Elimination of the artifacts on myocardial perfusion Single Photon Emission Tomography (SPECT) scintigraphy-new prospects

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ABSTRACT Introduction: This study aims to explore clinical values and possibilities of heart artifact elimination for patients who underwent SPECT myocardial perfusion scintigraphy. The main focus is on nuclear medicine technologists and their knowlodge of the new technologies developed in nuclear cardiology. **Methods:** A qualitative descriptive study, review article has been performed for this research. Pubmed, Web of Science, and Embase were searched using a predefined electronic search strategy. Eighteen studies were deemed eligible for this systematic review. **Results:** Based on the literature we found average age for the patients with coronary artery disease is 59.69 years for women and 57.39 yeras for men. False positive findings, blurred images, respiratory artifacts and sinogram and linogram interruption is very often, especially with patients with irregular breathing cycles, fear of the reasults, anxiety and patients with high BMI. Many studies performed on phantoms or on patients suggest image artifacts can be reduced or even eliminated with the new scanning methodology, software application upgrade, and with right nuclear medicine technologist education. **Conclusion:** Coronary artery disease can affect men and women equally so the best diagnostic modality is essential for adequate treatment. Interruption of sinogram or linogram, truncation of the heart and blurred image is the first sign artifact of the image. Essential and the first step of every cardiac proccesing software is sinogram and linogram inspection combined with motion correction evaluation of the raw images. New technologies can improve image quality which can increase sensitivity and specificy of myocardial perfusion scintigraphy in all patients.

KEYWORDS respiratory motion, motion correction, attenuation correction, SPECT, SPECT/CT, myocardial perfusion scintigraphy, coronary artery disease

Introduction

Coronary artery disease is a significant public health problem and the leading death cause in the world. Effective assessment of coronary artery disease is a big problem in clinical practice.

Acute coronary syndrome (ACS) is one of the manifestations of ischemic heart disease. The term is used to describe any constellation of symptoms that suggests that acute myocardial ischemia is occurring. ACS encompasses the following clinical entities: unstable angina (UA), non-ST segment elevation myocardial infarction (NSTEMI) and ST-segment elevation myocardial infarction (STEMI). The most common mechanism for acute myocardial ischemia represents coronary artery plaque rupture that results in thrombosis and leads to either partial or complete occlusion of the coronary artery. [1]

The estimated prevalence of coronary artery disease in the USA, including myocardial infarction (MI), is around 6% of the population.[6] In 2008, a report stated the incidence rate of STEMI in the USA was about 50 per 100000 and showing a decreasing trend when compared to earlier years. National registry of MI reported 2.5 million cases of MI between 1990 and 2006 and additionally demonstrated an increase in the proportion of the cases caused by NSTEMI from 14.2% to 59.1% during the

DOI:10.5455/IJMRCR.MPS-SPECT
First Received: October 09, 2019
Accepted: October 16, 2019
Associate Editor: Ivan Inkov (BG)
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registry timeframe. [1]

Coronary artery disease risk factors

The Comparative Risk Assessment (CRA) Study showed that CVD risk factors such as elevated blood pressure and smoking were among leading causes of mortality and morbidity in the world, with a large share of their health burden borne by low- and middle-income countries. The study also quantified the combined (joint) burden of multiple risk factors, accounting for the overlaps among their effects [2]. The joint effect analysis showed that nearly 80% of deaths from IHD and almost 70% of deaths from stroke in the world were attributable to a small number of physiological and behavioral risk factors including high blood pressure, high serum cholesterol, smoking, high body mass index (BMI), alcohol use, low intake of fruits and vegetables, and physical inactivity [3].

Coronary artery disease diagnostic modalities

Laboratory examinations enable risk factors diagnosis such as hyperlipoproteinemia, high glucose levels, anaemia, hypertension, hyperthyreosis etc [4]. **Electrocardiography (ECG)** can discover scar from myocardial infarction, left branch bundle block (LBBB), left ventricular hypertrophy etc. Normal ECG finding can exclude coronary disease [5]. **The cardiac stress test** is a routine method for angina pectoris and ischaemia extent detection [6]. **24-Hour Holter monitoring** is a very useful method for coronary insufficiency [5]. **Echocardiography (US)** can discover damaged regional contractility, other anomalies and diseases combined with heart disease. This method does not use ionising radiation thus can be repeated many times. With echocardiography we can diagnose congenital heart anomalies, acute myocardial infarction, cardiomyopathy, pericardial diseases etc, [7].

