Clinical PET: Repositioning Myocardial Studies After Bicycle Exercise

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Objective: Myocardial viability studies were assessed for repositioning accuracy as adequate or inadequate by evaluation of NH_3/FDG image correspondence and detection of measured attenuation correction (MSATN) artifacts.

Methods: Myocardial viability studies using ^{13}N-ammonia (NH_3) and ^{18}F-fluorodeoxyglucose (FDG) were evaluated in 29 normal subjects (21 rest and exercise, 7 exercise only and 1 rest only). Patients were positioned in the ECAT III gantry, and selected body landmarks were registered with the imaging bed. MSATN data were acquired. For exercise studies, upright bicycle exercise was then performed off the imaging bed. Intravenous NH_3 or FDG was injected during exercise and the patient was repositioned and imaged.

Results: Analysis revealed repositioning accuracy of 96% for rest NH_3, 91% for rest FDG, 57% for exercise NH_3 and 50% for exercise FDG.

Conclusion: The problems encountered with repositioning make upright bicycle exercise for cardiac PET restrictive for routine clinical use with existing technology.

Key Words: cardiac PET; repositioning accuracy; NH_3/FDG image correspondence; exercise perfusion studies; measured attenuation correction (MSATN)

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Clinical cardiac PET studies are performed for the detection of coronary artery disease and for the identification of viable myocardium (*1–5*). These studies require a transmission acquisition and two emission acquisitions. The detection of coronary artery disease is performed by comparing myocardial perfusion images acquired at rest to those acquired following physical exercise or pharmacologic stress (*3*). The determination of myocardial viability is performed at rest by comparing images of myocardial perfusion with those of glucose metabolism (*1*). Transmission imaging is performed for attenuation correction of the emission data to provide an accurate representation of the distribution of the radionuclide (*4*). The use of measured attenuation correction for PET increases the length of the time of the study, and the possibility of patient movement, because of the time required for the transmission study. Comparison of any two imaging data sets is compromised by patient movement and thus misalignment of the imaging sets that may occur between studies.

We are interested in studying the effects of exercise on glucose metabolism using FDG. For this study, the subjects underwent both rest and exercise ^{13}N ammonia perfusion and ^{18}F FDG metabolic imaging studies. The exercise studies were performed on an upright bicycle, and the patients were moved from the gantry for the exercise study and radiopharmaceutical administration. The purpose of this study was to evaluate the effect of repositioning the patient on image quality. The resting perfusion and metabolism study was also evaluated to determine the patient movement that occured in the gantry without moving the patient between the two imaging studies.

For the studies performed at rest, the patients had the transmission study, the ^{13}N ammonia injection and imaging, and the FDG injection and imaging, without moving between the three image acquisitions. For the bicycle exercise studies, the transmission image was performed first. The patient was then moved to an upright bicycle where ^{13}N ammonia was administered intravenously when the subject reached his target heart rate. The patient was repositioned with careful patient and gantry realignment. The patient was then moved to the bicycle where the exercise study was repeated using FDG, and the patient was again repositioned in the scanner. The ^{13}N ammonia and ^{18}F FDG studies at rest and following upright bicycle exercise were evaluated with regard to repositioning accuracy.

MATERIALS AND METHODS

Written informed consent as approved by the Duke University Medical Center Institutional Review Board was obtained from 29 normal male volunteers, 18–30 yr of age. The rest and exercise studies were performed one week apart. All subjects had a 20-gauge external jugular or antecubital catheter inserted for the radiopharmaceutical injections and an 18-gauge cannula placed retrograde in a dorsal

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hand vein for noninvasive sampling of arterialized blood using the heated hand technique (*6*). EKG leads were placed for 12-lead recording. Subjects were then moved to the ECAT imaging room where they were familiarized with the procedural steps. Bicycle adjustments were made for subjects undergoing exercise studies. Each subject was positioned supine on the imaging table with his head in the headholder and with his knees supported by a pillow for comfort. The cannulated hand was placed in a 44° C handwarmer for arterialization of the venous blood (*6*).

The bicycle exercise study was performed first in most cases. If this study was adequate a resting study was performed the following day. Positioning was accomplished using low energy lasers, bed position digital readouts and body landmarks (sternal notch, chest wall, etc.). Bed positions were recorded and indelible ink marks placed on the subject's skin for reference. The measured attenuation correction (MSATN) images were acquired for 10 min. At the completion of the MSATN acquisitions, subjects were moved, with the handwarmer, to the bicycle. Preliminary 12-lead EKG monitoring and blood pressure readings were obtained. The subject's target heart rate was determined as 85% of the age predicted maximum by the formula (220 − age) × 0.85. Coordination with the cyclotron and radiochemistry personnel was arranged so that a 15 mCi (555 mBq) dose of ^{13}N ammonia arrived approximately 2.5–3.0 min into the subject's exercise (*7,8*). The subject exercised with continuous blood pressure and EKG monitoring. When the subject reached his predetermined exercise target heart rate, the ^{13}N ammonia was injected through the external jugular line. Exercise continued for one minute, and the patient was returned to the imaging bed. Gantry and patient realignment were accomplished with the use of recorded bed position data, external lasers, and body landmarks. A 10-min static ^{13}N ammonia acquisition was performed. The subject rested on the imaging bed for approximately 50 min (five times the ^{13}N ammonia $T_{1/2}$ decay) prior to the exercise ^{18}F FDG study.

