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SPECT studies should be ungated to ensure the efficacy of post acquisition quality control.

# VISUAL QUALITY CONTROL OF GATED MYOCARDIAL PERFUSION SPECT.

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Foot line: MOTION AND GATING ERRORS IN CARDIAC SPECT

VISUAL QUALITY CONTROL OF GATED  
MYOCARDIAL PERFUSION SPECT.

## **ABSTRACT**

**Introduction:** While the functional data of gated SPECT is valuable, its collection should not compromise the perfusion data. Failure to detect patient motion or gating errors may result in the generation of a perfusion artefact. This possibility was thought to be more likely when the perfusion data was generated by summation of the reconstructed gated slices.

**Methods:** This study was a retrospective cross sectional study of 35 patients undergoing gated myocardial perfusion SPECT. The rotating cinematic display and sinograms for the gated and ungated datasets were visually assessed for the presence or absence of patient motion and/or gating errors. In three normal studies, a variety of motions were artificially introduced to produce 18 studies for random evaluation with 12 motion free studies.

**Results:** Only 51.1% and 34.9% of studies identified on ungated data as having gating errors and patient motions respectively demonstrated a corresponding finding on the gated data. Motion correction software effectively corrected for patient motion in 80% of the ungated data sets and 0% of the gated data sets. In detecting introduced motion, ungated data provided an accuracy of 100% compared to just 80% for the gated data. The ROC analysis provided evidence that visual assessment of the ungated sinogram is preferable to the gated sinogram for detecting patient motion.

**Conclusion:** Producing the ungated perfusion data set for qualitative assessment from a summation of previously reconstructed gated slices means routine post acquisition quality assurance is performed on a single count deficient gate interval. All gated myocardial perfusion SPECT studies should be ungated to ensure the efficacy of post acquisition quality control.

**Key words:** patient motion, gating errors, arrhythmia, gated SPECT, motion correction

## INTRODUCTION

Gated SPECT provides important diagnostic and prognostic information over SPECT alone by utilizing electrocardiographically linked myocardial perfusion images to provide ventricular wall motion and thickening information. This additional information allows both regional perfusion and global function to be assessed simultaneously at no extra cost and with no extra acquisition time (1).

A recent (2004) industry survey indicated that 31.1% of departments employ a gated myocardial perfusion SPECT reconstruction strategy that generates the ungated short axis, horizontal long axis and vertical long axis slices by simply summing the gate intervals of the reconstructed gated data (2). Intuitively, there are a number of potential problems arising from this strategy:

1. Perfusion data may be over filtered due to summation of low count filtered data causing possible false negative results.
2. Visual examination of raw data for patient motion, gating errors or other artifacts (e.g. incidental radiopharmaceutical accumulation in thorax outside reconstruction window) will rely on the poor count gated data.

The former is a significant problem, particularly for small and non transmural defects, and has been investigated by this group. In unpublished data by this author, a statistically significant decrease in both defect extent and severity was noted using this reconstruction method. The latter may be more problematic if motion or gating errors escape detection and are, thus, included in the reconstructed perfusion data.

The first rule of performing gated myocardial perfusion SPECT is that, while the functional data is valuable, its collection should not compromise the perfusion data.

Failure to detect patient motion and, therefore, omitting a repeat motion free study may

result in the generation of artefact that could mimic coronary artery disease. A number of investigators have examined the incidence of patient motion in ungated data sets with Wheat & Currie (3) reporting a 36% incidence of visually detectable motion, Botvinick et al. (4) reporting 25% and Prigent et al. (5) reporting the 26%. One suspects the presence of visually detectable patient motion is somewhat more difficult to reliably detect when examining the sinogram and cinematic display of a low count gate interval.

Gating the SPECT data requires implementation of a strategy to deal with arrhythmia with particular attention focussed on ensuring the ungated perfusion data is not compromised. Rejecting 'bad beats' using a narrow window means that perfusion data is lost unless all 'rejected' counts are acquired in an additional 9<sup>th</sup> bin / interval for subsequent summation into the ungated data set (6). Paul and Nabi (7) recommend a 20% acceptance window and DePuey (8) indicated that 25% to 35% is typical in clinical practice. The American Society of Nuclear Cardiology (ASNC) (8), however, recommend a 100% window so the functional information is not acquired at the expense of the perfusion data. That is, a 100% window will accept all beats. Only 20.9% of departments employ a 9<sup>th</sup> interval for rejected beats yet only another 22.0% abandon gating in arrhythmia (2). Not surprisingly then, Nichols et al. (9) reported that only 26% of gated myocardial perfusion SPECT patients had data sets free of gating errors.

