

Q.STATIC

Quantitative PET whole-body with automated motion correction

Respiratory motion presents significant challenges for PET/CT acquisitions that last several minutes for which breath holding is not an option. The induced motion artifacts may introduce significant image distortion, potentially leading to clinical misinterpretation involving apparent increase of lesion size, reduction of measured Standardized Uptake Value (SUV) and a potential miss of small lesions. Several techniques have been developed attempting to address these issues. While providing very interesting results, none of them addressed all the challenges simultaneously: image and quantification artifacts, CT dose and challenging workflow.

GE Healthcare's Q.STATIC is an innovative automated motion correction method, which addresses those challenges. It minimizes the effect of respiratory motion by extracting data only from the quiescent phase of the patient's respiration. Q.STATIC is fully integrated into the clinical whole-body PET protocol, which makes the technology accessible at any time for every patient in clinical practice. As it involves no processing of the data before the reconstruction, Q.STATIC motion-corrected images are available simultaneously with the conventional PET static images.



Q.STATIC is an innovative alternative PET acquisition protocol to any PET static acquisition. It integrates an automated motion correction technology to help enhance image quality and quantitative PET measurements.

GE Healthcare designed Q.STATIC to automatically isolate data when organs are in a low motion state. The result is a single image series with minimized blurring from organ motion, and therefore more consistent quantitation and image quality compared to conventional static image reconstruction.

MOTIONFREE PET/CT IMAGING

One of the biggest clinical challenges for PET/CT imaging is patient respiratory motion. This motion leads to a blurring of moving features in PET images. Blurring may in turn potentially lead to lower detectability of lesions, inaccurate SUV measurements and sub-optimal treatment planning volumes in radiation therapy. In addition, motion may lead to image artifacts due to respiratory displacement mismatch between CT and PET, since the CT is used for attenuation correction of the PET data.^{1,2} Some of the documented benefits of motion correction include enhanced fusion of PET and CT images, SUV accuracy and volume measurement of small lesions.^{3,4}

GE Healthcare's MotionFree PET/CT imaging techniques, including Q.STATIC, have been specially developed for the lung and abdomen region which is most often affected by patient respiratory motion and thus can potentially lead to under estimating tracer concentration up to 30% or more and over estimating tumor volume by a factor of 2 or more⁵.

An analysis of patient respiratory traces showed that a majority of patients tend to spend more breathing time dwelling at the end-expiration quiescent period and breathe to the same end-expiration location.⁶ These results indicate that imaging at end-expiration could involve less motion while still retaining a large fraction of the PET data.

Based on these findings, Q.STATIC was designed to extract a fraction of PET data from the end-expiration quiescent portions of patient breathing cycles, and form a single PET image volume for physician review. A respiration curve with a quiescent period indicated can be seen **Figure 1**. The conventional scanning method, referred to as 'static,' uses the entire signal in each respiration cycle. Q.STATIC only extracts data during the quiescent period of the respiration cycle.

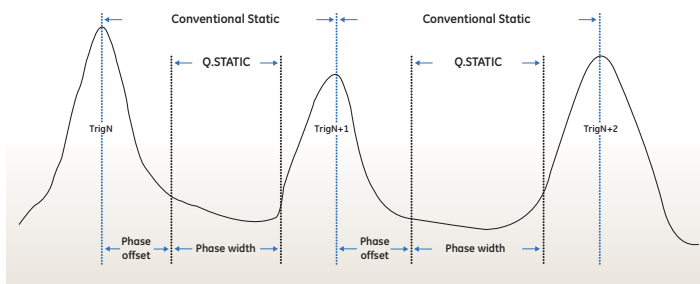


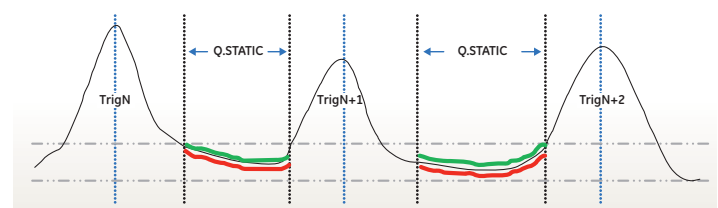
Figure 1: Typical patient respiratory curve with a longer quiescent phase with little respiratory movement.

