SPECT myocardial perfusion imaging in patients with Dextrocardia

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INTRODUCTION

Myocardial perfusion imaging has gained widespread acceptance for evaluation of ischemia in daily practice. Dextrocardia or other cardiac anomalies may be encountered during imaging, but because of altered position and orientation of the heart, some difficulties and artifacts during acquisition and processing may arise. In the present illustrated review, the intent is to present methods to improve the technique of acquisition and processing and prevent the emergence of artefactual defects in the myocardial perfusion SPECT in patients with Dextrocardia.

DISCUSSION

A Clinical Background: Classification and Terminology

Dextrocardia belongs to a group of congenital cardiac anomalies with respect to the position and orientation of the heart in the thorax. This anomaly is rare with an incidence of 1 in 10,000 live births and may be associated with other congenital intracardiac or extracardiac disorders. Contrary to Levocardia, as normally positioned heart and cardiac chambers with the apex pointing leftward, in Dextrocardia, the heart is laid on the right side and the apex is directed to the right, owing to an alteration in the development of the heart during embryogenesis. Whether the primitive cardiac tube in the fetus coils leftward or rightward, a normal loop or L-loop and D-loop will be created, that in turn produces Levocardia or Dextrocardia respectively.[1-6] This terminology is distinct from Dextroposition whose features are right-sided displacement but leftward orientation, usually as a consequence of an intrathoracic or diaphragmatic pathology, i.e., left to right shift. The association of the cardiac chambers is the same as normal hearts. This condition is closely correlated with the term Mesocardia, in which the heart and its apex are located midline. Besides, the term Dextroversion applies to the condition in which the heart is rotated horizontally or pivoted on a vertical axis. So that the right heart is located posterior to the left heart and the apex is oriented to the left.[2,6-8] Much confusion may arise in distinguishing from Dextrocardia.

In Dextrocardia, regarding the relationship of the heart to other structures in the abdomen, as a definition for the term ''situs'', this anomaly, in some way, consists of at least three major distinct types; Dextrocardia with situs solitus (DSS), Dextrocardia with situs inversus (DSI) and Dextrocardia with situs ambiguus (DSA). In DSS, visceral organs, e.g., liver, stomach and etc., show normal positional anatomy, but in contrast, in DSI, all abdominal structures are horizontally flipped or ''mirrored'' in terms of position, in that the liver is on the left and the stomach on the right. Thus, DSI is also known as ''mirror-image'' Dextrocardia that can be depicted by mirroring the cardiac structures and other visceral organs with respect to the midline or mid-sagittal plane of the body, a ''total inversion'' (Figure 1). In both DSS and DSI, as differ from Dextroversion, the right heart is located anterior to the left heart. Sometimes, the atrioventricular (AV) connection may also differ among patients as AV concordance or discordance and is frequently observed in DSA or

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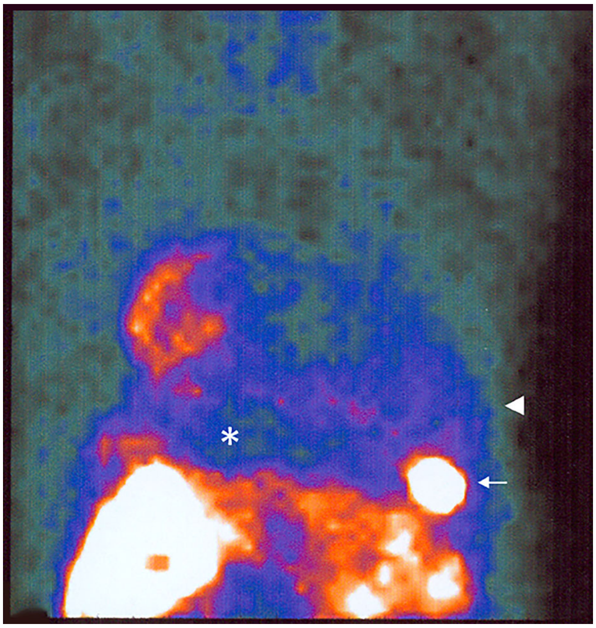

