# MotionFree Brain on the SIGNA PET/MR AIR Edition

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With recent advances in PET spatial resolution, timing resolution and sensitivity, the limiting factor for image quality is often patient motion. This is particularly true in the head, where high-resolution reconstructions are performed and post-filtering is unnecessary with advanced reconstruction algorithms such as Q.Clear. A recent study found that in a cohort of 50 randomly selected clinical brain studies, 24% had high motion, defined as 2 mm displacement.[1]

Various motion tracking and correction techniques exist, with most using an external tracker, such as a camera, to track a marker on the patient's head[2] or to track the head directly.[3] The motion-corrected reconstruction is typically performed using a frame-based approach[4] or event-by-event motion correction.[5,6] These techniques do not fully address the clinical need to provide motion correction without additional burdens being transferred to the technologist or the time required for post-processing.

Data-driven approaches to estimate the motion have been proposed, which avoid the use of external hardware.[7-9] These generally have low temporal resolution, on the order of tens of seconds, due to the low signal-to-noise ratio (SNR) in PET imaging and the long reconstruction time for a single frame. Such low temporal resolution may lead to residual intra-frame motion blurring and inaccurate motion estimates. Methods that use temporal resolutions on the order of 1 second[7,8] typically use centroid-of-distribution or inertial tensor calculations. However, these approaches have not been implemented into widespread standard clinical use.

## Introducing MotionFree Brain

MotionFree Brain is a fully retrospective and data-driven motion estimation and correction approach for PET brain imaging[1,10,11] on the SIGNA™ PET/MR AIR™ that produces highly accurate (<1 mm) motion estimates with high temporal resolution (~1 sec) and no impact on the standard clinical routine. It requires no additional scan time and uses all the acquired data. The estimated motion is used for a full event-by-event, motion-corrected list-mode reconstruction, resulting in up to 60% improvement in quantitation accuracy and up to 1.5x improvement in volumetric accuracy of lesion size, as compared to non-motion corrected images in phantom testing.

## Ultra-fast reconstruction

The first step is to perform ultra-fast reconstructions of very short frames over the entire scan duration (see Figure 1). The duration of these frames is calculated to ensure a constant number of non-random events in each frame.[11] In a typical clinical scenario, this translates to frames of about 1 second duration each. A maximum-likelihood expectation-maximization (MLEM) reconstruction is performed with few updates and large pixels, without attenuation correction (which may otherwise bias the motion estimates towards the attenuation map) and without scatter correction (for speed considerations). Randoms and normalization corrections are applied. This produces a series of 3D volumes spanning the duration of the acquisition.

## Motion estimation

This series of images is then used to perform image-based rigid registration to estimate the motion. A reference image for this registration is created by averaging the frames corresponding to the time that the MR-based attenuation correction (MRAC) acquisitions were performed. This ensures alignment of the motion-corrected PET coincidence events with the MR-based attenuation map. The