Computed tomography (CT) is widely used for assessment of the coronary arteries before and after therapeutic intervention. This method can detect calcifications in the coronary arteries with the calcium score applications. Multi-Detector Computed Tomography Coronarography (MDCT) enable precise stenosis position and is very useful for follow-up of the patients [7].

Magnetic Resonance Imaging (MRI) does not use ionising radiation, and it is suitable for children and young people. MRI is not so much in use comparing to CT the US. A significant advantage of MRI is in the possibility of follow-up of the congenital heart anomalies. Duration of the heart MRI exam is longer compared to CT and US, so adequate clinical indication is needed for the best outcome [7].

Coronary catheterisation is the only method for in vivo visualisation of the coronary arteries. The significant advance of coronary catheterisation is possibility of Percutaneous Coronary Intervention (PCI) [8].

Technological advances in the last 30 years now allow direct, real-time measurement of coronary flow and pressure in individual patients and this data can be applied directly at the time of coronary angiography to guide treatment of individual atherosclerotic lesions [9].

Myocardial perfusion scintigraphy (MPI)

Myocardial perfusion scintigraphy (MPS) using single-photon emission computed tomography (SPECT) with radiopharmaceuticals is widely used for non-invasive diagnosis of obstructive CAD. MPS provides comprehensive information on myocardial perfusion, regional and global left ventricular function that provides incremental diagnostic and prognostic information. MPS evaluate regional myocardial perfusion as well as giving information about functional parameters such as transient ischemic dilation (TID), extent of perfusion defect, etc [10].

In patients with established CAD, MPS has an essential role in the evaluation of symptoms suggestive of myocardial ischemia, and can also assess the risk of non-fatal myocardial infarction and cardiac death. Although the value of quantification of ischemia has been the subject of debate in recent years, it is undeniable that in clinical practice it can assist in therapeutic decision-making [11].

G-SPECT imaging technique

Gated myocardial perfusion SPECT (G-SPECT) is considered as one of the best techniques for the combined evaluation of the myocardial perfusion and the left ventricular ejection fraction (LVEF) within a single study. Sufficient count density in the ciné frames is necessary for best myocardial perfusion images quality and G-SPECT synchronized with the subject's electrocardiogram (ECG) to identify the temporal phases of the cardiac cycle. The variation in the cardiac cycle duration may cause fluctuation of the adjacent frames count, which compromises the quality of the perfusion image and decreases the left ventricle ejection fraction (LVEF) accuracy [12].

Image artefacts on g-SPECT due to irregular heart pulse

Irregular heart pulse can cause wrong ejection fraction results during g-SPECT study. These artefacts are common for patients with atrial fibrillation, extrasystoles and low R-wave voltage. Low R-wave causes low sensitivity and in final errors in gated series [13].

Respiratory and patient motion can also have a degrading effect on SPECT images, and several recent studies proposed techniques for mitigating these effects. As image resolution increases with advances in image hardware and software reconstruction, heart motion becomes the dominant degrading factor in MPS [14]. Truncation artefact is usually seen in obese patients who may deviate from a γ-ray detector field. The deviation of the body in the limited detector field sometimes causes the truncation of the left ventricle and low image quality. When the doctors read the SPECT images and technologists inspect the image quality, the recognition of raw projection datasets and the reconstructed axial image is useful for avoiding artefacts [15].

Materials and Methods

A qualitative descriptive study, review article has been performed for this research. Pubmed, Medline and Embase were searched using a predefined electronic search strategy. Eighteen studies were deemed eligible for this systematic review. This brief review covers the latest technological prospects in the elimination of artefacts on myocardial perfusion imaging with single-photon emission computed tomography (SPECT), We focus on the new types of hardware, and several software approaches recently introduced to clinical practice and describe various new imaging protocols made possible by these hardware developments.