Figure 1. An anterior projection of the myocardial perfusion SPECT image of a patient who is a known case of Dextrocardia with situs inversus. The LV is located in the right hemithorax and is oriented to the right. The position of the visceral organs is also reversed. The liver (arrowhead) and the gallbladder (small arrow) filled with radioactivity are on the right and conversely, the stomach (shown by the asterisk) is on the left side.

mixed Dextrocardia. It should be highlighted that there are no unanimously agreed, clear definitions for the nomenclatures mentioned above and their classification.[1-3,7-11]

Dextrocardia may be discovered by routine physical examination, during electrocardiography by its unique electrocardiographic pattern[12,13] or even during imaging investigation for any reason. Coronary artery diseases are relatively common in Dextrocardia patients, with an equal incidence to that in general population. Therefore, diagnostic workup for ischemia of coronary origin is of interest in these patients. Anatomical imaging modalities, including echocardiography, computed tomography and magnetic resonance imaging, depict the anatomical detail of the structures of the heart and even other intrathoracic organs with notable clarity and provide the necessary information to recognize the type and other related features. However, this finding may be discovered incidentally during myocardial perfusion SPECT imaging for ischemia evaluation. Routine electrocardiography before myocardial perfusion SPECT, as part of exercise or pharmacologic stress testing, discloses the presence of Dextrocardia, if yet undiagnosed. The electrocardiographic findings in Dextrocardia may be of relevance to and of interest for nuclear cardiology practitioners. Figure 2 shows findings on electrocardiogram (ECG) with placement and attachment of the limb and precordial electrodes as routine and then reversed accordingly.

Image Acquisition: Technical Considerations

In myocardial perfusion SPECT, the heart or mainly the left ventricle, is imaged using a gamma camera with detectors rotating at a 180-degrees arc around the patient's chest, normally from 45° right anterior oblique (RAO) to 45° left posterior oblique (LPO). This acquisition scheme assures the minimum distance between the patient's chest and the detector surface and thus maximum spatial resolution and also reduces the potential attenuation by other bony structures.[14] Obviously, in such acquisition scheme, the heart is assumed to be located in the left hemithorax and oriented leftward. But in Dextrocardia and also in other cardiac malpositions, it is necessary to implement minor modifications in the acquisition arc, i.e., specifically in Dextrocardia from LAO to RPO, otherwise potential perfusion defects may arise as a result of the detector standing increasingly at a far more distance from the heart when departing from RAO to LPO (see Figures 3 and 4 in the next section).[15-20] This issue emphasizes having knowledge and information about the position of the heart in the thorax, like that in Dextrocardia, prior to starting image acquisition. The necessary information may be on hand by the ECG performed during the stress test in undiagnosed patients. The reason for this issue is that the SPECT imaging of the heart is conducted at a 180° arc as compared to 360° arc around the patient in other imaging modalities such as cardiac positron emission tomography.

Image Processing: Pitfalls of Commercially Available Software Packages

In myocardial perfusion SPECT, the assessment of the LV is of particular interest. However, assessment of the RV holds less priority, but is gaining more attention and the walls of the atria are almost invisible. The recognition of the RV and LV is apparently easy in the absence of extensive myocardial infarct of the LV. Thus, the differentiation of the DSS and DSI with Dextroversion is relatively simple. However, these conditions could not be easily differentiated from DSA. Though the anatomical details of the atria and great vessels are barely visualized in myocardial perfusion SPECT images, the exact identification of the condition is not possible. Therefore, much of the features of various

Figure 2. ECG of the patient recorded by attaching the electrodes as routine or standard (**A**), i.e., precordial electrodes attached on the left side of the chest, and modified (**B**) according to Dextrocardia protocol (right-sided ECG). As is seen in (**A**), since the precordial leads are far from the LV myocardium, the voltage of the signals, more prominently of the QRS waves, shows a poor progression from V2 to V6, seemingly flattened electrical activity of the V6 lead. P, QRS and T waves are negative in I and AVL and positive in III and AVF. Right axis deviation is also present. Following reversal of the electrodes, the pattern is changed and a high QRS voltage is observed in precordial leads, without any significant abnormality. Here, mistakenly, the limb leads are not reversed.

