Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 4, Issue 5, 2026

QUANTITATIVE EVALUATION OF MOTION CORRECTION ALGORITHMS IN MYOCARDIAL PERFUSION SPECT IMAGING USING CLINICAL AND SIMULATED DATA

Ayesha Humna[*1], **Ayesha Farooq**[2], **Asma Saleem**[3] **Hira Nayab**[4]

[*1,3]*Department of Physics, University of Agriculture Faisalabad, Pakistan*
[2]*Department of Biochemistry, Government College University Faisalabad, Pakistan*
[4]*Department of Physics, Government College Women University Faisalabad, Pakistan*

[*1]ayeshahumna3141@gmail.com

DOI: https://doi.org/10.5281/zenodo.20152263

Keywords
SPECT imaging; motion correction; MDC; myocardial perfusion; OSEM; image artifacts

Article History
Received: 11 March 2026
Accepted: 21 April 2026
Published: 13 May 2026

Corresponding Author: *
Ayesha Humna

Abstract

During myocardial perfusion SPECT imaging, patient motion remains a persistent challenge in SPECT imaging, often leading to image degradation and misinterpretation of perfusion defects. It is obvious that when motions occurred in patient studies, there were alterations in the perfusion defects in the anterior and inferior walls. Various Algorithms are used to correct the motion during imaging. In this study, three motion correction techniques that is Stasis, Hopkins, and Motion Detection and Correction (MDC) were evaluated using both simulated motion patterns and clinical data. Image reconstruction was performed using the ordered subset expectation maximization (OSEM) algorithm. Motion introduced artificial defects, particularly in the anterior and inferior myocardial regions. Among the evaluated techniques, MDC demonstrated superior performance, achieving an artifact reduction of approximately 85-92%, compared to 65-70% for Stasis and 50- 60% for Hopkins. Statistical analysis using one-way ANOVA confirmed that the improvement was significant ($p < 0.05$). These findings suggest that MDC provides a reliable framework for motion correction and may improve diagnostic confidence in clinical SPECT imaging.

INTRODUCTION

Myocardial perfusion single-photon emission computed tomography (SPECT) is widely used for the evaluation of coronary artery disease. However, patient motion during acquisition continues to limit image quality and diagnostic reliability. Even minor movement can introduce artifacts that resemble perfusion defects, leading to potential misinterpretation. To ensure high quality images that can be properly interpreted, technicians and doctors put in a lot of effort. If necessary, the person interpreting the images can decide whether to repeat the scan if there has been any movement [16]. More recently, SPECT has been emphasized as a promising technique in the developing field of theragnostic/theragnostic, especially in the treatment of several diseases such prostate cancer, lymphoma, and neuroendocrine tumors [10][5].

The exact extent to which patients can move during a tomographic scan without affecting the accuracy of the resulting images is still uncertain. However, it is clear that detecting any patient movement during the scan is crucial for ensuring the quality of the tomography. One way to assess motion is by examining a sine display of the obtained planar images. Unfortunately, this method does not provide precise measurements of motion or easy-to-generate printed outputs. A number of factors, such as the number of projections, exposure time or dose, and the reconstruction method, affect the quality of the reconstructed image, which is crucial for scientific study[4].

So, another approach involves analyzing the obtained view data as a sinogram for quality control purposes. However, there is currently no quantitative technique available to determine the type and amount of motion, which introduces subjectivity and ambiguity in interpreting the results. Some other motion correction approaches have also been developed, including sinogram-based techniques, image registration methods, and iterative reconstruction strategies [17]. While these approaches have shown improvements, their performance varies under realistic clinical conditions. A particular device utilized for this purpose employs position-sensitive detectors to monitor three small lights affixed to the patient's head through the use of optical triangulation [20].

To explore a different approach, one could consider affixing sensors that reflect infrared (IR) to

the patient's skull. This would be coupled with a mechanical tracker that has six degrees of freedom. The tracker consists of a base with electronic components and a compact arm with multiple joints [19][17]. Our approach consisted of performing two scans: a rapid scan followed by a slower, more thorough scan. We utilized a summed one-dimensional correlation method to rectify any motion detected [1]. A technique created to detect accessibility in triple-scan SPECT imaging projection data.