Results

Patient motion

Despite advances in radiopharmaceuticals (99mTc-based) and instrumentation (gated SPECT on multiple-detector gantries), patient comfort is still problematic. Patient motion often occurs because of patient discomfort. The patient may have difficulty with hyperextension of the arms because of arthritis, weakness, fatigue after a stress test, previous surgery to the shoulders, or a general lack of fitness, flexibility, or cooperation. Anxiety about the procedure and the possible outcome can also cause the patient to move. A review of the literature reveals that patient motion has been reported in 10%–26% of clinical SPECT myocardial perfusion studies [16]. Respiratory and patient motion can also have a degrading effect on SPECT images, and several recent studies proposed techniques for mitigating these effects. As image resolution increases with advances in image hardware and software reconstruction, heart motion becomes the dominant degrading factor in MPS. Respiratory motion correction can be applied to conventional dual-head systems by modelling of approximate motion. Dual respiratory/cardiac-gated MPS imaging has been demonstrated in phantoms, and in patients showing progressive improvement of the myocardium to blood pool contrast when respiratory and cardiac dual gating was applied [14].

In the past two years, these new hardware systems and reconstruction techniques have been utilised clinically to reduce patient imaging time and radiation dose. Typically, these studies have been validated by comparing to studies performed with the same injected dose during the same patient visit on a conventional dual-head SPECT camera. Data were analysed by blinded visual or by quantitative analysis. Several of these studies combined data from multiple centres [17]. Based on the results of the study " Incidence and Characterization of Patient Motion in Myocardial Perfusion SPECT: Part 1" among the 800 studies analyzed, motion was seen in 36% (288/800; 95% CI, 32.7%–39.3%), of which 126 were rest studies, and 162 were stress studies. In 55% (220/400) of patients, motion was seen in at least one of their studies (95% CI, 50%–60%). In 14.5% (58/400) of patients, motion was seen in the rest study only; in 23.5% (94/400), in the stress study only; and in 17% (68/400), in both the rest and the stress studies [16].

Attenuation correction

Attenuation and Compton scattering of emitted photons are the main factors that limit the quantitative accuracy of single-photon emission computed tomography (SPECT). Although no analytically exact solution to the attenuation problem has been found, sufficient accuracy can be achieved using transmission measurements, particularly when combined with iterative correction techniques. Various scatter compensation methods have also been described, but few have addressed the complex scattering problem in objects with heterogeneous density such as the thorax [18]. Attenuation correction has been widely carried out using transmission computed tomography (TCT) scanning, with several mechanical configurations such as rotating rod sources fitted with parallel-beam collimator systems, and a single rod source placed at the focal line of the asymmetrical fan-beam collimator. It has been demonstrated that TCT data can also be used for scatter correction and that when coupled with kinetic analysis, the overall accuracy of reconstructed SPECT images is sufficiently high for quantitation of various physiological functions in the thoracic region and also in the brain. Several dedicated TCT systems developed by different manufacturers have resulted in improved diagnostic accuracy. Use of breath-hold CT attenuation maps at end inspiration and middle phases for attenuation and scatter corrections demonstrated accurate quantitative images in cardiac SPECT/CT studies [19].

Patient preparation and anxiety as a degrading factor of image quality

The patient's anxiety has been considered another cause of the patient's psychological and physical discomfort and thus contributing to the patient's motion during MPI and other imaging modalities. The careful visual review of projection images is considered the best way to identify any presence of motion. Moreover, the interobserver reliability of more than 90% in literature and the intraobserver reliability of more than 96% in our study are following the high visual motion assessment reproducibility. Visual inspection is a widely acceptable method for detecting vertical body displacements (parallel to the axis of gantry rotation) even in the order of 3.25 mm (corresponding to half pixel in our study) rather than lateral body displacements (perpendicular to the axis of rotation and detected as a fraction of the actual motion in the particular projection). Several reports suggest that vertical motion is the most common type of motion with greater likelihood in producing clinically significant artefacts [20].

