A Triple-Head Solid State Camera for Cardiac Single Photon Emission Tomography (SPECT)

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***Abstract* -- The Cardius®3 XPO (C3XPO) camera is a triple-head dedicated cardiac SPECT system featuring Digirad's 15.6 cm x 20.1 cm (6"x8") solid-state pixilated detectors with 6mm x 6mm CsI(Tl) crystals. The system utilizes upright imaging with the patient rotating in a SPECTour™ chair while the gantry keeps stationary during data acquisition. A region of interest (ROI) tool on the persistence scope (p-scope) is used to position the heart at the center of rotation to avoid cardiac-truncation. The tool also provides the count rate in the ROI to allow the users to determine the recommended acquisition time for individual patients to meet the American Society of Nuclear Cardiology (ASNC) published guidelines. The intrinsic energy resolution, reconstructed spatial resolution with scatter and NEMA extrinsic planar sensitivity of the solid-state detector are measured and results are reported. Anthropomorphic phantom and patient studies performed in this work showed that C3XPO image quality and diagnostic outcomes were equivalent to those from a dual head camera, but the acquisition time could be reduced by 38%. The reduced acquisition time (compared with conventional Anger style dual and single-head systems) not only improves the patient comfort but also reduces patient motion, which in turn can improve the image quality.**

Keywords: SPECT, nuclear imaging, cardiac SPECT, cardio-centric imaging

I. INTRODUCTION

Cardiac Single Photon Emission Computed Tomography (SPECT), a nuclear medicine imaging protocol, is a diagnostic tool to detect and follow Coronary Artery Disease (CAD). Image quality is determined by many factors [1], the most important one of which is the number of counts acquired in the studies. Since the number of acquired counts varies from patient to patient even with the same injected dose and imaging protocol (mostly due to photon attenuation), nuclear medicine societies or professional organizations, such as ASNC, have set specific guidelines for the acquired counts to ensure optimal image quality. In addition to the image quality, system sensitivity and system footprint are other important parameters meriting practical considerations.

System sensitivity affects the number of counts acquired in the same acquisition time, the higher the sensitivity, the more the counts. From another point of view, system sensitivity affects the total acquisition time of a patient study if the same number of counts is to be acquired. The duration of a patient study affects the patient comfort and likeliness of patient motion during the acquisition. The higher the sensitivity, the shorter the acquisition time, and in turn more patient comfort and less likelihood of patient motion.

For a conventional dual-head Anger SPECT camera, the two heads acquire data simultaneously. Thus, its sensitivity is 100% higher than a single-head camera. The acquisition time can then be half of the time needed by a single-head camera to acquire the same number of counts. Similarly, a triple-head camera will have 50% more system sensitivity than a dual-head camera with an acquisition time up to 2/3 less than that required by a dual-head camera.

The most common SPECT systems sold during the last decade for nuclear cardiology are dual-head variable and fixed 90-degree systems. Triple-head dedicated cardiac SPECT imaging systems represent a fairly new innovation to nuclear cardiology with their introduction and commercial availability occurring in late 2003. Early generation general purpose triple-head Anger cameras developed during the 1980's featured detector heads that were positioned 120-degrees from each other. These cameras were primarily used to acquire brain SPECT studies. When 120-degree configuration triple-head cameras were used for cardiac SPECT studies, one of the three heads was always in a posterior position. This posterior head contributed little to the counts used to construct the images. Therefore, in clinical practice, one of the following two imaging protocols were performed. One approach was to perform a 360-degree acquisition tomographic study to increase the total data sampling and the other approach was to perform a 180-degree acquisition with overlapping frames [2]. This results in longer total acquisition time or repetitive data. Neither of these earlier protocols made effective use of the increased system sensitivity of a triple-head detector geometry for cardiac SPECT imaging. Hence, these earlier conventional triple head cameras of the 120-degree variety were usually operated as dual head cameras during cardiac SPECT procedures because data from the third detector was not used due to the issues previously described. In addition, these Anger-based systems were heavy as well as large in size which mandated the need for large rooms and often extensive site modifications, such as custom built flooring or special structural support to accommodate floor loading requirements.

