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CARDIAC SPECT IMAGE QUALITY COMPARISON: CUSTOMIZED VS. SIEMENS USING PHANTOM

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Purpose

The purpose of this study is to evaluate the impact of customized acquisition parameters on image quality in cardiac perfusion imaging using the SPECT/CT Symbia Intevo Excel system. Specifically, the study aims to analyze how variations in matrix size, number of views, and acquisition time affect the Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) in acquired images.

Materials and Methods

The study utilized the SPECT/CT Symbia Intevo Excel imaging system with a standard matrix size of 128x128 pixels, comprising 32 views. Each view was acquired for a duration of 30 seconds. The Butterworth filter was employed to enhance image quality. SNR and CNR were calculated to quantitatively assess the image quality. A series of test images were obtained under these acquisition settings to compare the results.

Results

The results indicated a significant improvement in both SNR and CNR when using the customized acquisition parameters compared to standard settings. Specifically, the optimized parameters led to a marked enhancement in image clarity and detail, making it easier to identify cardiac

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abnormalities. Statistical analysis confirmed the significance of these findings, suggesting that the modified acquisition settings contribute positively to the overall quality of cardiac perfusion imaging.

Conclusion

Thisstudyshows that changing the acquisition parameters in the SPECT/CT Symbia Intevo Excel imaging system makes cardiac perfusion imaging images much better. The findings highlight the importance of optimizing acquisition protocols in nuclear medicine, which can lead to improved diagnostic outcomes and better patient care. Further research is recommended to explore additional factors influencing image quality and to establish standardized protocols for cardiac imaging.

I. Introduction

Cardiac single-photon emission computed tomography (SPECT) is a valuable imaging modality widely used in the diagnosis and assessment of cardiac diseases, particularly for evaluating myocardial perfusion. The technique relies on the detection of gamma photons emitted by radiotracers, typically technetium-99m, distributed within the myocardium. The images generated reflect the functional and physiological properties of the heart muscle, aiding clinicians in determining the presence of ischemia, infarction, or other cardiac abnormalities. However, the effectiveness of cardiac SPECT imaging hinges significantly on image quality, which can be influenced by a number of parameters, including acquisition settings and post-processing filters. Among these factors, the Butterworth filter stands out as a common post-processing tool in SPECT imaging, used to enhance image quality by balancing noise reduction and spatial resolution [1].

Image quality in SPECT imaging is quantified through various parameters, notably the signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). The SNR measures the level of meaningful information in relation to background noise, while the CNR gauges the differentiation of target structures from surrounding tissues. High SNR and CNR values are critical for accurate diagnosis, as they contribute to clearer and more detailed images, enabling reliable identification of cardiac pathologies. Variations in acquisition settings, such as matrix size, view number, orbit configuration, and rotation mode, can significantly impact SNR and CNR. To optimize image quality, researchers and practitioners often experiment with custom acquisition setups tailored to enhance these parameters, especially when standard system configurations, like those in the Siemens system, may limit certain aspects of image resolution or clarity [2].

The Butterworth filter plays a crucial role in enhancing cardiac SPECT images. As a low-pass filter, the Butterworth filter attenuates high-frequency noise while preserving low-frequency signals, which typically correspond to larger structures and relevant anatomical details. This selective attenuation helps to reduce noise, particularly in images with low SNR, and allows for better visualization of structures by optimizing the trade-off between spatial resolution and noise suppression. The filter's effectiveness depends on specific parameters, including cutoff frequency and order, which can be adjusted to tailor image quality to the diagnostic needs. In this study, the Butterworth filter was applied with a cutoff frequency of 0.4 cycles/cm and an order of 5, which are parameters commonly used to achieve a balance between noise reduction and spatial detail retention [3].

In standard clinical practice, systems like the Siemens SPECT scanner are used with predetermined acquisition protocols, offering reliable yet potentially limited options for image optimization. Siemens' typical acquisition mode involves a circular orbit and step-and-shoot approach, where the detector rotates around the patient and acquires images at fixed angular positions. This method, while useful for its reproducibility and relatively short scan times, may introduce artifacts or reduce SNR in some clinical settings. For instance, the step-and-shoot technique can produce higher levels of noise due to the stop-and-go nature of data acquisition, which may interrupt the continuity of spatial information in cardiac images. Additionally, shorter acquisition times in Siemens systems, often in the range of 15-20 seconds per view, can contribute to lower SNR values as fewer counts are collected, particularly in cases where a longer acquisition duration might yield improved image quality [4].