New strategies in motion elimination

To minimise artefacts and obtain high-quality diagnostic images, quality control of the SPECT camera is requisite. Daily uniformity and energy-peaking tests and weekly COR tests must be run to check the performance of system. However, even if all standard tests for various artefacts are run, there may be discrepancies in the final results because of some unexpected system error. The sinogram or linogram in the final printout can provide valuable information about COR, patient motion, and off-peak artefacts. Therefore, the sinogram and linogram should be reviewed by the operator to check for motion artefacts [21].

The technologist performing the study should ensure that the patient is relaxed and comfortable before the start of acquisition to limit the possibility of motion throughout the scan. Observation of the patient during the acquisition is also recommended to ensure that the patient remains still. Prone imaging may also be introduced to reduce patient motion. In addition to taking steps before and during the acquisition to limit patient motion, the technologist must review the raw data in cine mode afterwards to assess for motion. A decision must then be made as to whether additional steps are required [22].

Kortelainen et al. in study "Effect of respiratory motion on cardiac defect contrast in myocardial perfusion SPECT: a physical phantom study" performed on the phantom showed respiratory motion could damage myocardial images. Correction for respiratory motion in myocardial perfusion imaging requires sorting of emission data into respiratory windows where the intra-window motion is assumed to be negligible. However, it is unclear how much intra-window motion is acceptable. This study aimed to determine the optimal value of intra-window residual motion. They suggest the intra-window respiratory motion should be limited to 2 mm per window to effectively correct for respiratory motion blur [23].

The results of the study "Effects of Motion, Attenuation, and Scatter Corrections on Gated Cardiac SPECT Reconstruction" showed use of temporal processing in reconstruction (Methods 1, 4, and 5 above) could significantly improve the reconstructed myocardium in terms of both error level and perfusion defect detection. In low-count gated studies, it can have even more significant impact than other degrading factors. The results demonstrate that both attenuation and scatter corrections can lead to reduced error levels in the myocardium in all methods; in particular, with 4D the bias can be reduced by as much as four-fold compared to no correction Correction for degrading factors such as resolution, attenuation, scatter, and motion blur can all lead to improved image quality in cardiac gated SPECT reconstruction. However, their effectiveness could also vary with the reconstruction algorithms used. Both attenuation and scatter corrections can effectively reduce the bias level of the reconstructed LV wall, though scatter correction is also observed to increase the variance level [24].

Phantom study "Correction of hysteretic respiratory motion in SPECT myocardial perfusion imaging: Simulation and patient studies" showed respiratory motion (RM) impact on the quality of images. Authors suggest use of Bouc-Wen (BW) model in the process of elimination of respiratory artefacts. Further clinical studies need to be performed for better results [25].

Parker et al. in the study "Respiratory motion correction in gated cardiac SPECT using quaternion-based, rigid-body registration" presented a new method for correction of respiration-induced cardiac motion using a rigid-body model with a rotation matrix parametrized by a unit quaternion. The method minimizes an image-registration function using an optimized conjugate gradient routine. The implementation uses no user-defined input parameters or prior terms, simplifying the use of the method in a clinical setting. Images corrected with the quaternion-based motion estimate were found to be more similar to images corrected with the known, true motion compared to uncorrected images on both phantom and simulated data. The ejection fraction calculated from images corrected with the method demonstrated a 6% improvement in accuracy over uncorrected images. They have also tested this method on humans. The corrected images have increased uniformity and decreased motion blur in areas of the myocardium running perpendicular to the axial direction. Furthermore, the method was shown to be relatively insensitive to changes in segmentation and extramyocardial activity level, an essential requirement for clinical use. This method shows potential, but for the future clinical use further testings are needed [26].