The patient was again moved from the imaging bed to the bicycle. Another baseline blood pressure was obtained and EKG monitoring was performed. The subject exercised again to the predetermined target heart rate (requiring approximately three minutes of exercise) and 10 mCi (370 mBq) of ^{18}F FDG were injected (*8,9*). The patient continued to exercise at the target heart rate for the next 10 min. Following exercise the subject was moved to the imaging bed and gantry/imaging bed realignment was verified. ^{18}F FDG images were started 40 min after injection and were acquired for 10 min.

The next testing day the subjects had their rest study performed. The rest study consisted of acquiring MSATN images for 10 min followed by the intravenous administration of 15 mCi ^{13}N ammonia. After a three-minute delay for blood clearance, perfusion images were acquired for 10 min. Approximately 50 min after administration of ^{13}N ammonia, 10 mCi of ^{18}F FDG were administered. Forty minutes after FDG administration, images were obtained for 20 min.

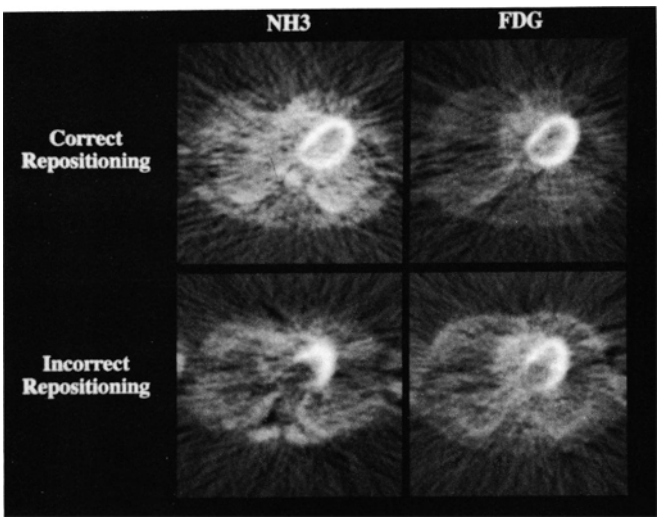

FIGURE 1. Representative images of correct repositioning (top row) and incorrect repositioning (bottom row).

Imaging was performed with a 65 mm FOV. The images have a 20 mm plane-to-plane separation and a FWHM of 16.0 mm. Data reconstruction of all images was performed using a Hann filter. The measured attenuation, ^{13}N ammonia images, and ^{18}F FDG images were hard copied onto film for visual comparison.

Three image planes of the ^{13}N ammonia and ^{18}F FDG myocardial images were used in the assessment of whether the images were adequate or inadequate for comparison. Image correspondence and detection of MSATN artifacts were evaluated using visual assessment by three experienced observers. If the three image planes corresponded on the NH_3 and FDG images, and there were no artifacts related to attenuation correction, the study was considered adequate. If the image planes did not correspond or if there were artifacts related to measured attenuation correction, the study was considered inadequate.

RESULTS AND DISCUSSION

Of the 22 resting NH_3/FDG myocardial studies, 18 had good correspondence of NH_3/FDG images, and 3 studies demonstrated the effects of patient motion at some time between ^{13}N and ^{18}F FDG image acquisition (Fig. 1). One of the rest NH_3 studies had MSATN artifacts present which appear as horizontal streaks across images. Thus, 4 of the 22 rest studies were considered inadequate. Of the 28 exercise NH_3/FDG myocardial studies, 14 had inadequate correspondence of the NH_3 and FDG images. Seven of these were axially misaligned by <1 cm and 5 by >1 cm. There were 2 additional FDG studies with >1 cm MSATN artifacts (Table 1).

The average repositioning time after the NH_3 injection (3–4 min of exercise) was 4.3 min, and 5.3 min after the FDG injection (13–14 min of exercise). The longer average time for repositioning after the strenuous FDG exercise was probably due to greater patient fatigue, increased respiratory

TABLE 1
Myocardial Repositioning Results

	Rest (N = 22)	Exercise (N = 28)
Adequate	18	12
Inadequate MSATN	1	2
Inadequate correspondence	3	14
NH_3	1 (4%)	12 (43%)
FDG	2 (9%)	14 (50%)

motion and increased muscle tone, which slows patient movement and hampers speedy realignment despite pre-exercise rehearsal. Repositioning problems following exercise were grouped into three categories: patient physical condition, patient peripherals and bed/gantry realignment.