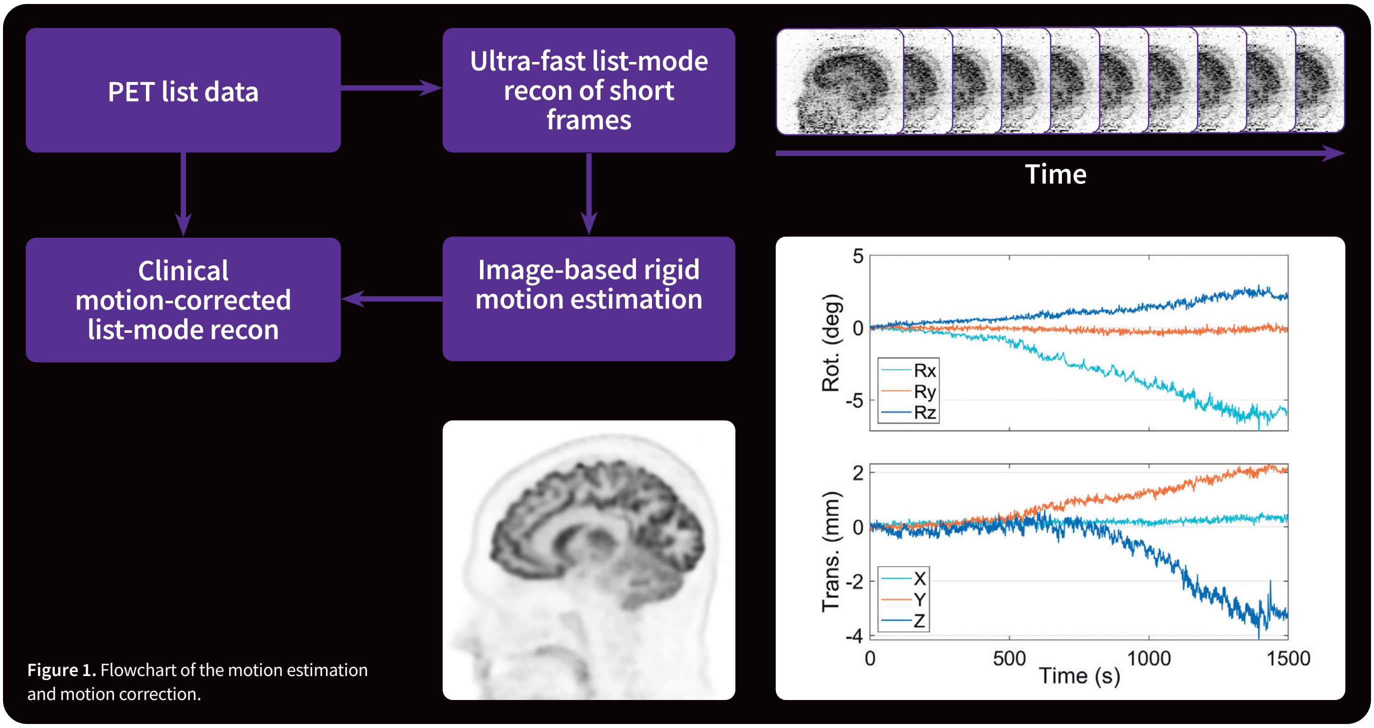


**Figure 1.** Flowchart of the motion estimation and motion correction.

accuracy of the motion estimates is less than 1 mm displacement as compared to a ground truth.[11] The current motion estimation approach is limited to cases where the tracer distribution can be assumed to be largely static throughout the acquisition. Thus, flow studies are not addressed.

For reporting purposes, each dataset is assigned to one of three possible motion groups based on the magnitude of motion. Two points located in image space at 70 mm anterior and 70 mm posterior to the brain center are chosen and moved according to the estimated motion parameters. The median absolute displacement from the reference is calculated for each point. The larger of these two medians is used as a metric to classify the data sets into three motion groups:

- Low – median displacement less than 1 mm
- Medium – median displacement between 1 mm and 2 mm
- High – median displacement greater than 2 mm

This group classification was chosen empirically based on our experience with many clinical data sets.

## Clinical reconstruction

Following the motion estimation, a full event-by-event, motion-corrected list-mode reconstruction is performed, including all PET corrections. A new reconstruction type, Event-Based, uses the list-mode data directly, and enables MotionFree Brain. The reconstruction can be performed with a standard algorithm (ordered subset expectation maximization, OSEM) or with regularization (Q.Clear) and uses a novel hybrid-space implementation of point spread function (PSF) modeling.[12] This new PSF model produces reconstructions of improved image quality with small pixels and is particularly impactful for Q.Clear reconstructions with lower β values.

New reconstruction options for Event-Based reconstruction include the ability to select from three slice thicknesses: standard (2.78 mm), half (1.39 mm), and thin (1.0 mm), the latter two providing a more natural visualization in sagittal and coronal images. For non-regularized reconstructions, the convergence level is specified as the total number of updates to the image; this number is analogous to the product of the number of iterations and number of subsets in sinogram-based (VUE Point) reconstruction.

## Case studies

Figure 2 shows the motion plots and reconstructions for two cases with high motion. The motion blur in the uncorrected images has been effectively removed in the corrected images. Additionally, since the reference position for the motion correction corresponds to when the MRAC was acquired, the PET is well-aligned with the attenuation map, leading to quantitatively accurate reconstructions.

A phantom study was performed using the Hoffman brain phantom. The phantom was manually moved during image acquisition in varying degrees of motion: slow and fast continuous motion, stepwise motion, and left in a stationary position. Multiple frames covering different portions of the acquisition were reconstructed with and without motion correction (see Figure 3).

Extensive blurring can be seen in some frames in the uncorrected images. In all frames, the motion-corrected reconstructions are essentially equivalent to each other and to the first frame, where the phantom was stationary. This indicates that the algorithm produces quantitatively accurate reconstructions regardless of the extent of the motion and does not degrade the images when there is very little or no motion.