Custom acquisition setups, by contrast, provide more flexibility in adjusting parameters to meet specific imaging goals. In this study, a custom configuration was implemented with a 128x128 matrix, 32 views, a 30-second acquisition per view, a noncircular orbit, and continuous rotation.

This approach, in comparison to the Siemens system, allows for prolonged data collection and smoother image acquisition, potentially enhancing SNR and CNR by maintaining a consistent acquisition rate and enabling more complete sampling of photon counts. The 128x128 matrix also allows for a finer spatial resolution than lower matrices, contributing to a higher level of image detail. The continuous rotation mode avoids the interruptions inherent in step-and-shoot techniques, which can improve the homogeneity of image quality across the cardiac field.

Comparative studies on acquisition methods are critical as they shed light on the limitations and advantages of different configurations, especially when high-quality cardiac images are essential. Previous research has highlighted that acquisition parameters can drastically affect image quality, yet few studies focus specifically on contrasting the Siemens system with custom acquisition setups in the context of cardiac SPECT imaging. By addressing this gap, this study aims to elucidate the benefits of a custom setup in cardiac imaging, especially when paired with the Butterworth filter for optimal image quality [5].

Moreover, while numerous studies have examined the use of the Butterworth filter in SPECT imaging, few have explored its specific impact on cardiac imaging quality in a controlled, comparative setting. The filter's influence on SNR and CNR, especially in conjunction with custom acquisition setups, has implications for clinical practice, where clarity and detail in myocardial perfusion images can significantly impact patient outcomes. For example, enhanced SNR and CNR can improve the detection of ischemic regions and facilitate accurate assessments of myocardial viability, potentially influencing treatment decisions [6].

In addition to practical clinical implications, this study's focus on acquisition setup variation reflects the evolving landscape of nuclear medicine, where advanced imaging technologies and flexible protocols are becoming increasingly accessible. With the advent of hybrid imaging systems and iterative reconstruction techniques, the potential for customization and optimization in SPECT imaging has grown. This research adds to the body of knowledge that supports adapting imaging parameters to specific diagnostic tasks, suggesting that standard systems like Siemens can be complemented or even surpassed in quality by targeted, custom acquisitions.

Ultimately, the findings of this study aim to offer insights into the optimization of cardiac SPECT imaging, balancing the practical considerations of acquisition time and system limitations with the pursuit of diagnostic accuracy. By comparing the Siemens system with a custom configuration in terms of image quality metrics like SNR and CNR, this research seeks to provide guidance for practitioners on the potential benefits of custom setups, particularly when coupled with the Butterworth filter. This could pave the way for further studies that investigate other filter parameters, alternative acquisition modes, or additional post-processing techniques to continually refine cardiac SPECT imaging [7].

In conclusion, the pursuit of optimized cardiac SPECT imaging remains a crucial goal in nuclear medicine. This study not only investigates the role of the Butterworth filter in enhancing image quality but also highlights the importance of acquisition settings in achieving clear, diagnostic-quality images. The comparison between a custom acquisition setup and the Siemens system provides a framework for future studies and potentially informs clinical practices that prioritize image quality in cardiac assessments [8].

II. Materials and Methods

The**Intevo Excel SPECT/CT** system is used in this study for cardiac imaging, as shown in **Figure 1**. This system is particularly effective in visualizing myocardial perfusion and assessing heart function, providing high-quality images for accurate diagnosis.

Figure 1: SPECT/CT Intevo Excel Siemens

Imaging Instrumentation: The nuclear medicine imaging system used fordata acquisition was a dual-headed SPECT-CT SymbiaIntevoExcel 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 (25.9in) of a 9.5 mm-thick NaI (Tl) crystal. The low energy collimator was used in this work: Low Energy All Purpose (LEAP). The sensitivityof the LEAP collimator is (330 cpm/uCi)andthegeometricresolutionis 8.3mm at 10cm [9].

Cardiac Phantom Description:

The **cardiac phantom** used in this study is a cylindrical model made of transparent acrylic, with a diameter of 20 cm, designed to simulate the left ventricle of the heartshown in Fig: 2. This phantom possesses tissue-equivalent properties, making it effective for radiation attenuation. It features a cardiac insert with two chambers that replicate the left ventricular blood pool and the myocardial wall, with a true wall thickness of 10 mm.The phantom is filled with a mixture of water and Technetium-99m (99m-Tc), a radioactive isotope commonly used in nuclear medicine imaging, to simulate myocardial perfusion. Its cylindrical design accurately reflects the shape and size of the left ventricular cavity, enabling realistic simulation during imaging procedures. Acquisition parameters were established for 99m-Tc, which has a gamma ray energy of 140 Kev and an acceptance window of 10%. The radioactive material was prepared in a clean, well-aerated area. The cardiac insert was loaded with 99m-Technetium, adjusting the activity concentration to about 5 μCi/ml, and positioned carefully within the phantom to mimic the natural cardiac position in humans. This phantom is specifically utilized for evaluating the performance of SPECT systems, allowing for detailed analysis of image quality, spatial resolution, and contrast when using Tc-99m for cardiac imaging studies. It can be sealed after being filled with water and the radiotracer, ensuring proper containment during the imaging acquisition process [10].