## **MATERIALS AND METHODS**

The aim of this investigation was to compare the accuracy and appropriateness of assessing the sinogram and rotating cinematic display on the gated versus ungated raw data for identification of patient motion or gating errors that may have deleterious effects of the reconstructed data. Can the gated raw data sinogram and cinematic display be relied upon to identify data sets requiring repeat scanning?

### **Study Population Demographics**

This study was a retrospective cross sectional study of 35 patients undergoing gated myocardial perfusion SPECT. The study population consisted of 70 myocardial perfusion studies (35 rest and 35 stress). The age of the study population was normally distributed ( $P = 0.20$ ) with a mean of 68.5 years, a median age of 72 years and the age range was 46 to 84 years. The study population consisted of 18 (51.4%) males and 17 females (48.6%) ( $P = 0.87$ ).

### **Study Protocol**

All data were acquired following two day stress/rest (34.3%) or two day rest/stress (65.7%) myocardial perfusion SPECT protocols ( $P = 0.06$ ). All myocardial perfusion SPECT studies employed a 740 MBq dose of  $^{99m}\text{Tc}$  tetrofosmin (Nycomed-Amersham, Amsterdam). A triple detector gantry was used to acquire all patient data. All data acquisitions employed low energy, high resolution collimation with step and shoot mode, elliptical orbits and a 64x64 matrix. The zoom was 1.23 and projections were acquired at three degree intervals for 20 seconds per projection to provide a total acquisition time of 15 minutes. All patients were positioned supine with their feet into the gantry for an eight interval gated SPECT acquisition. The gating window was variable with a narrow window (20%) being preferable where the patients rhythm



permitted. The window was expanded to as much as 100% as deemed necessary to eliminate potential loss of perfusion data due to gating errors.

### **Clinical Evaluation**

The raw gated SPECT dataset for each study (rest and stress) was converted from an eight interval gated study to an ungated dataset by summation of the eight intervals for each projection. The rotating cinematic display and sinograms for the ungated datasets were visually assessed by two experienced technologist observers independently from one another and blinded to both the second observers' responses and the clinical outcome of the study. Each study was assessed for the presence of visually detectable motion and the presence of gating errors. Each was reported on a five point scale; definitely present, probably present, equivocal, probably absent and definitely absent. After completion of the analysis of all 35 patients' ungated data, the gated studies were evaluated in a similar fashion. This order insured any bias associated with remembered information would benefit the gated study assessment. The end diastolic gate interval was used for all evaluations of the gated data.

All data was presented and assessed using a grey scale (16 bit, 64000 shades). The presence of motion on the cinematic display and the sinogram was indicated by the identification of an obvious disruption to their smooth progression. It has been reported in the literature that motion less than one pixel is not likely to be detected visually (10,11). Gating errors were characterized by horizontal bands of low counts relative to adjacent projection data.

### **Motion Correction**

A motion correction algorithm was applied to each set of gated and ungated myocardial perfusion SPECT studies where the ungated data was deemed to 'definitely' contain motion and the corresponding gated data was deemed to either 'definitely' or 'probably' contain motion. Ten studies were identified to satisfy this criteria (seven stress, three rest, six male and four female). The motion correction algorithm corrects for both 'x' and 'y' axis motions and uses parabolic interpolation for fractional shifts. The algorithm re-projects reconstructed data to their original angles to produce a reference for the true projection data and motion estimation (12).

A window of interest and thresholding allowed the limitation of the region of comparison to the organ of interest and thus, improving the success rate of motion correction. The motion correction algorithm was applied to corresponding pairs of gated and ungated data. The corrected gated data was subsequently ungated to provide an equitable comparison with the corrected ungated data. Each corrected rotating cinematic display and sinogram were visually examined for motion and reported on a five point scale; definitely present, probably present, equivocal, probably absent and definitely absent.

