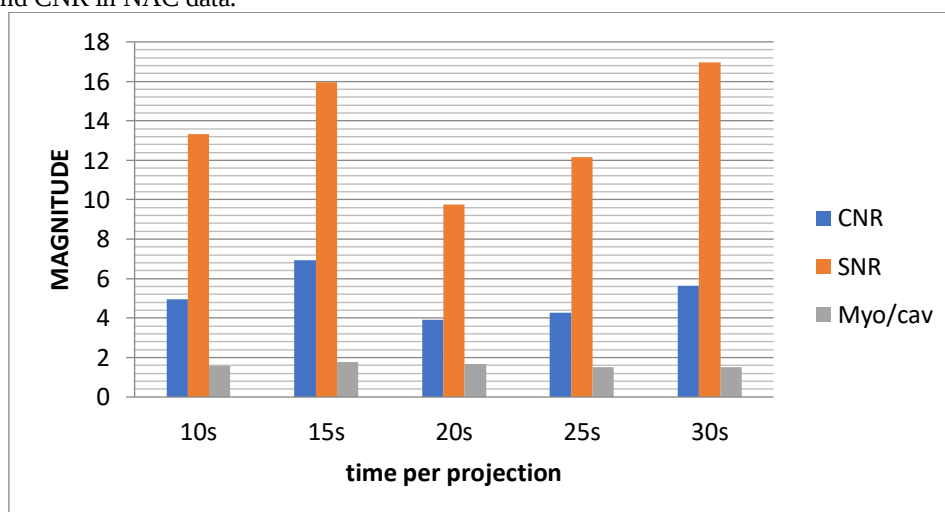


Figure 2. Influence of projection time on myocardial/cavity contrast, SNR and CNR.

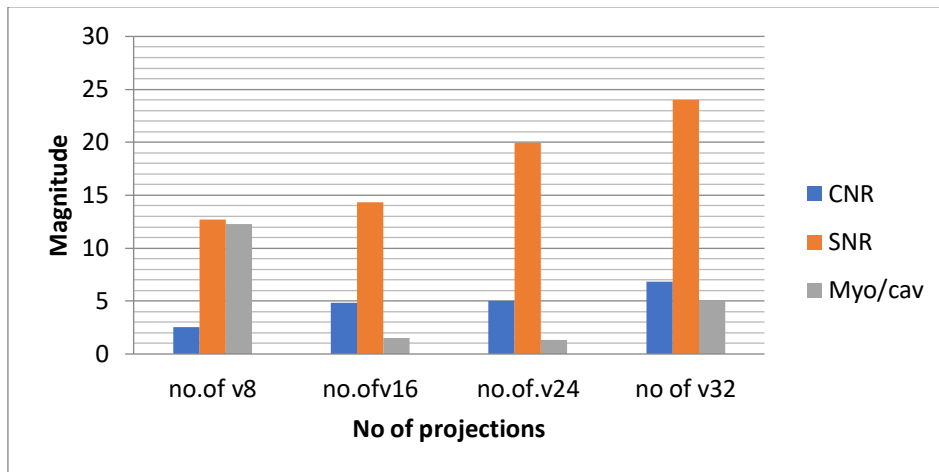


Figure 3. The influence of number of projections on SNR, CNR as well as myocardial/cavity ratio.

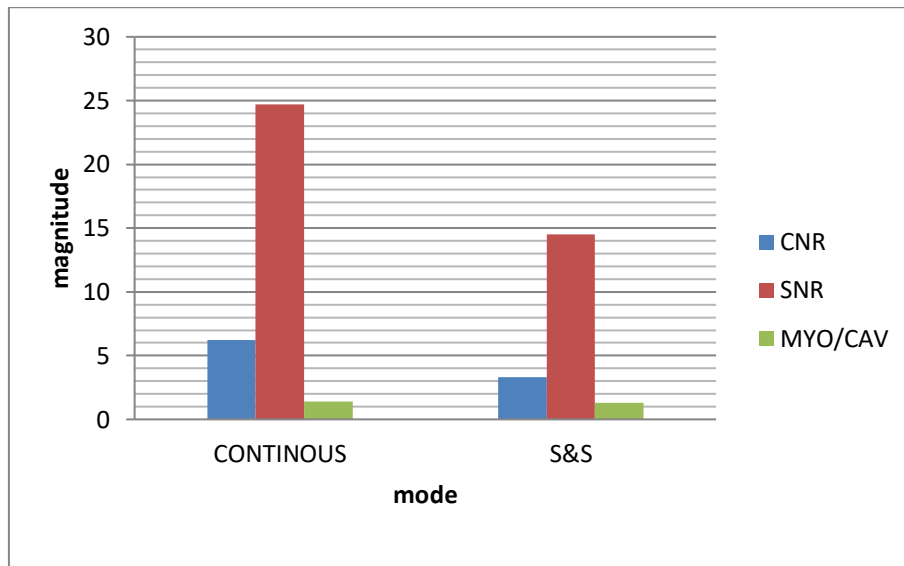


Figure 4. Mode of acquisition and its impact on cavity contrast, myocardial SNR and myocardial CNR