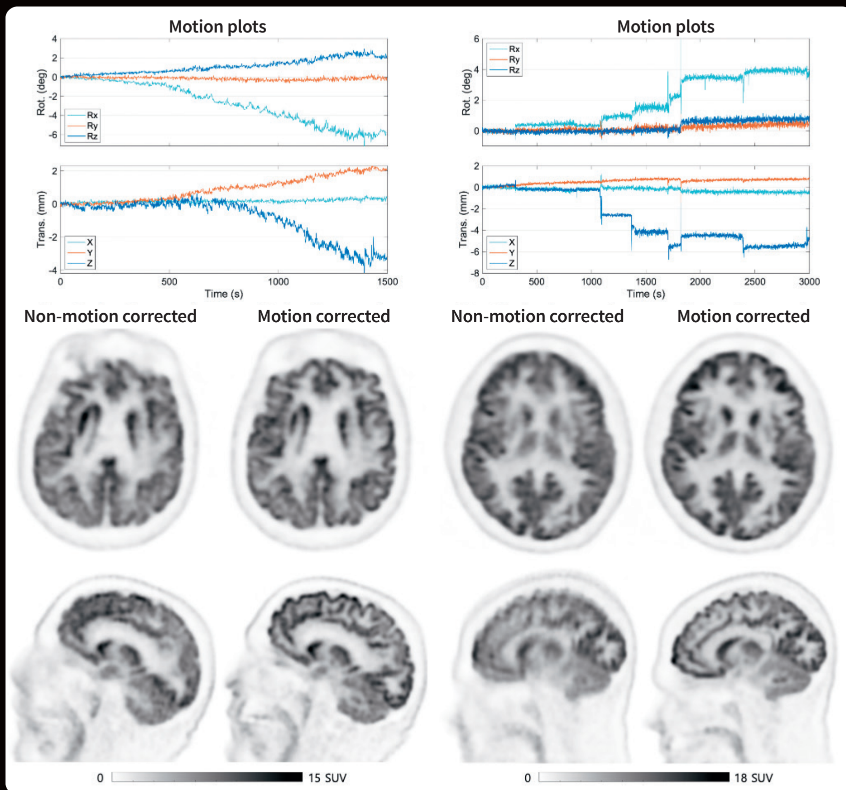


**Figure 2.** Two patient cases with high motion, reconstructed with TOF Q.Clear with a β of 100 and a pixel size of 1.17 x 1.17 x 1.39 mm. The motion blurring evident in the uncorrected images has been removed in the corrected images. Left: An $^{18}$F-FDG case with 386 MBq injected activity, 25 min acquisition. *Images courtesy of the University of Wisconsin-Madison.* Right: An $^{18}$F-FDG case with 407 MBq injected activity, 50 min acquisition. *Images courtesy of Mayo Clinic-Jacksonville.*

## Summary

The new motion-corrected PET reconstruction solution, MotionFree Brain, delivers a significant improvement in quantitative accuracy and volumetric accuracy of lesion size as compared to non motion corrected images, especially for small brain lesions. It is designed to improve the image quality of brain images by removing motion blur and ensuring alignment with the attenuation map without affecting scan time or clinical protocol.

MotionFree Brain is compatible with all SIGNA™ PET/MR and PET head reconstruction corrections and features, such as Q.Clear and zero-echo time (ZTE)-MRAC, and it is applicable to any tracer with a static distribution during the acquisition.

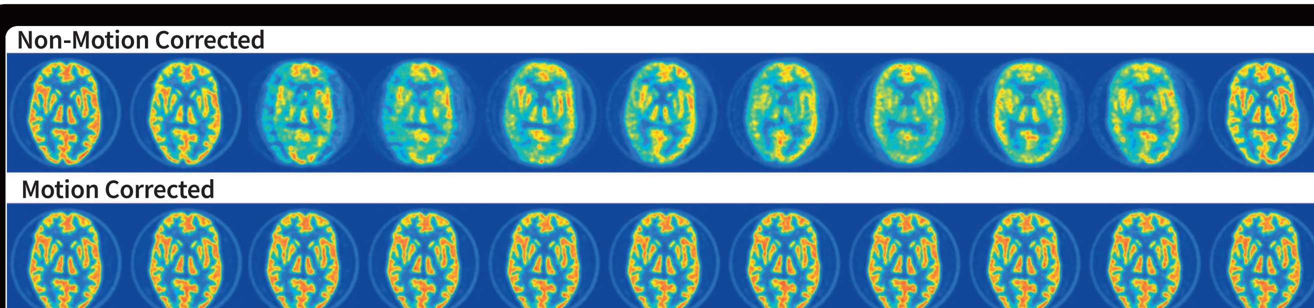


**Figure 3.** Reconstructions of various frames throughout the phantom study with varying degrees of motion. The phantom was stationary during the first frame (far left). In the non-motion corrected reconstructions (top) the motion blur is evident, while in the motion-corrected reconstructions (bottom) all the images are visually very similar.

**References**

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