This method allows for the acquisition of three full sets of SPECT data, which can then be combined effectively to generate a motionless set of projection data [7]. Uncommonly used in SPECT imaging, techniques such as the time-dependent image fractionation method mentioned earlier are not commonly employed. Furthermore, they disregard projections that display noticeable motion. In such cases, some of the collected data from the system would be eliminated, leading to lower signal-to-noise ratios [2]. Another approach based on data involves minimizing the error measurements between the measured data and predicted future reconstructions [3]. In addition, motion detection can be accomplished by employing both an external motion tracking device and a nuclear medicine imaging system in an alternating manner. A particular device utilized for this purpose employs position-sensitive detectors to monitor three small lights affixed to the patient's head through the use of optical triangulation [20].

Most previous studies focus on individual methods or rely on simulated data. Comparative studies that incorporate both clinical and simulated motion remain limited. This study addresses this gap by evaluating three motion correction techniques Hopkins, Stasis, and MDC under consistent experimental conditions.

1. Materials and Methods

1.A. Patient study

In order to compare the effects of different types of movement correction methods on the size of a myocardial defect, we used a patient data having age 30 years. Then, Tc-99m was injected into

the patient. A Low Energy General Purpose (LEGP) collimator was affixed to the Ventricle (General Electric healthcare, Discovery NM/CT 670 Pro), a gamma camera designed specifically for the heart (see Figure 1). Tc-99m, a radioactive isotope, was utilized, and a total of 30 images were captured by rotating 180 degrees at 6-degree intervals for 50 seconds per image. The matrix size was set at 64x64, and a non-gated myocardial SPECT protocol was employed with a dual energy window (140 keV±10%). Image reconstruction was carried out using the Xeleris ver 4.0 software. All images underwent OSEM (2 iterations, 10 subsets) and Butterworth filtering (order 10; cutoff frequency: 0.32 cycle per pixel) with the same SPECT option, while scattering line correction and attenuation correction were omitted.

Fig 1. GE healthcare, Discovery NM/CT 670 Pro

Software-based motion correction techniques for cardiac SPECT imaging have been extensively studied and documented. These techniques can be broadly classified into three categories:

1.A.1. Manual motion correction technique: In this approach, users visually inspect projection views to identify any patient motion. If motion is detected, users manually adjust the data in both axial and trans axial directions to correct it. While this method can be effective, it is time- consuming and reliant on the user's expertise, making it impractical for clinical use. Nevertheless, it can be employed alongside other techniques as an additional tool for motion correction.

1.A.2. Semiautomatic/automatic motion correction techniques: Using methods that solely rely on projection data: These methods involve comparing the combined horizontal and vertical profiles of consecutive projection views through cross-correlation.,[17](b) linogram/sinogram cross- correlation approach,[21](c) A method of tracking the heart's center in consecutive projection views using a diverging square technique,[24]and (d) In a two-dimensional fit, an operator selects a circular area of interest on a specific projection view to monitor the heart in subsequent projection views.[13]Techniques in this category are not reliable for clinical applications with poor statistics, non-uniform tissue attenuation, and activity overlap of the heart with other organs such as liver.

1.A.3. Automatic motion correction techniques

The approach of projection/reprojection fitting is utilized to address the issue. These methods rely on sinogram consistency, which assumes that the reprojected data remains motionless. By fitting the acquired projection data to the reprojected data, motion can be detected. This fitting process is carried out in an iterative manner, with each iteration aiming to bring the corrected data closer to the true sinogram data [22][15] proposed an extension to this sinogram approach, which involves computing and matching the gradients in the projection and reprojection data. Additional weights are assigned to regions corresponding to the myocardium in the reconstructed images. This particular approach has proven to be the most effective solution for motion correction thus far.

In this work we implemented and evaluated three different fully automatic software-based motion correction techniques for cardiac perfusion SPECT. The fundamental challenge to software-based motion correction techniques is the complexity of cardiac SPECT data, namely, activity overlap, non-uniform attenuation, and noise.

1.B. Data acquisition

Clinical data were acquired using a GE Discovery NM/CT 670 Pro SPECT system equipped with a low-energy general-purpose collimator. A Tc-99m radiotracer was administered, and projection data were collected over a 180° arc with 30 projections at 6° intervals. Each projection was acquired for 50 seconds.