disorders of cardiac malposition is not particularly pertinent to nuclear cardiology practice. In cardiac SPECT, the planes for visualizing the LV is arbitrarily chosen case-by-case based on the spatial orientation of the long axis of the LV. So that, for ease of interpretation, the LV is visualized in short-axis, horizontal and vertical long-axis tomographic slices and in such slices, the RV is located either on the left or right of the LV.[14]

In DSS and DSI, by routine processing of the raw data in standard software packages of cardiac analysis, including Cedars-Sinai software, the LV and RV are swapped or flipped horizontally in short-axis and horizontal long-axis slices. The lateral free wall is on the left and the interventricular septum is on the right of the image. In the presence of significant asymmetry in the length of the septal and lateral walls, the condition is instantly recognizable on visual interpretation. But in semiquantitative and quantitative analyses, perfusion defects may be evident on the lateral wall and the corresponding region in the polar plot. The wall motion,

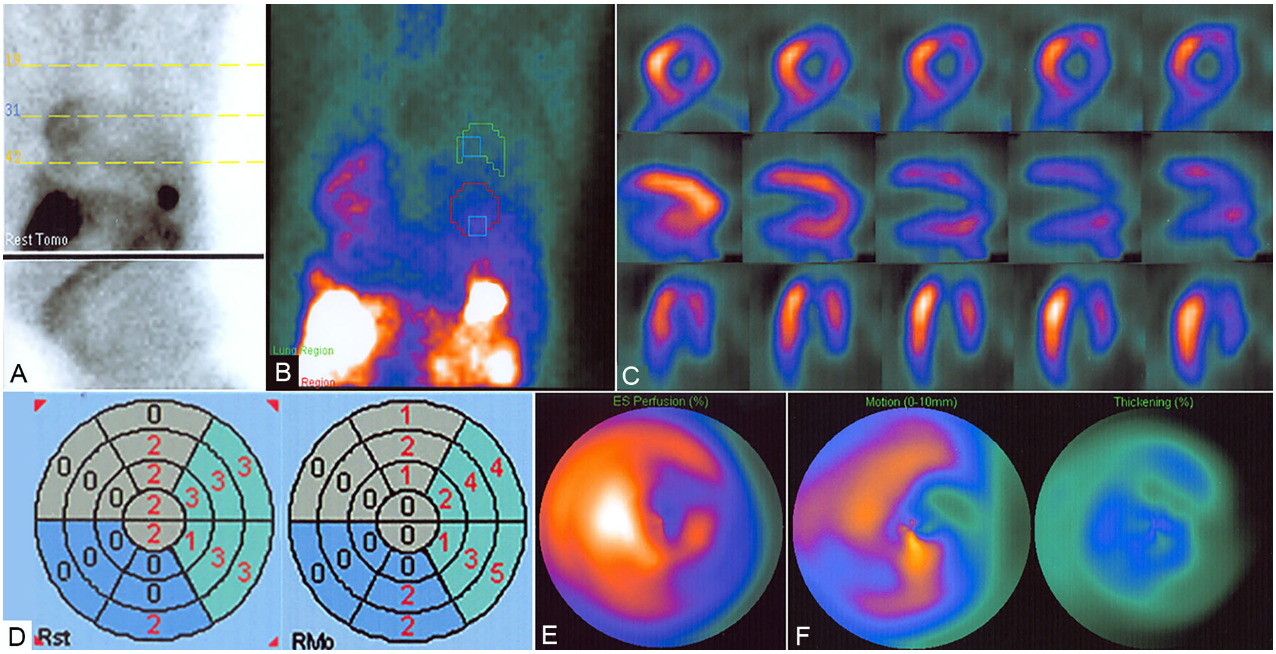

Figure 3. SPECT image acquired with routine acquisition arc (from RAO to LPO) as in patients with Levocardia results in faulty processing with emergence of artefactual defects. (**A**) the sinogram at the level of the LV is halved in length, because the LV in the half of the acquisition arc is distant from the detector. (**B**) Processing for derivation of the lung-to-heart ratio shows erroneous placement of lung and myocardium ROIs and thus incorrect calculation, as a result of unsuitable selection of the projection. By default, an anterior or left anterior oblique (or better to say, mid-arc) projection is chosen and here, the LV is standing distant from the detector and