The Cardius®3 XPO (C3XPO) system (Digirad Corporation, Poway, CA) is a triple-head small field-of-view (FOV) camera dedicated to cardiac SPECT imaging. The detectors are built on solid-state technology using 768 6mm x 6mm CsI(Tl) crystals with a camera FOV of 15.6 cm x 20.1 cm. The three high-definition solid-state detector heads (HDSD) are positioned to face the center-of-rotation (COR) in approximately a π-arc with an angular spacing of 67.5º. This leads to significant improvement of detector count sensitivity and the reduction of system footprint. The minimum office size required for the system to fit in is 3.7m x3.3m (8'x7'). The C3XPO system consists of an acquisition and processing unit (A/PS) and a gantry with an upright chair (Figure 1). The system performs upright imaging with the patient sitting in the rotating chair while the detectors keep stationary during data acquisition. The camera performs cardiocentric imaging that keeps the heart on the Center of Rotation (COR) during the SPECT acquisition to eliminate cardiac truncation. The C3XPO A/PS unit allows for the simultaneous operation of data acquisition and processing. During the data acquisition of one patient, one can process the data of previous patients. This allows for better system workflow and improves system usability.

Figure 1: C3XPO system with HDSD detectors

In this paper, the technical specifications and some features of the C3XPO system are discussed. The intrinsic energy resolution, reconstructed spatial resolution with scatter and NEMA extrinsic planar sensitivity of the system are measured and the results are reported. Finally, phantom and patient studies are used to evaluate the image quality.

II. METHODS

1. Performance Measurements

Intrinsic Energy Resolution, Reconstructed spatial resolution (RSR) with scatter and extrinsic planar sensitivity were measured for the system. Methods described in NEMA Publications NU-1 [3] were performed. For the RSR measurement, the 3-line source phantom from Data Spectrum (www.spect.com) was used. The center line source was filled with 4mCi and the two edge line sources were filled with 2.5mCi of Tc-99m radioactive source [4]. A 128-projection tomographic data was acquired using stop conditions per step such that the entire study contained 24 million counts. Measurements using a low energy high resolution (LEHR) collimator with borehole length of 32 mm and a Cardiac (CARD) collimator with borehole length of 27 mm, are reported. A spectrum mode study was acquired for intrinsic energy resolution calculation. A program written in Interactive Data Language (IDL) was used to calculate the resolution numbers.

2. Data Acquisition

The system acquires 30 or 60 –projection settomographic studies using high-resolution collimators over an angular range of 202º. With the use of three detector heads, acquisition time can be greatly reduced as compared to using one or two detector heads. A C3XPO can acquire high dose tomographic studies in 7 minutes at 20 seconds/projection (based on a 60 projection actual patient study done according to ASNC Guidelines) versus a standard dual-head camera that will take 11.2 minutes for the same protocol and 64 projections. This not only improves patient comfort during acquisition, but also reduces patient motion, which, in turn, improves image quality.

For patient setup, a region of interest (ROI) tool on the persistence scope (p-scope) is used to position the heart of the patient on the COR (Figure 2). The ROI tool also provides the count rate in the ROI. This information can be used to determine the acquisition time per projection for the patient study to meet the ASNC guidelines [5] of at least 21,000 counts (for a high count stress study) and 11,000 counts (for a low count rest study) in the myocardium in the LAO projection.

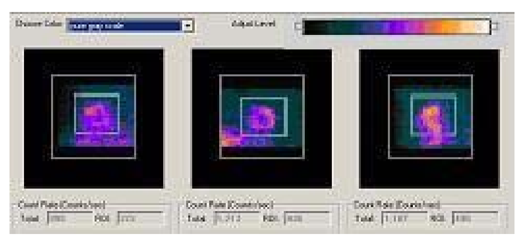

Figure 2: TruACQ Count-Based Imaging™ utilizes an ROI tool to assist in patient setup and count analysis

3. Data Processing

For data processing, the system allows for motion correction of the acquired data prior to image reconstruction. For image reconstruction, a 2D Ordered Subset Expectation Maximization (OSEM) iterative reconstruction algorithm [6] is used.