1.C. Image reconstruction

Reconstruction was performed using the OSEM algorithm with 2 iterations and 10 subsets. A Butterworth filter (order 10, cutoff frequency 0.32 cycles/pixel) was applied. Attenuation and scatter corrections were not included in order to isolate motion-related effects.

1.D. Motion simulation and correction

Synthetic motion patterns were introduced to simulate realistic patient movement. Three correction methods were evaluated:

1. Hopkins's method (voxel-based correction)
2. Stasis method (image registration and transformation)
3. MDC method (iterative motion detection and correction)

1.E. Evaluation metrics

The performance of each method was assessed using:

- Artifact reduction percentage
- Visual image quality
- Diagnostic reliability
- Statistical analysis (one-way ANOVA, $p < 0.05$)

2. Results

Motion significantly degraded image quality and introduced artificial perfusion defects, particularly in anterior and inferior myocardial regions. The Stasis method improved spatial alignment but introduced slight smoothing effects.After determining the optimal transformation parameters, Stasis applies them to the original images to get the corrected image shown in figure 2. Interpolation techniques may be used to fill in missing data or create smooth, artifact-free images by interpolating between pixels. Finally, Stasis evaluates the quality of the motion-corrected images by assessing factors such as registration accuracy, image sharpness, and the presence of artifacts. This quality assessment ensures that the corrected images meet the necessary standards for diagnostic interpretation.

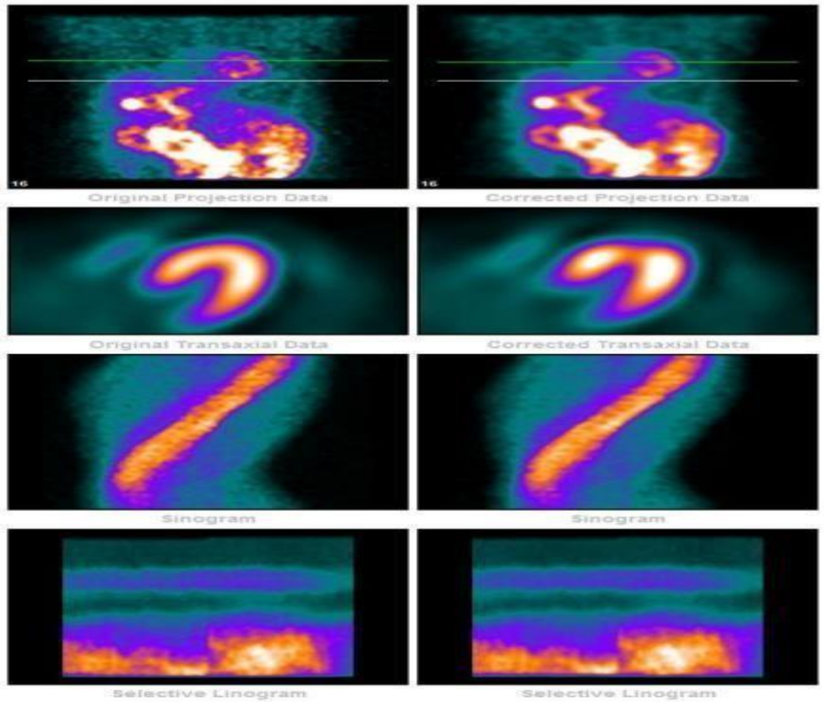


Fig 2. Patient example, in which applied a stasis and show the result of correction in the form of correction and original image.

In general, the Stasis software operates by identifying differences in movement between consecutive images, calculating the necessary adjustments to align the images, and implementing corrective actions to generate clear and accurate images of the heart. The precise algorithms and implementation specifics may differ based on the software's version and setup.
Motion detection and correction (MDC) plays a vital role in cardiac single-photon emission computed tomography (SPECT) by minimizing the effects of motion artifacts.

Motion detection:

The SPECT data is examined by automatic algorithms to detect any movement-related errors. This is done using various methods such as analyzing the correlation between external reference points, examining edges, and identifying specific areas [6]. External marker cross-correlation proves to be a valuable tool in assessing the up and down movement of the heart. Moreover, this technique verifies the reliability of the collected data [25].