thus, poorly visualized. (**C**) Tomographic slices show a large severe perfusion defect affecting the apex, inferolateral, lateral and anterolateral regions of the LV myocardium, the half of the LV myocardium which is distant from the detector and attenuated considerably by the soft tissue intervened. (**D**) 20-segment, 5-category models of scoring of perfusion and motion show assignment of scores to the segments affected by attenuation as well as the effect of faulty quantitative analysis in Dextrocardia as a result of comparison with normal ''Levocardia'' databases. Similar findings are evident in perfusion (**E**), motion and thickening (**F**) polar maps.

but not thickening, because of circumferential homogeneity of the degree of thickening of the LV walls, also reveals concordant abnormality in the same region. Figures 3 and 4 show the results of the processing of the SPECT images acquired with usual and modified acquisition arcs respectively. The mentioned classic pattern in Dextrocardia is well-known and the reason is that the perfusion status and degree of motion of the interventricular septum, which is ''incorrectly assumed'' as the lateral wall, is compared to the values of perfusion and motion of the ''true'' lateral wall of the LV of the patients with Levocardia included in the normal database.[15-17]

A recommendation is to check the regions of interest or contours automatically drawn around the LV walls whether to include or cut off the basal portion of the ''incorrectly assumed'' septal wall or ''true'' lateral wall. This is because a fixed predefined template is used to contour the LV in horizontal long-axis slices. In this template for contouring the LV, the septal wall is supposed to be shorter than the lateral wall. The result is miscalculation of the LV volumes and thus the EF.[17]