### **Motion Simulation**

During the evaluation of patient studies outlined above, three studies were selected to have motion artificially introduced. Only the stress studies were utilized for motion simulation to capitalize on the superior heart to background count ratio and heart to liver count ratio (compared to the rest studies). All three patients were also lean to reduce the possibility of physiological artifacts. Cooperative evaluation of the patient

studies indicated both to be motion free and without other technical errors (e.g. gating errors). Two patients were male and one was female.

Vertical patient motion was simulated using software to shift the selected projections in the gated stress studies. In essence, vertical motions were simulated by relocating the original motion free projection. Bounce motion was simulated by upward vertical shifting of the raw projection data in a returning pattern while abrupt motion used a non returning pattern. That is to say, shift for bounce simulation only required relocation of three projections while abrupt motion required all subsequent projections represented per detector to be relocated. There were a number of variables that were considered in simulating motion in the studies including:

- Type of motion; vertical bounce and abrupt,
- Direction of motion; vertical motions were simulated in an upward direction,
- Magnitude of motion; two pixels (abrupt) and four pixels (bounce) – this is the minimum for each that will create an artifact (*11*),
- Duration of motion; three frames (bounce) or 20 frames (abrupt),
- Location of motion; RAO 45, LAO 45 and LPO 45.

A total of 18 motion simulation studies were produced as a result of combining these variables for the three patients. A further 12 studies were produced from the original motion free study of each patient; one as raw data and three modified in appearance by count truncation, temporal smoothing and a combination of truncation and temporal smoothing. Thus, a total of 30 gated files required ungating to produce 60 patient files for visual evaluation for motion. The cinematic display and sinogram were randomized

for visually inspection and reported on a five point scale; definitely present, probably present, equivocal, probably absent and definitely absent.

### **Statistical Analysis**

The statistical significance was calculated using Chi square analysis for nominal or ordinal data and Student's *t* test for continuous data. A *P* value less than 0.05 was considered significant. The  $X^2$  Pearson Chi Square test was employed for categorical data with normal distribution and the  $G^2$  Likelihood Ratio Chi-Square test for categorical data without normal distribution. Confidence intervals (CI) were employed with 95% confidence. Relative risk (risk ratio) was used to determine the strength of association between exposure and outcomes with a risk ratio of 1.5 indicative of the exposure of interest being 1.5 times more likely to result in the outcome of interest. Receiver operating characteristic (ROC) analysis was performed using JROCFIT software version 1.0.2 developed by Dr John Eng at Johns Hopkins University (Baltimore, USA) as a translation of the ROCFIT program developed by Dr Charles Metz at the University of Chicago (USA).

Data collection and analysis was approved by the Charles Sturt University School of Clinical Sciences, Ethics in Human Research Committee.

## RESULTS

The inter-observer correlation for visually detected motion was excellent with a 96% correlation between observers for the presence or absence of visually detectable motion. Similarly, excellent inter-observer correlation was noted for the presence or absence of gating errors with a 94% correlation between observers.

### Gating Errors

No statistically significant difference was noted in the presence of gating errors between genders ( $P = 0.54$ ), age ( $P = 0.09$ ), study type (rest or stress) ( $P = 0.32$ ) or protocol (rest/stress or stress/rest) ( $P = 0.22$ ). For stress studies, 42.9% (15/35) of studies demonstrated ‘definite’ gating errors and for rest studies, 54.3% (19/35) of studies demonstrated ‘definite’ gating errors. A further 25.7% (9/35) of stress studies and 11.4% (4/35) of rest studies ‘probably’ contained gating errors. Only 31.4% (11/35) of patients showed ‘definite’ gating errors in both rest and stress studies although 48.6% (17/35) of patients had both rest and stress studies classified as either ‘definitely’ or ‘probably’ containing gating errors. This translates to 65.7% (23/35) of patients ‘definitely’ exhibiting gating errors in at least one of their studies which increases to 85.7% (30/35) when ‘definite’ and ‘probable’ gating errors are pooled.