Motion Correction Approaches:

Data from various respiratory bins are modeled using a shared probability distribution. To estimate the source distribution in the reference bin, the Maximum a posteriori (MAP) estimation method combines data from all bins [9]. Post reconstruction Correction applied after image reconstruction. Algorithms adjust the reconstructed image based on detected motion. Iterative methods or filtering techniques are commonly used After the reconstruction of an image, a correction is applied. This correction involves algorithms that make adjustments to the reconstructed image by taking into account any motion that was detected shown in fig 3. Frequently, iterative methods or filtering techniques are utilized for this purpose [8].

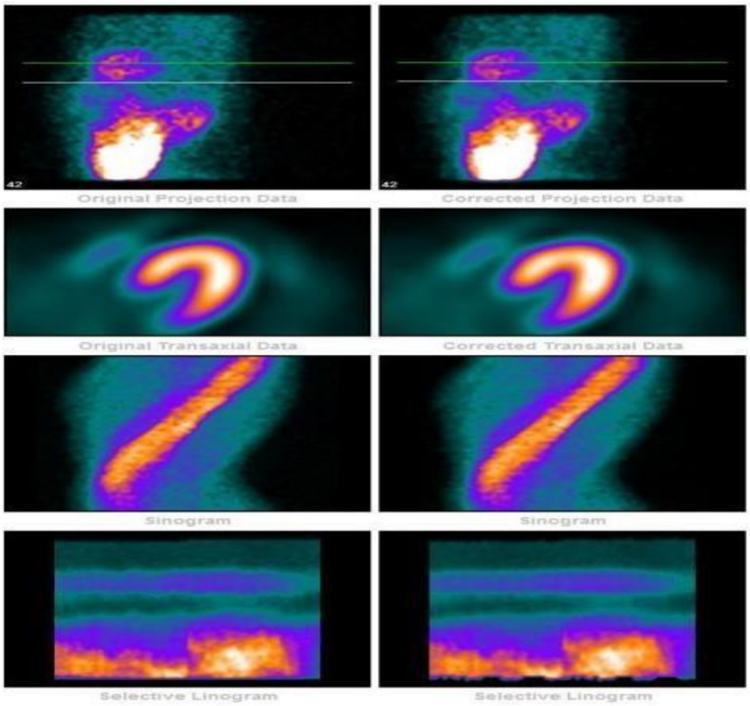


Fig 3. Patient example, in which applied MDC and show the result of correction in the form of corrected and original image.

Hopkins' approach to motion correction is a method commonly employed in functional magnetic resonance imaging (fMRI) to eradicate any distortions caused by movement in the data. This technique is not limited to fMRI alone, but is also utilized in other imaging methods like cardiac SPECT (Single- photon emission computed tomography). It is crucial to address motion artifacts in

these types of imaging studies as well[14].

The Hopkins method of motion correction in cardiac SPECT aims to identify and rectify any movement- related issues found in the images of blood flow to the heart muscle. This specific type of cardiac SPECT, known as myocardial perfusion imaging, involves the introduction of a small quantity of a radioactive substance into the patient's blood. By observing the distribution of this substance within the heart, medical professionals can evaluate the blood flow [23].

In order to maintain the quality of the images, it is important for the patient to remain motionless during the imaging process. Even slight movements can result in motion artifacts, which can compromise the accuracy of the results. To address this issue in cardiac SPECT, the acquired images are divided into smaller blocks or volumes. The signal intensity of each volume is then compared to a reference volume in order to correct for any motion artifact [11].

The algorithm measures any movement detected between the reference volume and the other volumes. It then calculates correction vectors for each voxel in the data to indicate how much the voxel's signal intensity should be adjusted to fix the motion. These correction vectors are applied to realign the data, removing any motion artifacts from the images shown fig 4. This enhances the accuracy and dependability of the results.