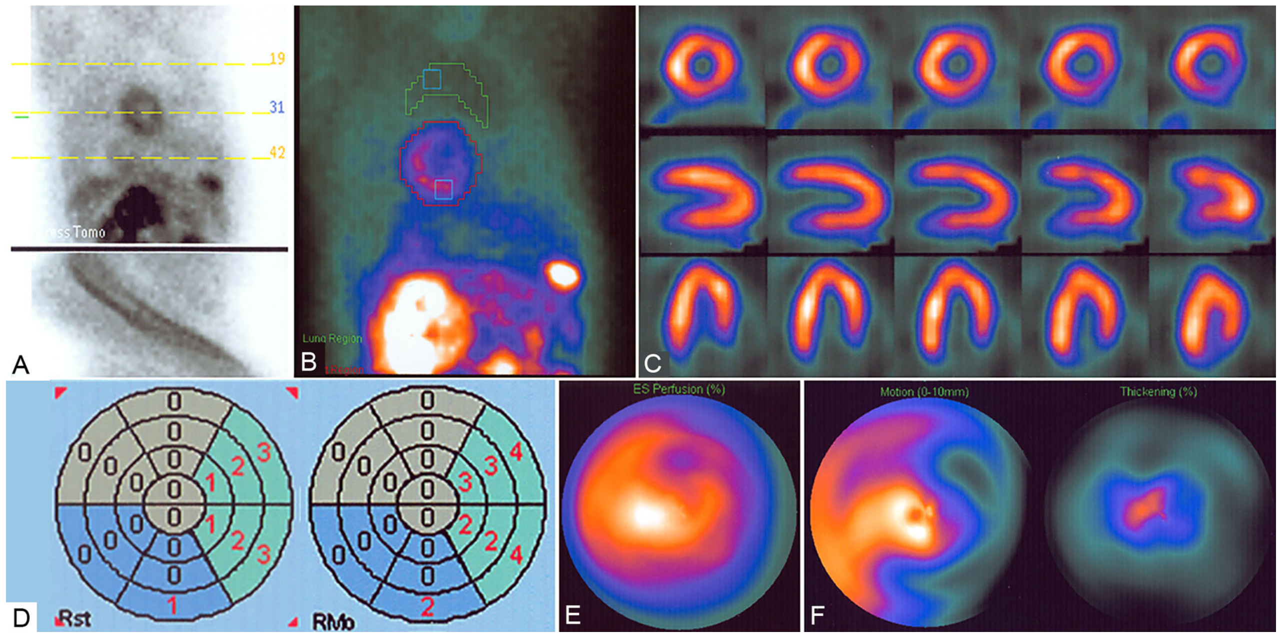

Figure 4. SPECT image acquired with modified acquisition arc (from LAO to RPO). (**A**) The sinogram at the level of the LV is continuous over 180° arc. (**B**) Calculation of lung-to-heart ratio is properly processed. (**C**) Visually, the perfusion defect of the regions in Figure 3 disappeared but as mentioned in the text, semiquantitative and quantitative analyses (**D**) perfusion and motion scores and (**E**) perfusion plot and (**F**) motion and thickening polar plot) demonstrate the classic pattern of perfusion defect and motion abnormality of the lateral wall.

Solutions to Accurate Quantitation

In contrast to visual or qualitative interpretation, the quantitation suffers from emerging artefactual defects on the lateral wall. A solution to this problem is to incorporate and load a normal database of patients with Dextrocardia into the cardiac processing software installed on the workstation to compare with the index patient's data. Another simpler one is to make some especial modifications in the original raw image data. Since the spatial configuration and geometry of the heart in Dextrocardia is the mirror of the heart in Levocardia, mirroring or flipping of the image to 180° again causes the heart converts from Dextrocardia to Levocardia, and thus, comparison with the normal database available in the software is possible. To implement the above modifications in the image, defining parameters of the image should be manipulated in the image file header or metadata. As is presented in Figure 5, one of such parameters in the image metadata is the ''orientation'' of the image as ''Feet-in'' or ''Head-in''. The selection depends on the user's preference and specific settings made prior to acquisition. A conversion from ''Feet-in'' to ''Head-in'' makes the image dataset to become overturned or flipped. Through this process, the image is mirrored and thereby, in the tomographic slices, the