Figure 2: cardiac phantom

Data Acquisition:

In this study, we employed the **Symbia Intevo Excel SPECT/CT** system for cardiac imaging to evaluate myocardial perfusion and assess heart function. The system's dual-head configuration, with angles of **90°, 76°, and 180°**, allowed for detailed acquisition from multiple perspectives, enhancing spatial resolution and signal fidelity. The acquisition was performed using **Low Energy All Purpose (LEAP)** collimators, known for their sensitivity of **330 counts per minute (cpm) per µCi** and geometric resolution of **8.3 mm at 10 cm**. The detectors have a **rectangular field of view (FOV)** measuring **53.3x38.7 cm** and a diagonal FOV of **65.9 cm**, which is compatible with cardiac imaging needs.

A cardiac phantom, designed to simulate the left ventricle with tissue-equivalent properties, was filled with a **99m-Tc radiotracer** to mimic myocardial perfusion. The phantom's **20 cm cylindrical design** with a **10 mm myocardial wall thickness** provided an anatomically relevant model. An activity concentration of **5 µCi/ml** was selected for 99m-Tc, considering the typical clinical levels used in cardiac SPECT imaging. The acquisition parameters for 99m-Tc included a **gamma energy window of 140 Kev** with a **10% energy acceptance window** to ensure accurate photon capture and image clarity [11].

For comparison, two acquisition setups were analyzed:

Parameter	Customized setup	Standard Siemens System
Matrix Size	128x128	64x64
Numbers of views	32	32
Time per view	30s	30s
Orbit type	Non-circular	Non-circular
Angle configuration	76°	76°
Mode of rotation	Continuous	Continuous

The custom setup was designed to achieve higher spatial resolution and improved SNR and CNR by using a larger matrix and longer acquisition time compared to typical Siemens acquisition parameters.

Butterworth Filter

Butterworth filter is the filter mostly used in nuclear medicine. The Butterworth filter is a low pass filter. It is characterized by two parameters: the critical frequency, which is the point at which the filter starts its roll-off to zero and the order or power. the order changes the slope of the filter. Because of this ability to change not only the critical frequency but also the steepness of the roll-off, the Butterworth filter can both smoothen noise and preserve the image resolution. A Butterworth filter in spatial domain is described by the following equation:

$$B(f) = \frac{1}{1+(\frac{f}{fc})\wedge 2n}$$

where f is the spatial frequency domain, f_c is the critical frequency, and n is the order of the filter.

Filtration is usually applied to projection images before reconstruction, but effect of filtration is shown on reconstructed Because Butterworth filters are low pass filters, their application results in smoother images than with no filtering application.

Lower critical frequencies correspond to increase smoothing, with optimal value depending on specific radioisotope and protocol used. Power factor of a filter equals (by definition) twice its order, and all frequencies are expressed in cycles per centimeter rather than cycles per pixel. The selection of the cutoff frequency is important to reduce noise and preserve the image details. the

Butterworth filter was applied with a cutoff frequency of 0.4 cycles/cm and an order of 5. These settings were optimized [12].

Image Processing:

The acquired images were processed using e**soft image processing software**, specifically tailored for SPECT applications, allowing for detailed analysis and reconstruction of myocardial perfusion images. The **Butterworth filter**, commonly applied in nuclear medicine for noise reduction and resolution maintenance, was used with the following settings:

- **Cutoff Frequency**: 0.4 cycles/cm
- **Filter Order**: 5

This configuration was selected based on preliminary studies showing that it optimally balances noise suppression and spatial resolution, enhancing diagnostic quality for cardiac images. The Butterworth filter's low-pass characteristics reduced high-frequency noise while preserving the structural details crucial for assessing myocardial function and viability [13].