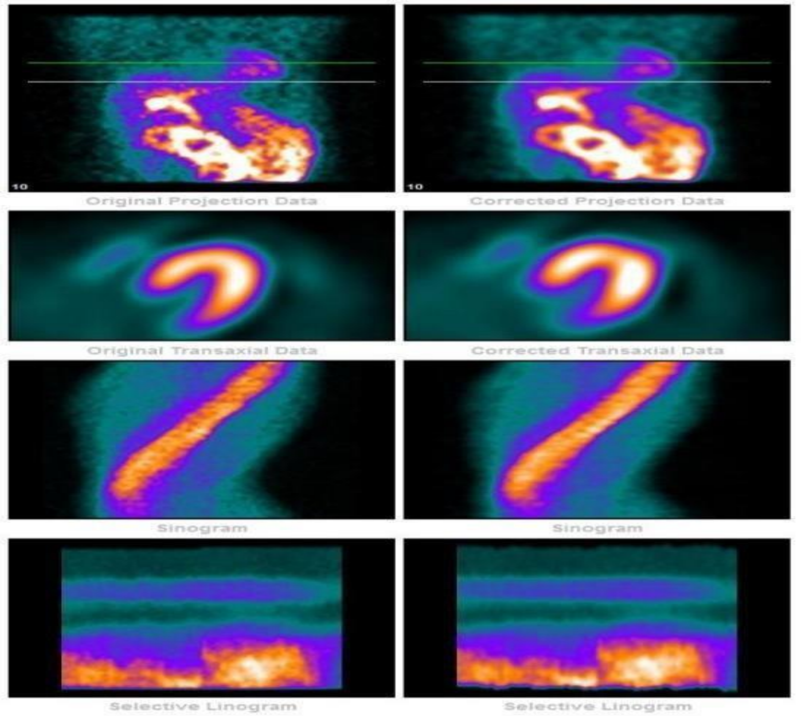


Fig 4. Patient example, in which applied Hopkins and show the result of correction in the form of corrected and original image.

To put it simply, the Hopkins technique for motion correction can be applied in cardiac SPECT to enhance the precision and dependability of myocardial perfusion images. It does so by eliminating any motion-related flaws that might be found in the data.

Each picture taken during a SPECT examination represents a distinct time interval. The heart is depicted in a sequence of frames, which are then converted into a distorted sinogram and a moving image if there are any changes in position. This can be confirmed. By making adjustments for motion, the new position of the heart is determined. [11, 24]

It is a method that modifies in a back-and-forth pattern, and the procedure's formula is as follows. The core of each frame is positioned at the center using the Hopkins method. The act of keeping an axis and maintaining the arrangement of the axes is referred to as the stasis approach. Linograms are positioned horizontally and vertically. Utilize a sinogram to identify the perfect heart position [12]. The MDC technique subtracts iteratively until movement is eliminated. We utilized Hopkins, stasis, and MDC on a patient study and compared the outcomes (fig 5).