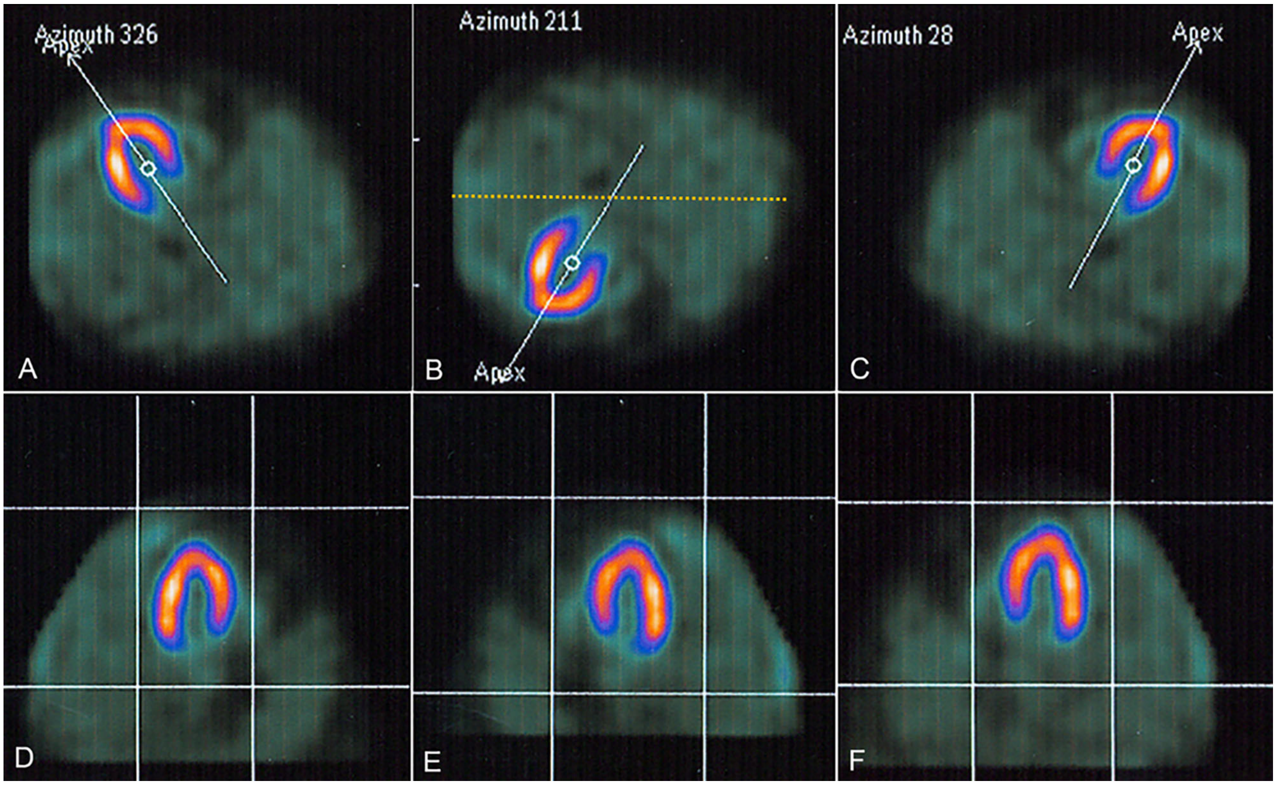

Figure 5. (**A**) the transverse slice of the original SPECT image during reconstruction with the following parameters; orientation: Feet-in, position: supine. The LV is located in the upper right quadrant of the transverse slice. The corresponding reconstructed horizontal long-axis slice (**D**) shows a mirrored image of the LV, with swapped septal and lateral walls. (**B**) By changing the parameter of orientation (from Feet-in to Head-in), the LV is mirrored against the horizontal orange dotted line. Now, the LV is in the bottom right quadrant of the transverse slice and by reorientation, the LV in the corresponding reconstructed horizontal long-axis slice (**E**) is similar to that in Levocardia and the septal and lateral walls are in the correct position and ready to be compared with the normal database. (**C**) Changing the parameters of the original image to orientation: Head-in and position: prone, makes the LV located in the upper left quadrant of the transverse slice, as that in Levocardia. Compared to the image in (**B**), the LV is rotated 180°. By reorienting, the result (**F**) is the same as in that in (**E**).

swapping of the ventricles and septal and lateral walls of the LV would be evident. By this means, the mirrored Dextrocardia image could be converted to the Levocardia image and then feasible to be compared with and analyzed using the available databases. No artefactual perfusion defect or motion abnormality will then be created (Figure 6).[15,17] Though the contours of the LV walls are drawn correctly even using a fixed predefined template, as described in the preceding section, the volumes and EF are accurately estimated.

''Reorientation'' as an important step following ''segmentation'' in the processing of cardiac images, offers flexibility to the operator to reconstruct images in the arbitrary planes more suitable for interpretation.[14] This facility in the software plays a key role in the reorientation of the mirrored image of the heart in Dextrocardia patients (see Figure 5).

CONCLUSION

Consideration of some minor modifications during acquisition and processing, causes the images become more pleasing visually and prevents potential misinterpretation of the artefactual perfusion abnormalities.