Heavy breathing after exercise compromised alignment of body landmarks (Fig. 2). To minimize this effect, all laser and body landmark alignments within the gantry were performed at end-expiration. Holding the end-expiration volume for long periods of time is difficult following exercise, so the subjects may need to hold their breath at end-expiration multiple times. Excessive sweating during exercise caused smudging of the body landmarks, impairing right to left centering. Placing one of the permanent marker points on the V_1 EKG lead solved this problem.

Increased shoulder muscle tone following exercise often caused anterior and cephalad displacement of the arms compared to the initial resting position (Fig. 3). To prevent this change, arms were placed more cephalad during the resting study. This simplified adjustment of the humerus, made with the laser, and improved subject comfort and prevented excessive motion.

Peripheral equipment required for radiopharmaceutical administration and exercise resulted in imaging artifacts. Retained or adherent tracer in intravenous lines, in the arm following antecubital injections, as well as tracer spilled on the body surface, created "hot spots" within the FOV and caused scaling problems for the rest of the images. The presence of a blood pressure cuff bulb or gauge within the FOV occasionally resulted in MSATN artifacts (Fig. 4).

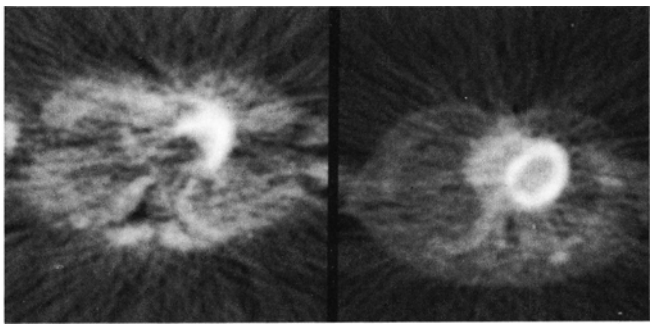

FIGURE 2. Inaccurate repositioning post-^{13}N ammonia exercise resulted in measured attenuation correction artifacts (left image) as compared to accurate repositioning (right image) in corresponding ^{18}F FDG post-exercise image.

Subject positioning was significantly affected by the shifting of padding material on the imaging bed as the subjects mounted and dismounted the bed. This problem was corrected by the use of velcro to secure the bed pads and by use of the headholder. The system of laser and body landmark alignment verified approximate gantry-bed coordination.

SUMMARY

The multiple problems encountered with repositioning a patient on the imaging bed and realigning the patient to the MSATN gantry position can be grouped into the following categories: patient physical condition after exercise, patient peripherals and bed/gantry alignment. Some of these problems can be resolved with careful attention to detail, as discussed above. Other problems require the technologists to be vigilant and flexible in their problem-solving approach to accurately reposition and realign the patient following exercise. Repositioning and alignment need to be accomplished with efficiency and expediency to minimize radionuclide decay prior to imaging. Our 43% accuracy repositioning exercise NH_3 subjects and 50% accuracy repositioning exercise FDG subjects makes upright bicycle exercise for cardiac PET restrictive for routine clinical use with existing technology. With the use of pharmacologic stress, repositioning is not necessary and positioning errors are minimized (*3,4*).

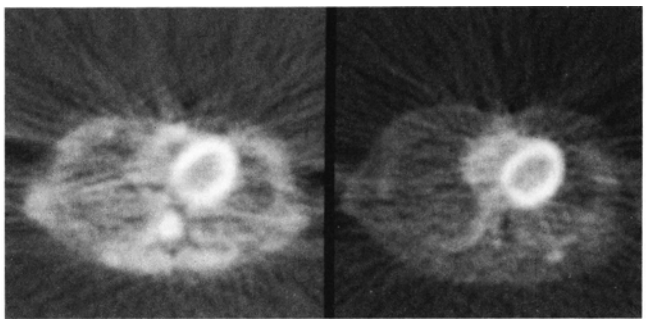

FIGURE 3. Artifact due to arm motion or mispositioning post-exercise (left image) compared with accurate measured attenuation correction (right image).

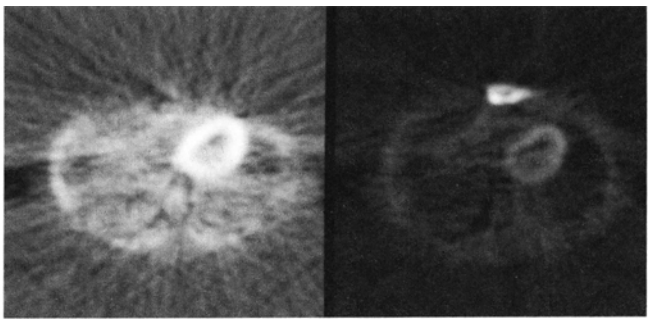

FIGURE 4. Blood pressure cuff gauge in field of view (left image) and scaling artifact due to residual activity in injection line (right image).

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