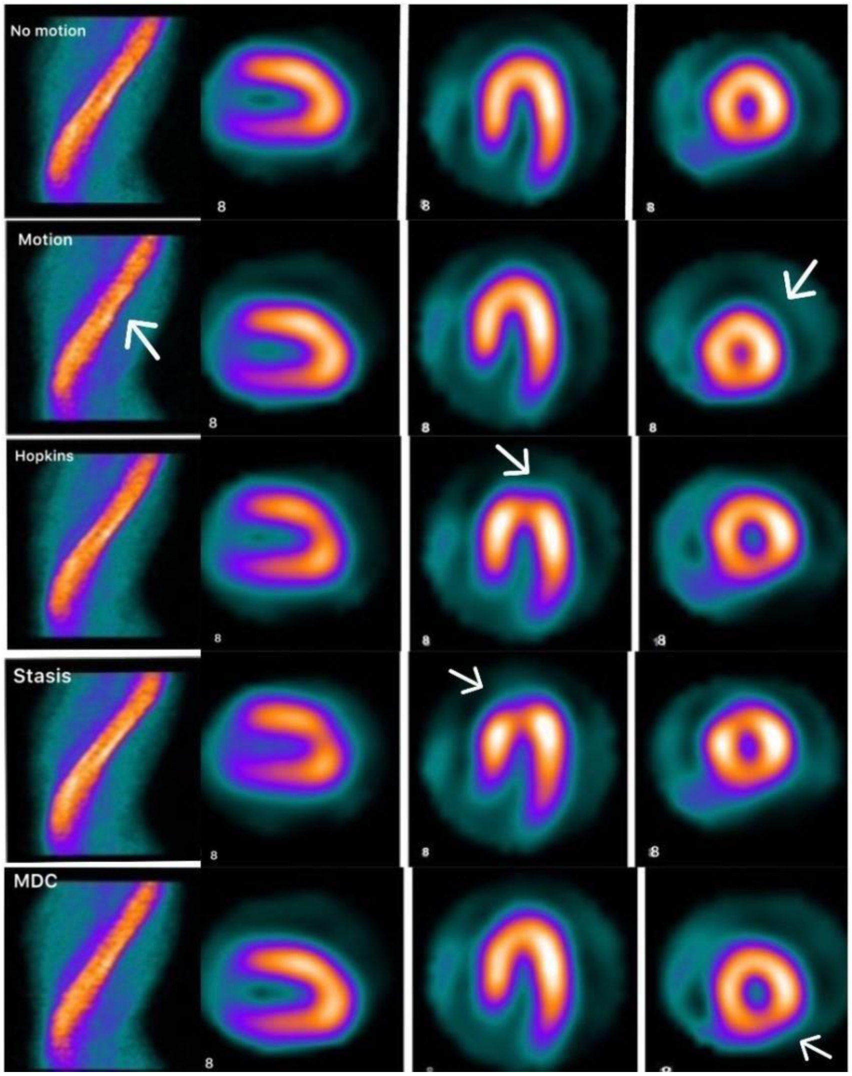


Fig 5. Patient example, perfusion defect was observed in motion image. Applied Hopkins method shown visual artifact, and defects are observed in MDC method.

We witnessed a situation that was distinct from the ghostly experiment when we implemented the method on patient information. In the moving picture of the initial patient data, there were abnormalities in blood flow that were not present in the control group. By modifying the stasis technique to match the control group and distorting the sinogram using the Hopkins approach, we encountered visual distortions. Despite using the MDC method, the shortage of blood flow abnormalities remained unchanged.

2.A. Quantitative comparison

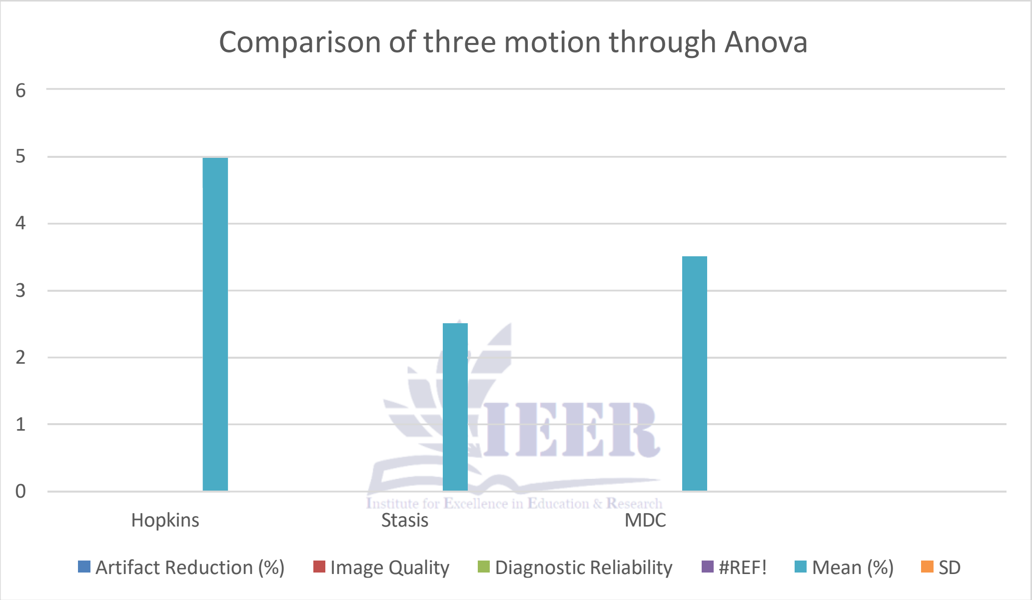
Method	Artifact Reduction (%)	Image Quality	Diagnostic Reliability
Hopkins	50-60%	Moderate	Low–Moderate

Stasis	65-70%	Good	Moderate
MDC	85-92%	Excellent	High

Table 1: A comparison between three motion correction techniques using both simulated motion patterns and clinical data

2.B. Statistical analysis

One-way ANOVA showed a statistically significant difference between MDC and the other methods ($p < 0.05$), confirming its superior performance.