Table 1 provides an overview of the gated data versus the ungated data for the presence or absence of gating errors. The highlighted row and column (bold border) demonstrate a predominance of ‘definitely present’ observations for gating errors on the ungated data with ‘probably absent’ predominating the gated data. The  $G^2$  Likelihood Ratio Chi-Square test revealed a statistically significant difference between gated and ungated data ( $P < 0.001$ ). The confidence with which gating errors are detected deteriorates in 61.8% (21/34) of studies where a definite gating error was noted on the

ungated data set. Similarly, 92.3% (12/13) of studies where the ungated data determined a 'probably present' gating error were interpreted as 'probably absent' on the gated data set. Furthermore, only 51.1% (24/47) of studies identified as having gating errors ('definitely' or 'probably' present) on ungated data were identified as having gating errors on the gated data. Relative risk suggests assessing the raw sinogram and cinematic display on the ungated files detects twice the incidence of gating errors than the gated files. Less significantly, the confidence with which observers could exclude the presence of gating errors was also lower for the gated data with 70% (7/10) of ungated data receiving a 'definitely absent' response also receiving a 'probably absent' response on the gated data.

### **Patient Motion**

A statistically significant difference was noted in the presence of patient motion between genders ( $P = 0.03$ ) with males more likely to exhibit patient motion. No statistically significant difference was noted in the presence of patient motion for age ( $P = 0.25$ ), study type (rest or stress) ( $P = 0.08$ ) or protocol (rest/stress or stress/rest) ( $P = 0.48$ ). For stress studies, 42.9% (15/35) of studies demonstrated 'definite' patient motion and for rest studies, 44.1% (15/34) of studies demonstrated 'definite' patient motion. One of the rest studies was excluded due to a gating error corrupting the data. A further 17.1% (6/35) of stress studies and 20.6% (7/34) of rest studies 'probably' contained patient motion. Only 29.4% (10/34) of patients showed 'definite' patient motion in both rest and stress studies although 47.1% (16/34) of patients had both rest and stress studies classified as either 'definitely' or 'probably' containing patient motion. This translates to 58.8% (20/34) of patients 'definitely' exhibiting patient motion in at least one of their studies which increases to 76.5% (26/34) when 'definite' and 'probable' patient motions are pooled.

Table 2 provides an overview of the gated data versus the ungated data for patient motion. The highlighted cells (bold border) demonstrate a predominance of ‘definitely present’ observations for patient motion on the ungated data with ‘equivocal’ increasing substantially on the gated data. The  $G^2$  Likelihood Ratio Chi-Square test revealed a statistically significant difference between gated and ungated data ( $P = 0.03$ ). The confidence with which patient motion is detected deteriorates in 90.0% (27/30) of studies where a definite patient motion was noted on the ungated data set. Moreover, only 34.9% (15/43) of studies identified as having patient motion (‘definitely’ or ‘probably’ present) on the ungated data were identified as having patient motion on the gated data. Relative risk suggests assessing the raw sinogram and cinematic display on the ungated files detects 2.9 times the incidence of patient motion than the gated files. It is also worth noting that 23.2% (16/69) of gated data was deemed equivocal for detection of patient motion compared to just 2.9% (2/69) for the ungated data.

### **Patient Motion Versus Gating Errors**

Not surprisingly, 46.4% (32/69) of studies exhibited both patient motion and gating errors. Perhaps patient motion was sufficient to alter heart rate enough to cause beat rejection. More importantly although of minor significance in this cohort, difficulty in assessing for patient motion resulting in an ‘equivocal’ classification was always associated with gating errors (2/2). The relative risk of having a gating error in the presence of patient motion is 1.5.

### **Motion Correction**

All 10 ungated data sets demonstrated an improvement in the severity of patient motion while three (30%) of the gated studies demonstrated a worsening of the motion severity after application of the motion correction algorithm. The motion correction algorithm effectively corrected for patient motion in 80% (8/10) of the ungated data sets and 0% of the gated data sets.

### **Motion Simulation**

As illustrated in table 3, there were no false positive or false negative results for the ungated data while the gated data produced an 11.1% (2/18) false negative rate and 33.3% (4/12) false positive rate. Both the sensitivity and specificity for detection of patient motion in the ungated data set was 100% which compared favourably with the 88.9% sensitivity and 66.7% specificity in the gated data set. The predicted value of a positive result (PVP) was 80% for the gated data and 100% for the ungated data. Similarly, the predictive value of a negative result (PVN) was 80% for the gated data and 100% for the ungated data. Note surprisingly then, a statistically significant difference was noted for responses between gated and ungated data ( $P < 0.001$ ) (table 4).