Combination of multi-slice CT and SPECT systems has been shown to result in accurate reconstruction in myocardial studies. A problem, however, has been noted when applying CT information to attenuation correction in the thoracic region [27]. Previous studies have demonstrated improvements in diagnostic accuracy when applying corrections for both attenuations and scatter. Attenuation correction has been widely carried out utilizing transmission computed tomography (TCT) scanning, with several mechanical configurations such as rotating rod sources fitted with parallel-beam collimator systems, and a single rod source placed at the focal line of the asymmetrical fan-beam collimator. TCT data can also be used for scatter correction, and that when coupled with kinetic analysis, the overall accuracy of reconstructed SPECT images is sufficiently high for quantitation of various physiological functions in the thoracic region and also in the brain. Use of breath-hold CT attenuation maps at end-inspiration and middle phases for attenuation and scatter corrections demonstrated accurate quantitative images in cardiac SPECT/CT studies. This technique might apply to routine clinical study. Quantitative assessment of absolute MBF and coronary flow reserve in clinical settings would be an additional potential application [28].

Conclusion

According to our results, myocardial perfusion scintigraphy is a valuable non-invasive diagnostic modality for coronary artery disease. Improved equipment, scanning technique, new radiopharmaceuticals knowledge can increase sensitivity and specificity of this imaging modality. A major novelty in basic methodology is introduction of CT in SPECT technique for SPECT/CT myocardial perfusion scintigraphy. Phantom and clinical studies around the world are focused on respiratory and cardiac motion management, attenuation and scatter elimination and improvement of image quality. The first results are encouraging.

Conflict of Interest

There are no conflicts of interest to declare by any of the authors of this study.

Funding

None

References

1. Petrovic L, Chhabra L. Selecting A Treatment Modality In Acute Coronary Syndrome. StatPearls Publishing. 2019.

2. Ezzati M, Lopez AD, Rodgers A, Murray CJL. Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors (volumes 1 and 2). 2004:2248

3. World Health Organization (WHO). Global health risks: Mortality and burden of disease attributable to selected major risks. Geneva: World Health Organization;2009.

4. Saunders R, Lankiewicz J. The Cost Effectiveness of Single Patient Use Electrocardiograph Cable and Lead Systems in Monitoring for Coronary Artery Bypass Graft Surgery. Front Cardiovasc Med. 2019;6:61. doi:10.3389/fcvm.2019.00061.

5. Rog B, Salapa K, Okolska M, et al. Clinical Evaluation of Exercise Capacity in Adults with Systemic Right Ventricle. Tex Heart Inst J. 2019;46(1):14–20. doi:10.14503/THIJ-17-6408.

6. Pevnick JM, Birkeland K, Zimmer R, Elad Y, Kedan I. Wearable technology for cardiology: An update and framework for the future. Trends Cardiovasc Med. 2018;28(2):144–150. doi:10.1016/j.tcm.2017.08.003.

7. Atzeni F, Corda M, Gianturco L, Porcu M, Sarzi-Puttini P, Turiel M. Cardiovascular Imaging Techniques in Systemic Rheumatic Diseases. Front Med (Lausanne). 2018;5:26. doi:10.3389/fmed.2018.00026.

8. Chodór P, Morawski S, Sulik-Gajda S, et al. Evaluation of the usefulness of coronary catheters and 4 Fr insertion sets for transradial access coronarography in comparison with catheters and 5 Fr sets. Postepy Kardiol Interwencyjnej. 2013;9(4):332–336. doi:10.5114/pwki.2013.38860.

9. Shah SM, Pfau SE. Coronary Physiology in the Cardiac Catheterization Laboratory. J Clin Med. 2019;8(2):255. Published 2019 Feb 18. doi:10.3390/jcm8020255.

10. Hasbek Z, Ertürk SA, Çakmakçılar A, Gül İ, Yılmaz A. Evaluation of Myocardial Perfusion Imaging SPECT Parameters and Pharmacologic Stress Test with Adenosine Versus Coronary Angiography Findings: Are They Diagnostically Concordant?. Mol Imaging Radionucl Ther. 2019;28(2):53–61. doi:10.4274/mirt.galenos.2019.47450

11. Shaw LJ, Berman DS, Maron DJ, Mancini GB, Hayes SW, Hartigan PM. Optimal medical therapy with or without percutaneous coronary intervention to reduce ischemic burden results from the Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation (COURAGE) trial nuclear substudy. Circulation. 2008;117(1):1283–1291.

12. Khedr MH, Abdullah M, Monem AS. evaluation for the effect of arrhythmia and gating errors in the gated myocardial spect perfusion and function. Romanian J. Biophys. 2017,; 27 (1-2): 23–34.