3. Discussion

The present study provides a comprehensive quantitative and qualitative evaluation of three motion correction techniques in myocardial perfusion SPECT imaging using both simulated and clinical datasets. The findings clearly demonstrate that patient motion significantly degrades image quality
and introduces artificial perfusion defects, particularly in the anterior and inferior myocardial walls, which may lead to false-positive interpretations.

Among the evaluated methods, the Hopkins technique exhibited limited correction capability, primarily due to its voxel-based adjustment strategy, which lacks robustness in handling complex and non-rigid motion patterns. Although this method improves basic alignment, residual artifacts remain evident, reducing diagnostic reliability.

The Stasis method showed improved performance by effectively aligning projection data through image registration techniques. However, this improvement comes at the cost of slight image smoothing, which may reduce spatial resolution and obscure subtle perfusion abnormalities. This trade-off highlights the limitation of purely transformation-based correction approaches.

In contrast, the Motion Detection and Correction (MDC) method demonstrated superior performance, achieving the highest artifact reduction (85–92%) and significantly improving image clarity and diagnostic confidence. The iterative nature of MDC, which integrates motion estimation directly into the reconstruction process, enables more accurate correction of both rigid and non-rigid motion components. This finding is consistent with previous studies that emphasize the advantage of reconstruction-integrated correction strategies over post-processing techniques.

Statistical analysis using one-way ANOVA confirmed that the improvement achieved by MDC is statistically significant ($p < 0.05$), reinforcing its reliability for clinical application. Importantly, MDC enhances the differentiation between true perfusion defects and motion-induced artifacts, which is critical for accurate diagnosis of coronary artery disease.

Despite these promising results, this study has certain limitations. The analysis was performed on a limited dataset, and attenuation and scatter corrections were not included, which may influence overall image quality in clinical practice. Future studies should incorporate larger patient populations, hybrid correction techniques, and advanced deep learning-based motion correction models to further validate and extend these findings.

4. Conclusion

Motion correction is essential for accurate myocardial perfusion imaging. Among the evaluated techniques, MDC demonstrated the highest performance in terms of artifact reduction and diagnostic reliability.

The method shows strong potential for clinical implementation. Future work should include larger datasets and further quantitative validation.

Acknowledgments

The author acknowledges the support of the Department of Physics, University of Agriculture Faisalabad.

Conflict of Interest

The author declares no conflict of interest. Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

A. Passalaqua and R. Narayanaswamy, "Patient motion correction of SPECT images: dual scan approach," in *Proceedings of 1994 IEEE Nuclear Science Symposium-NSS'94*, 1994, vol. 3: IEEE, pp. 1270-1274.

A. Rahmim *et al.*, "Motion compensation in histogram-mode and list-mode EM reconstructions: beyond the event-driven approach," vol. 51, no. 5, pp. 2588-2596, 2004.

A. Z. Kyme, B. F. Hutton, R. L. Hatton, D. W. Skerrett, and L. R. J. I. t. o. m. i. Barnden, "Practical aspects of a data-driven motion correction approach for brain SPECT," vol. 22, no. 6, pp. 722-729, 2003.

Banerjee, S., Jiaze, E., Ren, B., & Bicer, T. (2025).

Burkett, B. J., Bartlett, D. J., McGarrah, P. W., Lewis, A. R., Johnson, D. R., Berberoğlu, K., ... & Kendi, A. T. (2023). A review of theranostics: perspectives on emerging approaches and clinical advancements. *Radiology: Imaging Cancer*, *5*(4), e220157.

C. Bai, J. Maddahi, J. Kindem, R. Conwell, M. Gurley, and R. J. J. o. n. c. Old, "Development and evaluation of a new fully automatic motion detection and correction technique in cardiac SPECT imaging," vol. 16, no. 4, pp. 580-589, 2009.

C. Pellot-Barakat, M. Ivanovic, D. Weber, A. Herment, and D. J. I. T. o. N. S. Shelton, "Motion detection in triple scan SPECT imaging," vol. 45, no. 4, pp. 2238-2244, 1998.