4. Phantom Studies

In this paper, we used phantom and patient studies to evaluate the C3XPO image quality and the clinical application of the images. For comparison purposes, imaging of the same patients using a C3XPO system and a standard dual-head cardiac system was performed.

For the phantom study, an anthropomorphic phantom with a cardiac insert was used. The liver, cardiac wall, and the major chamber were injected with 3.6mCi (~ 3.0 µCi/cc), 330 µCi (~3.0 µCi/cc), and 2.7mCi (~ 0.27 µCi/cc) of Tc-99m activity. The phantom was acquired at 25 seconds/projection (ASNC protocol for a low count rest study) with a total of 60 projections. A circular orbit with a radius of 23 cm was used. The ROI tool on the p-scope in the acquisition software was used to position the heart insert in the center of the FOV in all detector heads (Figure 2). This ROI tool assisted in accurate cardio-centric imaging and imaging counts adhering to ASNC guidelines.

5. Patient Studies

Patient studies were acquired simultaneously with a C3XPO system and a conventional dual-head Anger camera (c.cam system – Siemens Medical Systems, Hoffman estate, IL). Rest and stress gated data for the same patient were acquired with 40 seconds/ projection and 30 seconds/projection respectively on both systems in a random order. The C3XPO camera acquired 30 projections while the dual-head system acquired 32 projections.

III. RESULTS

The Reconstructed Spatial Resolution (RSR) at 20 cm orbit radius for the LEHR and CARD collimators are shown in table 1. Extrinsic Planar Sensitivity calculation and Reconstructed Spatial Resolution were performed on three detector heads for both LEHR and CARD collimators and the average numbers are reported. All measurements reported are typical values since the planar sensitivity and RSR measurements are very tedious and time consuming tests. The NEMA intrinsic energy resolution for all the three detectors was <10.5%.

Collimator	**RSR w scatter (mm)**	**NEMA Sensitivity (cpm/uCi)**
CARD	15.4	234
LEHR	11.0	159

Table 1: Reconstructed Spatial Resolution and Extrinsic Planar Sensitivity values

Figure 3 shows the 3-view images, i.e., Short axis (SA), Horizontal Long Axis (HLA), and Vertical Long Axis (VLA) images of the cardiac insert of the phantom. The images showed good quality as measured by resolution, uniformity of the uniform region of the cardiac insert, and high contrast of the two fixed defects in the cardiac wall.

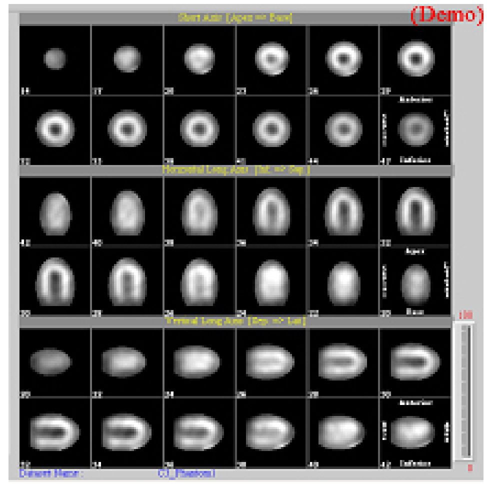

Figure 3: 3-View images of the cardiac insert of the anthropomorphic phantom.

To illustrate the patient image quality produced by the C3XPO system, Figure 4 shows a VLA view of the rest image from a normal patient study. The top row is the image from the C3XPO system and the bottom row the image from the conventional dual-head camera. Figure 5 shows an SA view of the summed stress image for a abnormal patient study. The top row is the image from the C3XPO system and the bottom row is the image from the dual-head camera. The images in Figures 4 and 5 show that the C3XPO system and the dual-head system produced images of equivalent quality.