The Q.STATIC quiescent period is determined by specifying the phase offset and phase width shown in **Figure 1**, as a percentage of the respiration cycle. Both parameters are adjustable to any patient respiratory patterns.

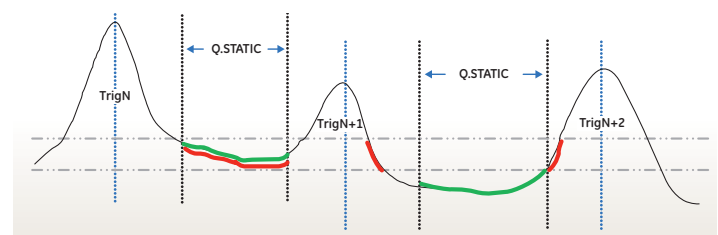
AMPLITUDE-GATING VS. PHASE-GATING

Quiescence Period Gating (QPG) techniques have been developed using either amplitude-gating or phase-gating. Q.STATIC is a phase-based gating method which avoids a major drawback of amplitude gating – namely the limited ability to compensate for patient respiratory curve baseline drift, which happens frequently in PET imaging.

Q.STATIC, based on phase-gating, offers an adaptive solution to patient respiration patterns, as shown in **Figure 2**. The green line represents the quiescent period based on phase-gating and the red line shows the quiescent period based on amplitude-gating. When the respiratory curve has no baseline drift, the phase-based gating and amplitude-based gating extract similar quiescent periods. However, when the respiratory curve does show baseline drift (e.g., table sagging), the amplitude-based gating includes data from the non-quiescent phase into the reconstruction while discarding the real quiescent phase, which causes blurring to the image and an extended acquisition time.



Regular breathing patterns



Regular breathing patterns with baseline drift

Green line: phase-based respiratory gating
Red line: amplitude-based respiratory gating

Figure 2: The effect of baseline drift in the quiescent phase estimate using phase- or amplitude-based gating techniques. Phase-based Q.STATIC is more robust to baseline drift than amplitude-based QPG methods. The green line in this figure is the quiescent phase based on phase-gating and the red line shows the quiescent phase based on amplitude-gating.

INTELLIGENT TRIGGER REJECTION

The other scenario where free breathing QPG techniques have shown limitations is when the patient respiratory pattern is irregular. Q.STATIC implements a trigger rejection mechanism to address this specific issue. When fast and shallow respiration happens, the trigger and the corresponding data will be rejected as shown in **Figure 3**.

The Q.STATIC solution integrates a respiratory gating device, which rejects triggers with too high or too low of a frequency to reduce and, in most cases, eliminate blurring induced by fast and shallow patient respiratory patterns. If the detected respiratory trigger happens too late or too early compared to the normal patient respiratory cycle, Q.STATIC will automatically reject it. The system will wait for the next "good" trigger to continue the Q.STATIC PET acquisition. The end result will then be motion-corrected images without blurring from shallow or fast breaths.

Results

PHANTOM STUDY

The performance of Q.STATIC can be demonstrated using five 2 mL Ge-68 filled spheres and a Respiratory Phantom from Anzai Medical Co., Ltd. Two spheres are put above the static portion of the respiratory phantom and the other three in the moving portion of the respiratory phantom. The spheres were set into motion using the Anzai™ moving phantom with its default respiratory motion pattern only in the axial direction of the scanner. The respiratory period was set to six seconds. The motion of the phantom was monitored and reported to the PET/CT scanner through a pressure sensor.

Data was acquired using a Discovery* PET/CT 610 (GE Healthcare – Waukesha, WI). A helical CT scan covering the PET imaging field-of-view was acquired with no phantom motion and was used for attenuation correction of all PET data. The PET acquisitions were then performed with no source motion and a single 2.5-minute PET acquisition. The data was used to form a single 2.5-minute dataset as a foundational baseline.

Another 2.5-minute PET acquisition was acquired while the moving phantom was in operation. Two of the five spheres had no motion, while the other three spheres move together with the respiratory phantom. Three datasets were generated from the list file: conventional static PET (STATIC), and Q.STATIC each using the same 3D OSEM iterative reconstruction (VUE Point HD).