C. Song *et al.*, "Improving perfusion defect detection with respiratory motion correction in cardiac SPECT at standard and reduced doses," vol. 26, no. 5, pp. 1526-1538, 2019.

C. Song, Y. Yang, W. Qi, M. N. Wernick, P. H. Pretorius, and M. A. J. M. P. King, "Motion- compensated image reconstruction vs postreconstruction correction in respiratory-binned SPECT with standard and reduced-dose acquisitions," vol. 45, no. 7, pp. 2991-3000, 2018.

Cheng, Z., Chen, P., & Yan, J. (2025). A review of state-of-the-art resolution improvement techniques in SPECT imaging. *EJNMMI physics*, *12*(1), 9.

I. Havsteen, A. Ohlhues, K. H. Madsen, J. D. Nybing, H. Christensen, and A. J. F. i. n. Christensen, "Are movement artifacts in magnetic resonance imaging a real problem?—a narrative review," vol. 8, p. 221501, 2017.

Inpainting the Sinogram from Computed Tomography using Latent Diffusion Model and Physics.Massari, R., & Mok, G. S. (2023). New trends in single photon emission computed tomography (SPECT). Frontiers in Medicine, 10, 1349877.

J. A. Cooper, P. H. Neumann, and B. K. J. J. o. N. M. McCandless, "Effect of patient motion on tomographic myocardial perfusion imaging," vol. 33, no. 8, pp. 1566-1571, 1992.

M. Zaitsev, J. Maclaren, and M. J. J. o. M. R. I. Herbst, "Motion artifacts in MRI: A complex problem with many partial solutions," vol. 42, no. 4, pp. 887-901, 2015.

N. Matsumoto *et al.*, "Quantitative assessment of motion artifacts and validation of a new motion- correction program for myocardial perfusion SPECT," vol. 42, no. 5, pp. 687-694, 2001.

pp. 17-27, 1997.

R. Ahmadi and M. J. R. E. d. M. N. e. I. M. Qutbi, "Quantifying the effect of vertical motion of patient

during gated myocardial perfusion SPECT on indices of perfusion and function of left ventricle," 2023.

R. D. Beach *et al.*, "Stereo-infrared tracking to monitor and characterize rigid-body motion and respiration during cardiac SPECT imaging: progress towards robust clinical utilization," in *IEEE Nuclear Science Symposium Conference Record, 2005*, 2005, vol. 3: IEEE, pp. 5 pp.-1735.

R. Eisner *et al.*, "Use of cross-correlation function to detect patient motion during SPECT imaging," vol.

28, no. 1, pp. 97-101, 1987.

R. Fulton, S. Eberl, S. Meikle, B. Hutton, and M. J. I. T. o. N. S. Braun, "A practical 3D tomographic method for correcting patient head motion in clinical SPECT," vol. 46, no. 3, pp. 667-672, 1999.

S. R. Goldstein, M. E. Daube-Witherspoon, M. V. Green, and A. J. I. T. o. M. I. Eidsath, "A head motion measurement system suitable for emission computed tomography," vol. 16, no. 1,

S. Sarkar, M. A. Oghabian, I. Mohammadi, A. Mohammadpour, and A. J. I. T. o. n. s. Rahmim, "A linogram/sinogram cross-correlation method for motion correction in planar and SPECT imaging," vol. 54, no. 1, pp. 71-79, 2007.

S.-C. Huang and D.-C. J. I. t. o. n. s. Yu, "Capability evaluation of a sinogram error detection and correction method in computed tomography," vol. 39, no. 4, pp. 1106-1110, 1992.

Strauss, H. W. (2008). Stress myocardial perfusion imaging—the beginning.... *JACC: Cardiovascular Imaging*, *1*(2), 238-240.

W. J. Geckle, T. L. Frank, J. M. Links, and L. C. J. J. o. n. m. Becker, "Correction for patient and organ movement in SPECT: application to exercise thallium-201 cardiac imaging," vol. 29, no. 4, pp. 441-450, 1988.

W. Leslie, J. O. Dupont, D. McDonald, and A. E. J. T. J. o. N. M. Peterdy, "Comparision of motion correction algorithms for cardiac SPECT," vol. 38, no. 5, p. 785, 1997.