ROC analysis (Fig. 1) demonstrates that assessment of the ungated raw data sinogram and cinematic display is superior to the same assessment on the corresponding gated data for detection of patient motion. The ROC area under the curve for the gated data, defined by the solid line in figure 1, was 0.889. By comparison, the ROC area under the curve for the ungated data, defined by the broken line in figure 1, was 1.00.



## **DISCUSSION**

This investigation reported the presence of gating errors in between 65.7% and 85.7% of gated studies. This is concordant with Nichols et al. (9) who reported that only 26% of gated myocardial perfusion SPECT patients had data sets free of gating errors. While gating errors are evident from visual examination of the raw data sinogram, visual detection does not actually translate to the introduction of artefact that may undermine diagnostic integrity. While one might expect that severe gating errors would undermine the diagnostic integrity of the perfusion data (Fig. 2a), one might also presume minimal impact from more subtle gating anomalies (Fig. 2b).

Only 51.1% of studies identified as having gating errors on the ungated data were identified as having gating errors on the gated data. Similarly, only 34.9% of studies identified as having patient motion on the ungated data were identified as having patient motion on the gated data. The higher count ungated data provides greater accuracy and confidence for decisions about the presence or absence of patient motion and gating errors over the low count gated data (Fig. 3 and 4). A fairly intuitive outcome, especially in Nuclear Medicine where a 'counts count' philosophy is the cornerstone of quality imaging. With an eight fold increase in counts per pixel, the ungated data provides greater statistical certainty than the gated data equating to a 2.9 fold decrease in sampling error.

The motion simulation study allowed qualification of the relationship between ungated and gated data with ROC analysis. The ROC analysis provided evidence that visual assessment of the ungated sinogram is preferable to the gated sinogram for detecting patient motion. Both the sensitivity and specificity for detection of patient motion in the ungated data set was 100% which compared favourably with the 88.9% sensitivity

and 66.7% specificity in the gated data set. In detecting known patient motion, ungated data provided an accuracy of 100% compared to just 80% for the gated data. One might imagine that this figure could be substantially worse if motions were introduced toward the lower end of visual detection (i.e. one pixel). The motions that were simulated were known to be of a magnitude and duration sufficient to cause a perfusion artefact (3). Thus, failure to detect the motion on the gated data set may translate to an artefact that mimics coronary artery disease, undermining diagnostic integrity. It is crucial that such motions are detected in routine post acquisition quality assurance so that the study can either be corrected, repeated or considered during interpretation. Unfortunately, in the event that motion is detected on the gated data, motion correction is eliminated as an option because the lower count statistics undermines the algorithm accuracy (Fig. 5).

## **CONCLUSION**

Producing the ungated perfusion data set for qualitative assessment from a summation of previously reconstructed gated slices is fraught with danger. This strategy requires routine post acquisition quality assurance to be performed on a single count deficient gate interval. The associated lack of statistical certainty may permit patient motion and gating errors to go undetected. While the presence of patient motion and/or gating errors does not necessarily render the data set worthless, it is important for the reporting physician to consider their presence carefully. All gated myocardial perfusion SPECT studies should be ungated to ensure the efficacy of post acquisition quality control.

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**TABLES**

Table 1: Contingency table of the evaluation confidence for gating errors in the gated data by the ungated data.

		<b>GATED</b>					
		<b>Definite</b>	<b>Probably</b>	<b>Equivocal</b>	<b>Probably Not</b>	<b>Definitely Not</b>	
<b>U N G A T E D</b>	<b>Definite</b>	13	10	1	10	0	<b>34</b>
	<b>Probably</b>	0	1	0	12	0	<b>13</b>
	<b>Equivocal</b>	0	0	0	0	0	<b>0</b>
	<b>Probably Not</b>	0	0	0	6	7	<b>13</b>
	<b>Definitely Not</b>	0	0	0	7	3	<b>10</b>
		<b>13</b>	<b>11</b>	<b>1</b>	<b>35</b>	<b>10</b>	<b>70</b>

Table 2: Contingency table of the evaluation confidence for patient motion in the gated data by the ungated data.