As shown in **Figure 5**, Q.STATIC reduces the motion blur compared to the conventional static reconstruction.

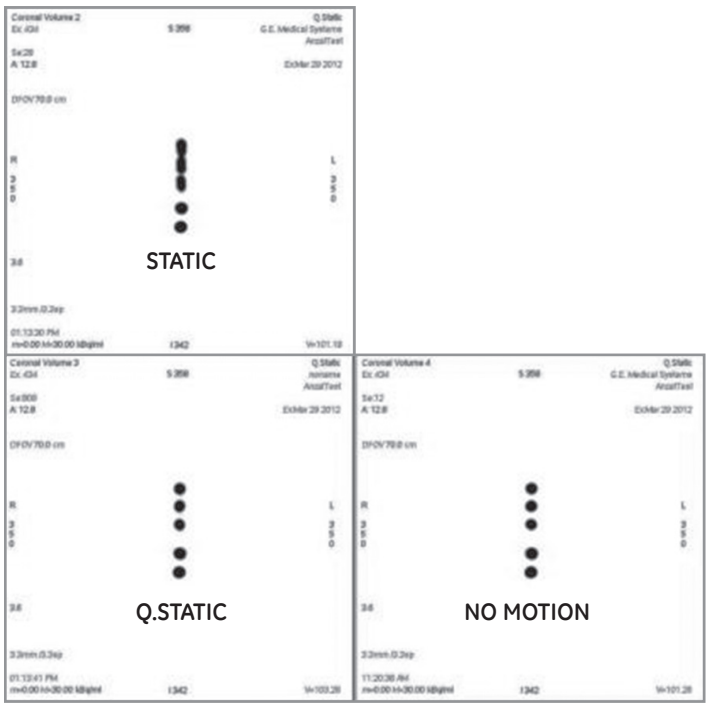


Figure 5: Coronal view of the moving spheres. The upper image shows the conventional static reconstruction with moving spheres. The lower left image shows a Q.STATIC gate with moving spheres and the lower right image is the benchmark image without sphere motion.

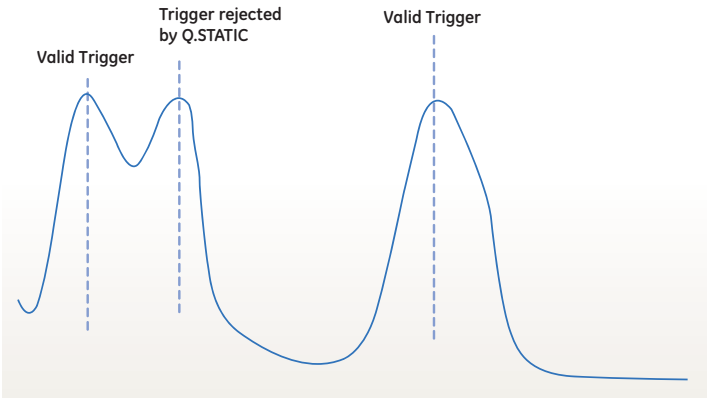


Figure 3: Phase-based Q.STATIC is ideal for fast and shallow respiration. When fast and shallow respiration happens, the trigger and the corresponding data is rejected due to the fast frequency. Thus it won't introduce blurry data to the reconstruction.

METHOD AND IMPLEMENTATION

Both the PET static and the Q.STATIC data are acquired simultaneously and reconstructed using the same reconstruction parameters. Q.STATIC requires a respiratory-gating device connected to the scanner† to generate the maximum inspiration trigger points.

The operator selects the appropriate bed positions, which could be several adjacent beds to cover the area that includes respiratory motion, and where Q.STATIC images are desired. Q.STATIC images are then embedded with the adjacent conventional whole-body PET images.

Figure 4 shows a conventional whole-body protocol with Q.STATIC beds highlighted, where Q.STATIC reconstruction will be performed. Q.STATIC seamlessly integrates the motion-corrected beds into the whole-body reconstruction, which allows the radiologists to review images free of respiratory-motion effects and without changing their routine review process.