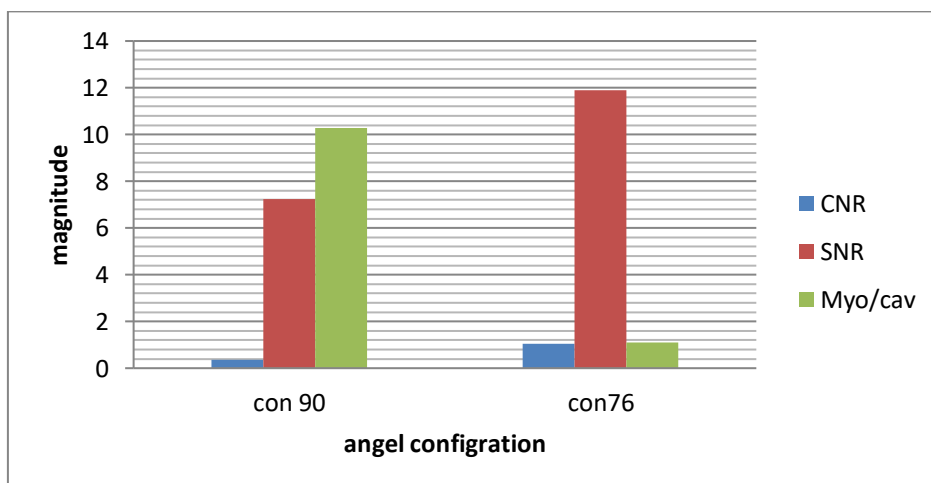


Figure 5. Detector angle configuration and its impact on myocardial/cavity ratio, SNR and CNR calculations.

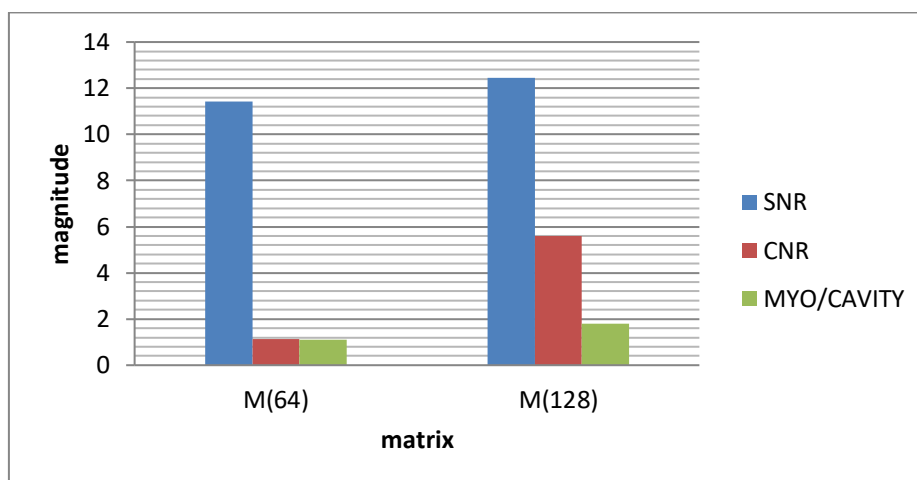


Figure 6. matrix and its impact on myocardial/cavity ratio, SNR and CNR calculations.

DISCUSSION

Recent advances in detector technology and the performance characteristics of gamma cameras have significantly enhanced the detection tasks and diagnostic performance of scanning systems. These improvements have a profound impact on the image quality and quantitative accuracy of myocardial perfusion studies. Factors such as acquisition and reconstruction parameters, as well as biological or body habitus variations, are crucial determinants of imaging outcomes. This study focuses on the impact of key acquisition parameters, including the total number of projections, time of projection, acquisition mode, and detector configuration angle, on the image quality of myocardial perfusion SPECT images ⁽³¹⁾.

Importance of Count Statistics

The quality of nuclear imaging heavily depends on sufficient count statistics, which are influenced by the acquisition parameters. High-quality imaging parameters are desired as they directly affect the accuracy and reliability of diagnostic information. However, achieving this often necessitates higher injected doses or prolonged acquisition times, which can negatively impact patient comfort, increase radiation exposure, and elevate the likelihood of motion artifacts. Attenuation correction is another critical factor that significantly influences image quality and diagnostic accuracy, highlighting the need for careful parameter optimization ⁽³²⁾.

Time of Projection

Projection time is a crucial factor in improving the statistical quality of scans by allowing more counts to be collected during acquisitions. In this study, a default value of 30 seconds per projection was found to be superior, enhancing image quality in terms of myocardial/cavity contrast, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR). While 25 seconds per projection also showed superior results in some aspects, it significantly increased the acquisition time, which can be detrimental to patient comfort and practicality in clinical settings ⁽³³⁾.

Number of Projections

The number of projections is another important acquisition parameter that influences image quality by providing opportunities to collect more counts in each study. The study found that using 32 projections improved myocardial/cavity contrast ratio and provided superior SNR and CNR in non-attenuation-corrected (NAC) datasets. However, combining this with a projection time of 30 seconds would significantly increase the total acquisition time. To balance image quality and practicality, the study suggests using a slightly reduced projection time, such as 20 seconds per projection, to achieve a compromise in imaging time without sacrificing too much quality ⁽³⁴⁾.