		GATED					
		Definite	Probably	Equivocal	Probably Not	Definitely Not	
U N G A T E D	Definite	3	7	5	15	0	<b>30</b>
	Probably	0	5	2	6	0	<b>13</b>
	Equivocal	0	0	1	1	0	<b>2</b>
	Probably Not	0	0	7	12	0	<b>19</b>
	Definitely Not	0	0	1	3	1	<b>5</b>
		<b>3</b>	<b>12</b>	<b>16</b>	<b>37</b>	<b>1</b>	<b>69</b>

Table 3: Contingency table of the evaluation confidence for patient motion versus the ungated and gated data. False positive and false negative results are highlighted by bold borders.

		REST					
		Definite	Probably	Equivocal	Probably Not	Definitely Not	
<b>No motion</b>	<b>gated</b>	0	<b>4</b>	0	4	4	<b>12</b>
	<b>ungated</b>	0	0	0	5	7	<b>12</b>
<b>Motion</b>	<b>gated</b>	12	4	0	<b>1</b>	<b>1</b>	<b>0</b>
	<b>ungated</b>	17	1	0	0	0	<b>5</b>
<b>Total</b>	<b>gated</b>	<b>12</b>	<b>8</b>	<b>0</b>	<b>5</b>	<b>5</b>	<b>30</b>
	<b>ungated</b>	<b>17</b>	<b>1</b>	<b>0</b>	<b>5</b>	<b>7</b>	<b>30</b>

Table 4: Contingency table of the evaluation confidence for patient motion in the gated data by the ungated data. False positive and false negative results are highlighted by bold borders.

		GATED					
		Definite	Probably	Equivocal	Probably Not	Definitely Not	
U N G A T E D	Definite	12	4	0	0	1	17
	Probably	0	0	0	1	0	1
	Equivocal	0	0	0	0	0	0
	Probably Not	0	2	0	3	0	5
	Definitely Not	0	2	0	1	4	7
		12	8	0	5	5	30



**FIGURES**

Figure 1: ROC curves for the gated (solid line) and ungated (broken line) data.

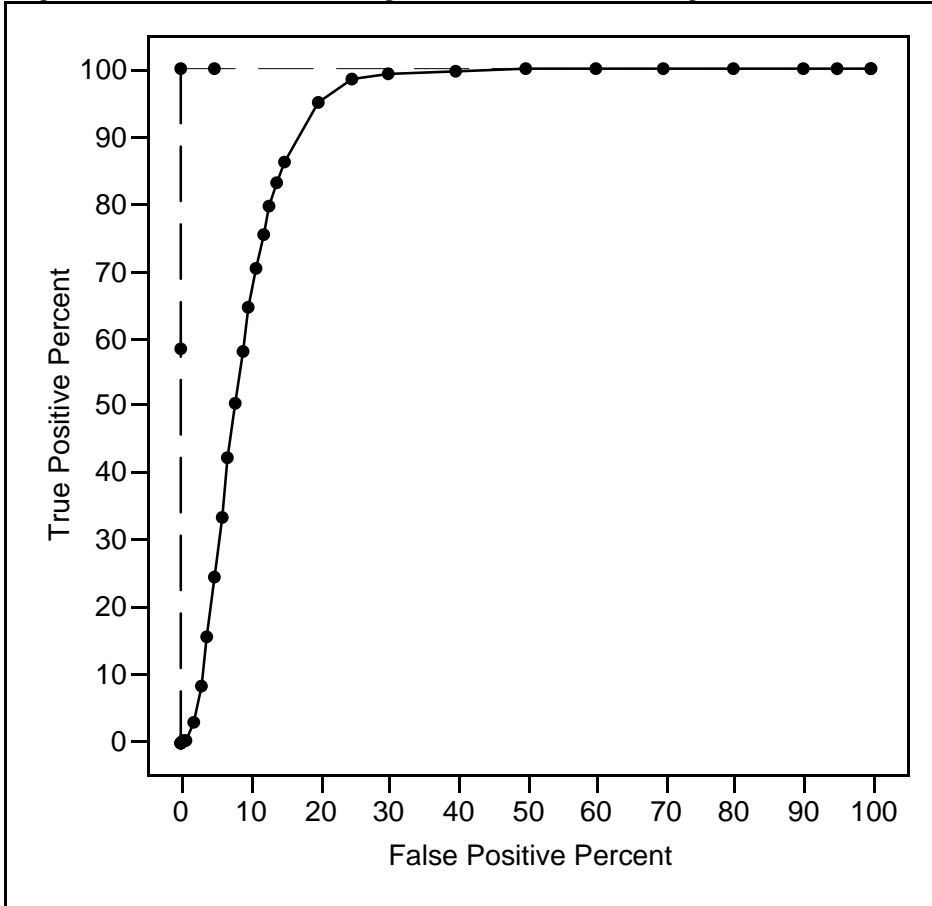


Figure 2: Raw data sinograms providing clinical examples of marked gating errors (A) and subtle gating errors (B).