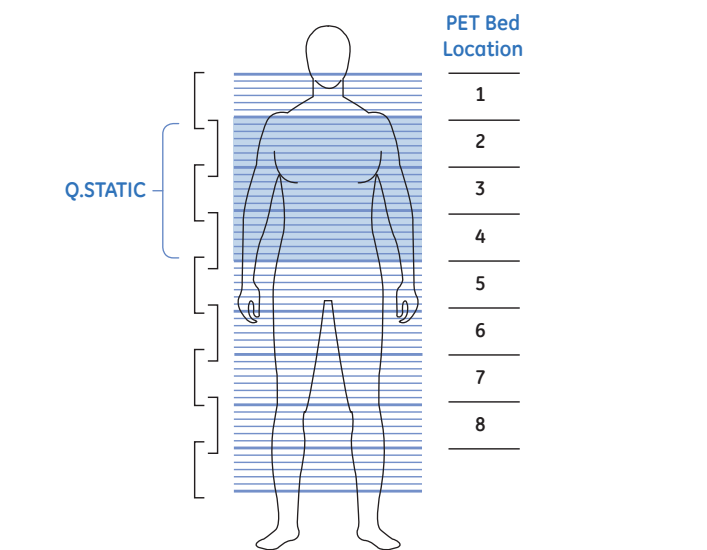


Figure 4: Whole-body protocol user interface gives the flexibility to the user to select the Q.STATIC coverage.

Quantitation results of the spheres in the Q.STATIC phantom study are listed in **Table 1**. The volume and maximum activity concentration (MAC) of the sphere were determined by the default clinical setting in the Discovery PET/CT 610 system. For a moving sphere, the volume difference drops from 63% in conventional static reconstruction to 15% in Q.STATIC, and to 6% with 4D PET. The MAC difference drops from 43% in conventional static reconstruction to 28% in Q.STATIC, and to 14% in 4D PET. For static spheres, the sphere volumes and MAC are the same as the benchmark.

Acquisition protocol	Volume (cm ³)	(%)	MAC (kBq/ml)	(%)
NO MOTION	1.80 +/- 0.11		192 +/- 9	
STATIC	2.93 +/- 0.10	63%	109 +/- 14	43%
Q.STATIC	1.90 +/- 0.10	6%	166 +/- 18	14%

Table 1: Quantitation of the phantom study. For moving sphere 1, the sphere volume difference drops from 50% in conventional static reconstruction to 6% for Q.STATIC. The maximum activity concentration (MAC) difference drops from 43% in conventional static reconstruction to 14% for Q.STATIC. For static spheres, the sphere volumes and MAC are the same as the benchmark.

Compared to conventional static images in the Discovery PET/CT 610, Q.STATIC leads to images with less motion blurring and enhanced quantification. The phase width can be reduced to reduce the motion, but with an extended acquisition time, or vice versa.

QUANTITATIVE EVALUATION

A retrospective clinical evaluation was conducted to assess the clinical performance of the Q.STATIC method. 25 respiratory-gated FDG clinical studies were reconstructed using the conventional static method as well as the Q.STATIC method. 29 known thoracic and abdominal lesions were evaluated in terms of the lesion SUV_{max} and the lesion size. A PET clinician also reported the overall image quality for blurring reduction and lesion definition.

The results demonstrated that the Q.STATIC method enhanced image quality to help clinicians improve the visual interpretation of images; increased the SUV_{max}; and decreased lesion volume measurements as shown in **Table 2**. This chart shows the average quantitative improvement of Q.STATIC over the 29 lesions.

Average on 29 lesions	STATIC	Q.STATIC	%
SUV _{max} (g/mL)	6.02	6.67	11%
Volume (cm ³)	4.11	3.10	24%

Table 2: Quantitative benefit of Q.STATIC over conventional static acquisition.

The overall image quality benefit of Q.STATIC over static images in the Discovery PET/CT 600-series over the 25 whole-body FDG PET clinical studies is demonstrated in **Figure 6**.

- In 16 out of 25 studies, Q.STATIC showed less blurring in images (64%) and equivalent in the remaining 9 cases (36%)
- In 6 out of 25 studies, there were no lesions (24%). In 8 out of 25 studies (32%), Q.STATIC showed more identifiable lesions, 10 with equivalent performance (40%) and one without improved performance (4%).

Figure 6 demonstrates the lesion detectability improvement obtained with Q.STATIC over the 29 FDG avid features in the 19 clinical FDG PET studies.