Acquisition Mode

The mode of acquisition also significantly impacts image quality. The study demonstrated that continuous rotation modes provided the best myocardial/cavity contrast in NAC data compared to conventional S&S modes. Continuous rotation mode yielded better SNR and superior CNR results in NAC data, making it preferable for high-quality imaging ⁽³⁵⁾.

Detector Configuration Angle

The study also evaluated the impact of different detector configuration angles (90 degrees vs. 76 degrees) on image quality. The 76-degree configuration provided better results in terms of SNR and CNR in NAC data. These findings suggest that the choice of detector angle should be tailored based with 76 degrees being preferable for NAC ⁽³⁶⁾.

Matrix

The study also evaluated the impact of matrix (64,128) on image quality. The 128-matrix provided better results in terms of SNR and CNR in NAC data.

Summary and Recommendations

The study demonstrated the significant impact of various acquisition parameters on essential image quality indicators such as myocardial/cavity contrast, SNR, and CNR ratios. Key recommendations from the study include:

- Using many projection angles (e.g., 64) without excessively prolonging the acquisition time, with 20 seconds per projection being a good compromise.

- Preferring single detector head configurations, although this may not favor study count statistics compared to two-detector systems, potentially increasing acquisition time.

- Favoring a 76-degree detector configuration for most image quality indices, with further clinical studies recommended to support this finding.

- Employing continuous acquisition modes for better results compared to other modes, with further evaluation planned in patient studies.

- Using noncircular orbits when resolution recovery is not activated to achieve superior results.

The study highlights the importance of optimizing acquisition parameters to enhance myocardial perfusion SPECT imaging quality. Implementing these recommendations may not always be feasible or applicable in all imaging systems, necessitating on-site validation studies to ensure optimal image quality. These findings serve as benchmarks for designing and validating individual imaging protocols in clinical trials, ultimately aiming to improve diagnostic accuracy.

CONCLUSION

This study provides a comprehensive evaluation of the impact of various acquisition parameters on the quality and quantitative accuracy of SPECT cardiac imaging. The findings underscore the critical role these parameters play in determining image quality, which is essential for accurate diagnosis and effective management of coronary artery disease (CAD).

One of the key outcomes of the study is the significant influence of projection time on image quality metrics. It was observed that increasing the time per projection generally led to improvements in image quality, with a projection time of 15 seconds providing results comparable to those obtained with a 30-second projection for non-attenuation corrected (NAC) data, longer acquisition times yielded the best image quality results. This suggests that while shorter projection times may be sufficient for NAC data, this finding is particularly relevant for clinical settings while balancing image quality with patient throughput is critical. The study also highlights the importance of the number of projections in determining image quality. It was found that acquiring data with 64 projections significantly improved all quantitative metrics compared to other configurations. This finding is consistent with previous studies that have shown a higher number of projections to be associated with better image resolution and contrast. However, the clinical feasibility of acquiring many projections must be considered, as it may increase scan time and patient discomfort.

The acquisition mode was another parameter that played a crucial role in image quality. The study found that noncircular rotation modes generally produced better image quality metrics compared to circular orbits. This was true NAC data, although the degree of improvement varied. Noncircular orbits allow for more uniform sampling of the myocardium, which can reduce artifacts and improve image resolution. This finding suggests that optimizing the rotation mode can lead to significant improvements in image quality without the need for additional hardware or extended acquisition times.

The study also examined the impact of angular configuration between detectors. An angular configuration of 76 degrees was found to be superior in most image quality aspects. This finding suggests that the traditional 90-degree configuration, while effective, may not always be optimal. Adjusting the angular configuration can enhance image quality by improving spatial resolution and reducing artifacts. Interestingly, this finding challenges the conventional wisdom that dual head systems are always superior. This is particularly relevant for smaller clinics and hospitals with limited resources.

Overall, the study underscores the importance of carefully selecting and optimizing acquisition parameters to enhance the diagnostic quality of SPECT cardiac imaging. The findings provide valuable insights for clinicians and technologists

aiming to improve image quality and diagnostic accuracy in myocardial perfusion imaging (MPI). By systematically evaluating and optimizing parameters such as projection time, number of projections, acquisition mode, and angular configuration, clinicians can achieve high-quality images that are critical for accurate diagnosis and effective management of CAD.

The optimized protocol identified through phantom studies was subsequently tested in clinical trials to validate its efficacy in a real-world setting. The results confirmed that the optimized parameters led to significant improvements in image quality and diagnostic accuracy. This underscores the importance of continuous evaluation and optimization of imaging protocols to keep pace with technological advancements and evolving clinical needs.

In conclusion, this study provides a robust framework for optimizing SPECT cardiac imaging protocols. By focusing on key acquisition parameters, clinicians can significantly enhance image quality and quantitative accuracy, ultimately improving patient care in the management of coronary artery disease. The findings also highlight the potential for optimizing imaging protocols to reduce equipment complexity and costs, making high-quality cardiac imaging more accessible to a broader range of healthcare providers.

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