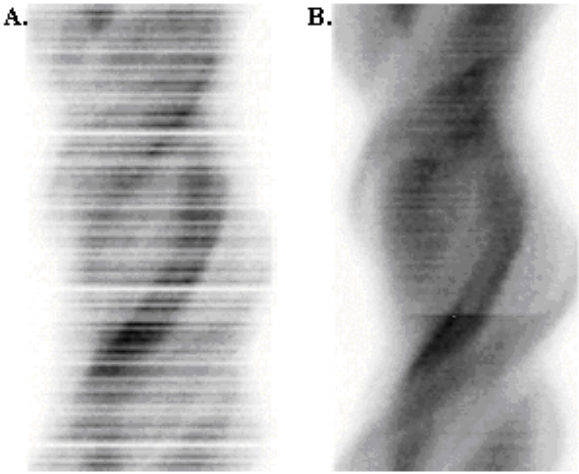


Figure 3: Raw data sinograms providing clinical examples of an obvious gating error on the ungated data (A) which is not obvious on the corresponding gated data (B). gating errors are seen as horizontal count deficient strips.

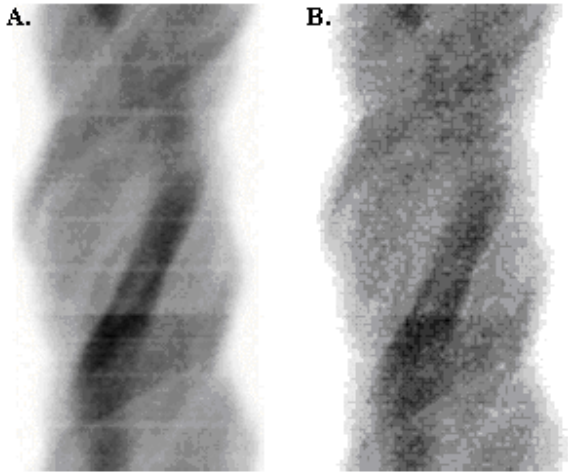


Figure 4: Raw data sinograms providing clinical examples of obvious multiple small motions on the ungated data (A) seen by tracing the right edge of the cardiac sinogram. This motion is not obvious on the corresponding gated data (B).

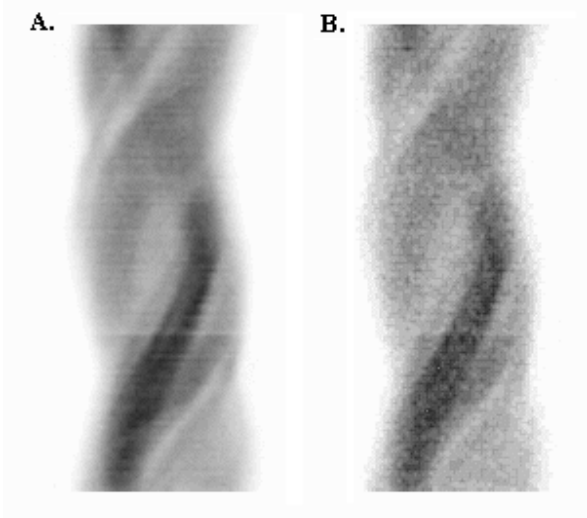


Figure 5: Raw horizontal sinograms post motion correction. Motion correction performed on the gated data (subsequently ungated for display) is illustrated on the left (A). Motion correction applied to the ungated data is seen on the right (B). The superior and inferior edges provide a map of the actual corrective motions applied to the raw data. The relatively subtle corrections determined by analysis of the ungated data eliminated visually detectable patient motion (B). Conversely, the gated correction introduced marked deviations that corresponded to a worsening of motion in the data (A).