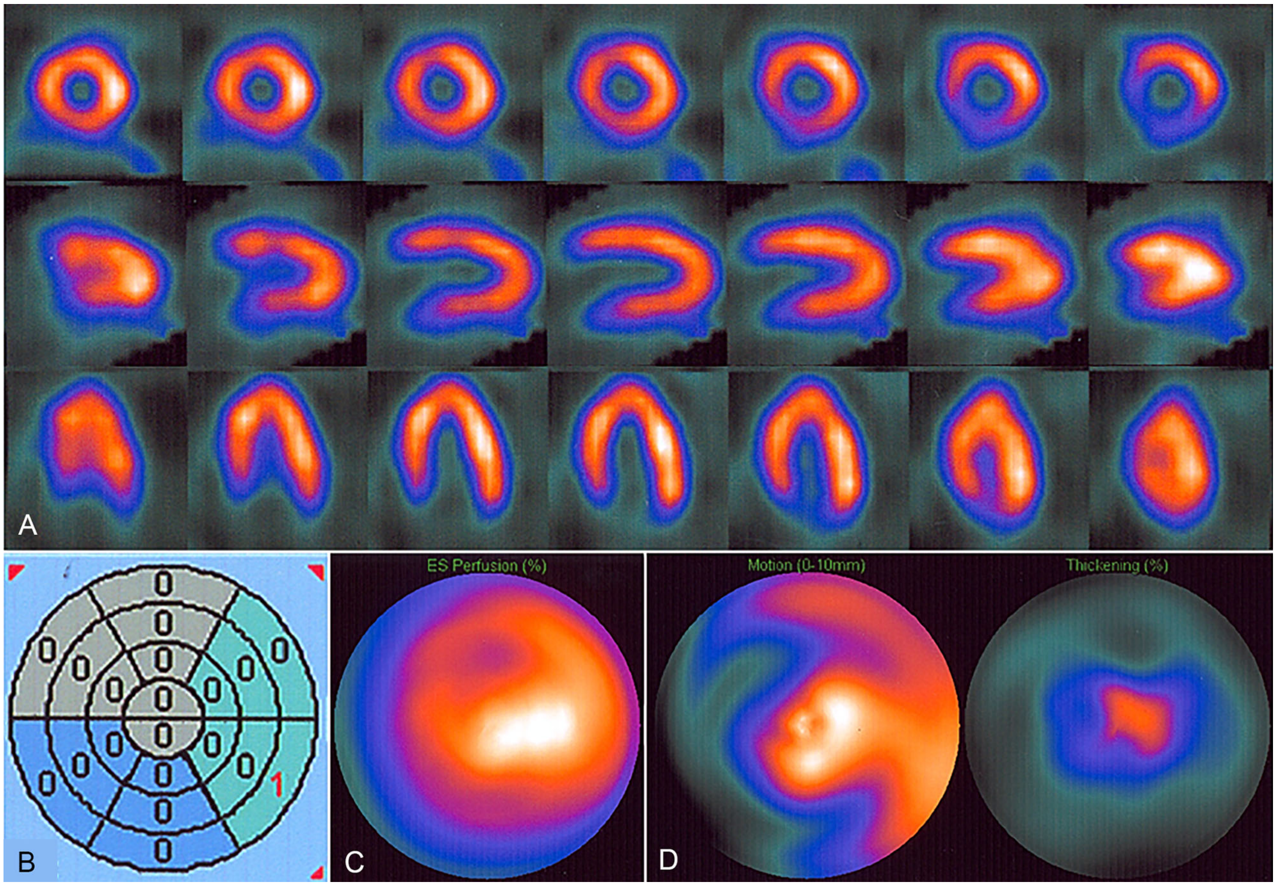

Figure 6. (**A**) Normal myocardial perfusion SPECT image with no assigned scores in semiquantitative segmental bull's eye map of the LV (**B**) and no distinct abnormality in the polar plots of perfusion (**C**) and motion and thickening (**D**) following considering and implementing the appropriate modifications in the acquisition and processing. The LV walls, septal and lateral, are seen in their expected position as in Levocardia. By this means, the defects apparent visually and also the artefactual defects created during quantitative analysis are mitigated.

Disclosure

Author of this manuscript declare no conflict of interest.

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