- In 19 out of 29 features, Q.STATIC measured decreased volume (66%), 7 with equivalent volume (difference < 5%) (24%), two with increased volume (7%) and one challenging to measure (3%).
- In 20 out of 29 features, Q.STATIC produces increased SUV_{max} (69%), eight with equivocal SUV (diff<5%) (28%) and one with decreased SUV (3%).

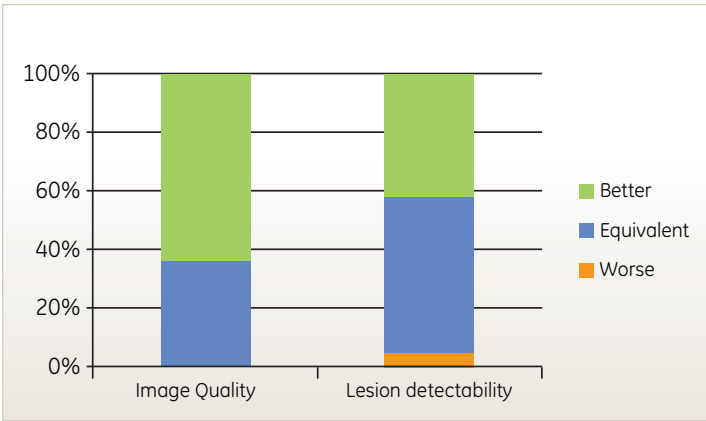
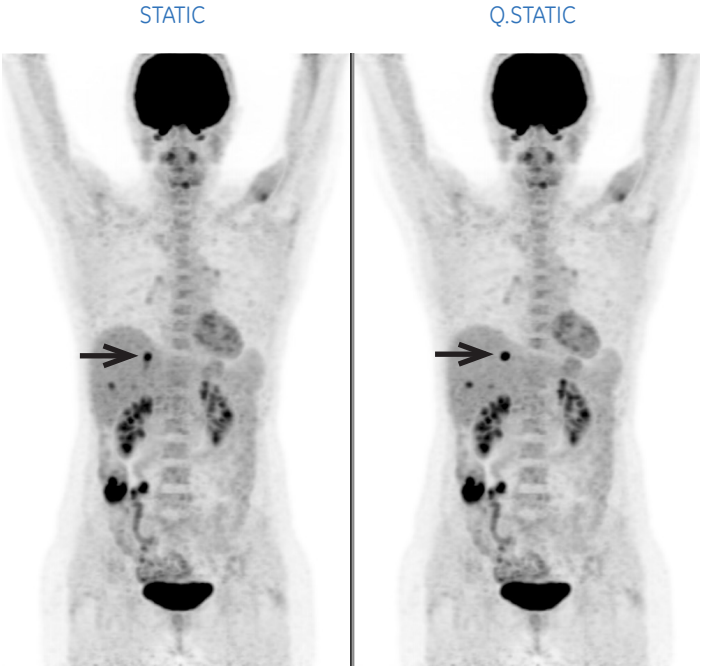


Figure 6: Method and results - A clinician visually assessed Q.STATIC results and conventional static results in 25 whole-body FDG PET clinical studies.

CLINICAL EXAMPLE



	STATIC	Q.STATIC	%
SUV _{max} (g/mL)	6.52	8.64	33%
Volume (cm ³)	2.25	1.54	32%

The lesion in the liver has an artifact tail on the conventional static images. Q.STATIC resolves this motion artifact from the images and therefore enhances the quantitative PET measurements.

Summary

GE Healthcare has designed the Q.STATIC motion correction method, which extracts data during the quiescent period of the respiration cycle in order to reduce the effects of respiratory motion in PET/CT exams. Q.STATIC allows free breathing for the patient and reduces motion blur without complicating the clinical workflow as compared with conventional static image reconstruction methods in the Discovery PET/CT systems. Q.STATIC is designed for everyday use to enhance the quantitative measurements in PET images. A retrospective clinical evaluation shows Q.STATIC measured decreased volume in 66% of the cases and Q.STATIC produces increased SUV_{max} in 69% of the cases.

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¹GE Healthcare's respiratory-gating device is an optional accessory to the Discovery PET/CT 600 series devices.

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DOC1392830

PET-0287-05.13-EN-US