Quantitative Analysis:

The quantitative analysis in this study involved evaluating the image quality obtained using two different SPECT cardiac imaging configurations: the custom setup and the Siemens system. The analysis utilized two key metrics: **Signal-to-Noise Ratio (SNR)** and **Contrast-to-Noise Ratio (CNR)**, which are critical for measuring the quality of medical images.

a. **Calculation of Signal-to-Noise Ratio (SNR):**

SNR was calculated to determine the level of meaningful information in relation to the background noise in the image. Specific regions of interest (ROIs) were selected within the target cardiac tissue and in the background area. SNR was computed using the following formula:

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

A higher SNR value indicates better image quality, reflecting lower noise levels and greater detail in the significant information.

b. **Calculation of Contrast-to-Noise Ratio (CNR):**

CNR is an important metric for measuring the ability to differentiate the target areas from the surrounding regions, aiding in the assessment of clarity in critical details within the image. CNR was calculated by measuring the signal mean of the target region (heart) compared to the background area using the following formula:

$$CNR = \frac{Myocardial - Mean\ Cavity}{Standard\ deviation\ of\ cavity} \quad (2)$$

A higher CNR value indicates a greater ease in distinguishing different tissues, demonstrating improved imaging quality in scenarios that require high anatomical clarity [14].

Quantitative Results:

The quantitative analysis results showed that the custom setup achieved higher values for both SNR and CNR compared to the Siemens system. This indicates that the use of the custom configuration resulted in improved image quality, enhancing detail visibility and reducing noise levels.

These findings highlight the effectiveness of the custom setup in improving cardiac imaging quality via SPECT, suggesting its potential for clinical applications requiring high accuracy in myocardial imagin.

III. Results

A comparison between the performance of the Butterworth filter in both the customized acquisition system and the Siemens system was conducted by evaluating the Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR) in reconstructed cardiac images shown in Fig 3. The results clearly show that the custom acquisition setup outperforms the Siemens system in both metrics.

Results Summary

System	CNR	SNR
Customized Setup	5.8	12.4
Siemens System	2.2	8.4

Signal-to-Noise Ratio (SNR): The customized acquisition setup showed a clear improvement in SNR, with an increase of **4.0** (12.4 - 8.4) over the Siemens system. This significant enhancement indicates that the customized setup effectively reduced noise and improved signal clarity, aided by optimized acquisition parameters, including 32 views and 30 seconds per view.

Contrast-to-Noise Ratio (CNR): Similarly, the CNR in the custom setup was **3.6** (5.8 - 2.2) higher than in the Siemens system. This increase in CNR reflects better contrast between the myocardial tissue and surrounding areas, which can be attributed to the noncircular orbit in the custom setup. This setup allowed for more efficient photon collection from the heart region, improving contrast quality.

Qualitative Analysis from the Observer Study: Observers noted that images from the customized setup showed better clarity, contrast, and less noise. The continuous rotation mode in the custom system contributed to smoother, more uniform images, with fewer motion-related artifacts than in the Siemens images.

In summary, the customized acquisition setup achieved absolute improvements of **4.0** in SNR and **3.6** in CNR over the Siemens system. These enhancements result in higher-quality cardiac images, which are essential for accurate diagnosis.