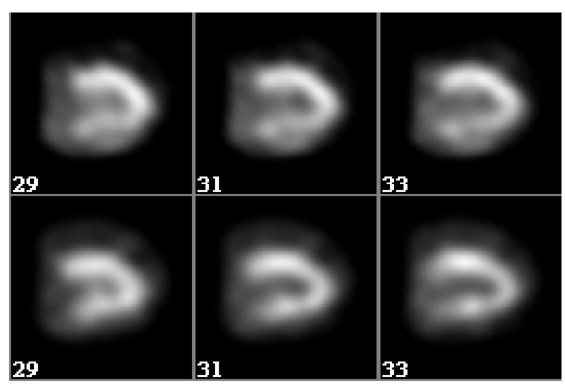

Figure 4: VLA view of the rest image for a normal patient study.
Top row: C3XPO images Bottom row: Dual head images

The total acquisition time when using the C3XPO system was about 62% of that compared to the dual-head system. Hence, the dual-head system has an acquisition time that is about 1.6 times longer than that of the C3XPO system.

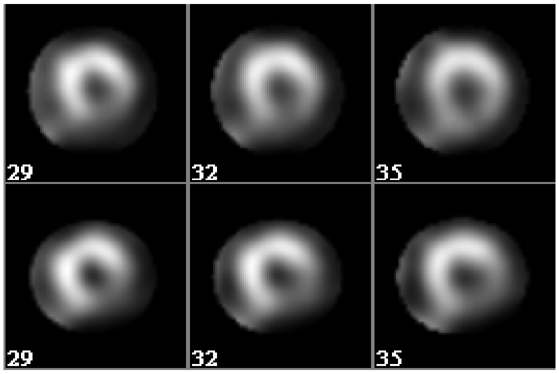

Figure 5: SA view of the summed stress images for an abnormal patient study.
Top row: C3XPO images Bottom row: Dual-head images

IV. DISCUSSION

Claustrophobia has been one of the major complaints from patients when undergoing a nuclear medicine study. The open gantry design of the C3XPO system and the upright imaging position, as well as the small detector size, significantly reduce claustrophobic effects in patients, as compared to the conventional SPECT cameras (supine/prone imaging position, large, bulky detectors).

Upright imaging (used in the Cardius XPO cameras) has certain advantages over supine imaging (used in the conventional Anger SPECT cameras). Upright imaging has shown reduction in diaphragmatic attenuation, as the diaphragm is lower than in supine imaging due to gravitational force. It also demonstrates a better separation between the gut (or liver) activity and the heart wall. A primary detriment to achieving high quality studies in SPECT, regardless of camera geometry, is patient motion. In upright imaging, this issue is addressed by improving comfort through employment of a special saddle-like chair with the armrest and use of a special passive-restraint binder to refrain patients from moving during the study. Motion correction software is typically used to correct patient motion after data acquisition. Furthermore, 38% shorter acquisition times of the C3XPO systems (as compared to dual-head systems) ensure greater likelihood of reduced patient motion.

For female patients, breast tissue has different distribution relative to the heart in upright and supine/prone imaging. This may introduce different attenuation artifacts into the images. For example, breast attenuation may introduce inferior wall artifacts in the upright images while supine images show anterior wall artifacts for the same patient. These variances must be taken into account by the reader. Attenuation artifacts may be demonstrated by viewing the raw cine datasets, which is recommended as a quality control measure for upright, semi-recumbent and supine imaging.

V. CONCLUSION

The C3XPO system, a triple-head solid-state SPECT system dedicated to cardiac imaging, has a small footprint that allows optimal use in offices with rooms as small as 8'x7' (56 sq. ft.). It's open upright design is very patient-friendly and the system generates high quality images in significantly less acquisition time than the conventional dual-head and single-head systems. The detector performance for reconstructed spatial resolution and planar sensitivity are equivalent to the conventional dual head Anger cameras. This work has also demonstrated that C3XPO image quality was at least equivalent to those from the dual-head camera, but with 38% shorter acquisition time.

VI. REFERENCES

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