13. Kasai T, DePuey EG, Sponder I. "W-shaped" Volume Curve with Gated Myocardial Perfusion Single Photon Emission Computed Tomography. Annals of Nuclear Medicine, 2005; 19(1): 59–64.

14. Slomka P, Hung GU, Germano G, Berman DS. Novel SPECT Technologies and Approaches in Cardiac Imaging. Cardiovasc Innov Appl. 2016;2(1):31–46. doi:10.15212/CVIA.2016.0052.

15. Matsumoto N, Suzuki Y, Yoda S, Hirayama A. The truncation artefact in patients with a high body mass index on myocardial perfusion SPECT. BMJ Case Rep. 2014;2014:bcr2014205407. Published 2014 Jul 15. doi:10.1136/bcr-2014-205407.

16. JM, Currie GM. Incidence and Characterization of Patient Motion in Myocardial Perfusion SPECT: Part 1. Journal of Nuclear Medicine Technology, 2004; 32(2): 60-65.

17. Slomka PJ, Berman DS, Germano G. New Imaging Protocols for New Single Photon Emission CT Technologies. Curr Cardiovasc Imaging Rep. 2010;3(3):162–170. doi:10.1007/s12410-010-9021-0.

18. Meikie SR, Hutton BF, Bailey DL. A Transmission-Dependent Method for Scatter Correction in SPECT. The Journal of Nuclear Medicine. 1994; 35(2): 360-367.

19. Koshino K, Fukushima K, Fukumoto M, et al. Breath-hold CT attenuation correction for quantitative cardiac SPECT. EJNMMI Res. 2012;2(1):33. Published 2012 Jun 22. doi:10.1186/2191-219X-2-33.

20. Lyra V, Kallergi M, Rizos E, Lamprakopoulos G, Chatziioannou SN. The effect of patient anxiety and depression on motion during myocardial perfusion SPECT imaging. BMC Med Imaging. 2016;16(1):49. Published 2016 Aug 22. doi:10.1186/s12880-016-0153-9

21. Kheruka SC, Naithani UC, Aggarwal LM, Painuly NK, Maurya AK, Gambhir S. An Investigation of a Sinogram Discontinuity Artifact on Myocardial Perfusion Imaging. Journal of Nuclear Medicine Technology, 2012,; 40(1): 25-28.

22. Burrell S, MacDonald A. Artifacts and Pitfalls in Myocardial Perfusion Imaging. The Journal of Nuclear Medicine Technology. 2006,; 34(4) 193-211.

23. Kortelainen MJ, Koivumäki TM, Vauhkonen MJ, Hakulinen MA. Effect of respiratory motion on cardiac defect contrast in myocardial perfusion SPECT: a physical phantom study. Ann Nucl Med. 2019,; 33(5): 305–316. doi:10.1007/s12149-019-01335-y.

24. Niu X, Yang Y, King MA. Effects of Motion, Attenuation, and Scatter Corrections on Gated Cardiac SPECT Reconstruction. American Association of Physicists in Medicine, 2011,; 38(12): 6571-6584.

25. Dasari PK, Könik A, Pretorius PH, et al. Correction of hysteretic respiratory motion in SPECT myocardial perfusion imaging: Simulation and patient studies. Med Phys. 2017;44(2):437–450. doi:10.1002/mp.12072.

26. Parker JG, Mair BA, Gilland DR. Respiratory motion correction in gated cardiac SPECT using quaternion-based, rigid-body registration. Med Phys. 2009;36(10):4742–4754. doi:10.1118/1.3215531

27. Willowson K, Bailey DL, Baldock C: Quantitative SPECT reconstruction using CT-derived corrections. Phys Med Biol 2008, 53: 3099–3112. 10.1088/0031-9155/53/12/002.

28. Koshino K, Fukushima K, Fukumoto M, et al. Breath-hold CT attenuation correction for quantitative cardiac SPECT. EJNMMI Res. 2012;2(1):33. Published 2012 Jun 22. doi:10.1186/2191-219X-2-33.