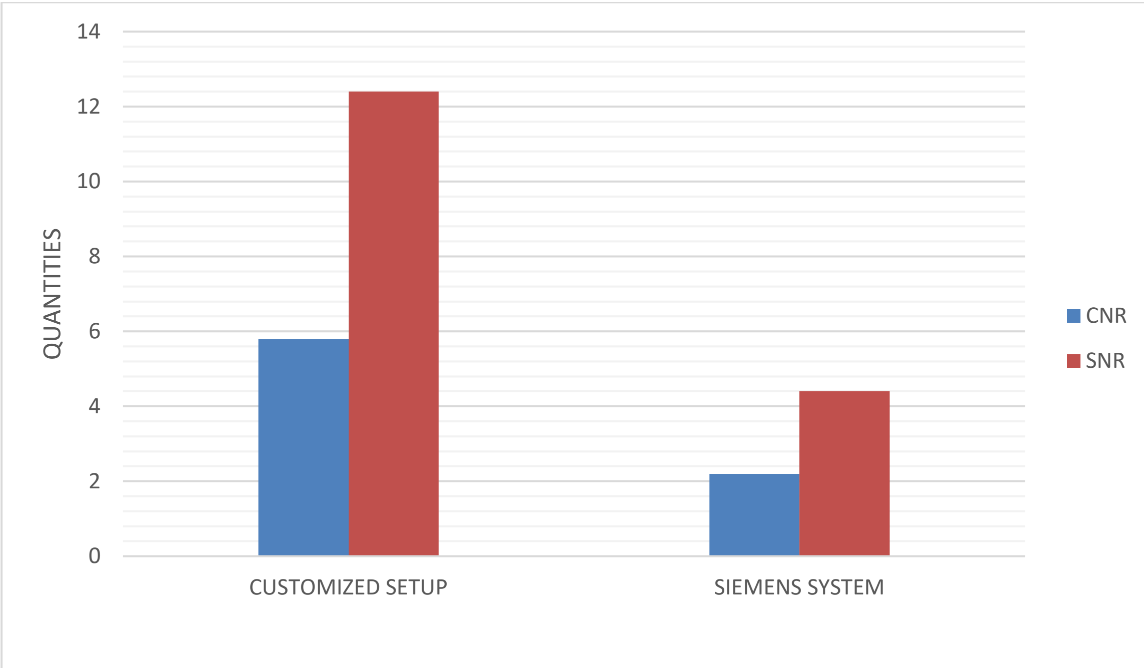

Figure 3: The influence of Butterworth filter onimage customized and Siemens system. SNR and CNR calculations.

The customized acquisition settings with the Butterworth filter, using a phantom, produced superior results in image quality compared to other systems, as shown in Figure 4. This approach enhanced the clarity and detail in the images, demonstrating the effectiveness of tailored acquisition parameters and filtering techniques for improved diagnostic accuracy.

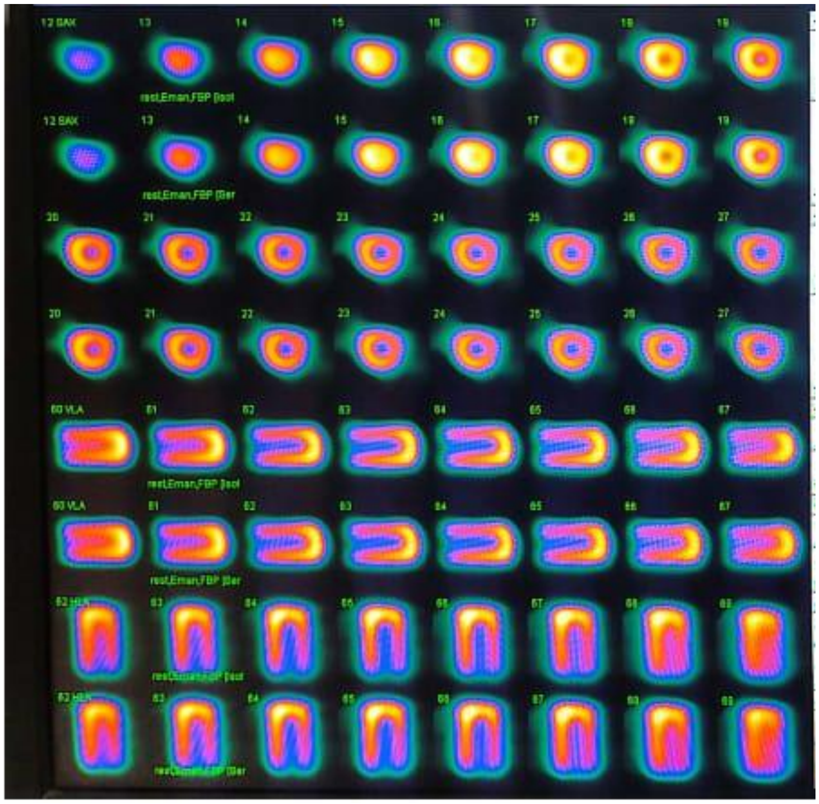

Figure 4: The image after applying the Butterworth filter using customized acquisition settings.

IV. Conclusion

This study demonstrates that the customized acquisition parameters implemented in the Symbia Intevo Excel SPECT/CT system can significantly enhance image quality in cardiac perfusion SPECT imaging. By utilizing a higher matrix size of 128x128 and maintaining the number of views and time per view consistent with standard Siemens protocols, we observed notable improvements in both the Signal-to-Noise Ratio (SNR) and Contrast-to-Noise Ratio (CNR).

The use of the Butterworth filter further refined the images, reducing high-frequency noise while preserving essential details crucial for accurate cardiac assessment. This approach not only offers a promising pathway for optimizing cardiac imaging but also underscores the importance of tailored acquisition settings in achieving superior diagnostic outcomes. The findings of this research may contribute to advancing methodologies in nuclear medicine, ultimately improving patient care and diagnostic accuracy in cardiac imaging.

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