Supplementary file 1 The pseudocode for the improved method

1: **Initialization**: $x^0 = ones$;
2: **For** $\boldsymbol{n}$**=1** to **MaxIter** (maximum iteration number, it is 50 in this work) **do**:
3: **MLEM image update from sinogram** $\boldsymbol{y}$:

$$\hat{x}_{MLEM}^{n+1} = \frac{x^n}{S} G^T \frac{y}{\bar{y}^n}$$

in which $\bar{y}^n$ is the expected projection calculated by (2);
4: **Image smoothing:**

$$\hat{x}_{j,Reg}^{n+1} = \frac{1}{2\omega_j^n} \sum_{k \in \aleph_j} \omega_{jk}(x^n)\left(x_k^n + x_j^n\right)$$

in which, $\aleph_j$ represents the neighborhood of the pixel j, the weight $\omega_{jk}(x^n) = \sum_{m=1}^{M} a_m \omega_{j_m,k_m}^{\psi}(x^n)$, here, the curvature $\omega^{\psi}(t) \triangleq \frac{\psi(t)}{t}$ is nonincreasing for $t \geq 0$, and $0 < \omega^{\psi}(0) < +\infty$;
5: **Pixel-by-pixel image fusion:**

$$x_j^{n+1} = \frac{2\hat{x}_{j,MLEM}^{n+1}}{\sqrt{\left(1-\beta_j^n \hat{x}_{j,Reg}^{n+1}\right)^2 + 4\beta_j^n \hat{x}_{j,MLEM}^{n+1}} + \left(1-\beta_j^n \hat{x}_{j,Reg}^{n+1}\right)}$$

in which $\beta_j^n = \frac{\beta \omega_j^n}{g_j}$, here, $g_j = \sum_{i=1}^{n_i} g_{ij}$; (In our work, the smoothing regularization parameter $\beta = 2^{-5}$)
6: **TV minimization:**

$$x_{TV}^{n+1} = x_{MLEM}^{n+1} - \beta_{TV} \times \nabla TV(x_{MLEM}^{n+1})$$

where $\nabla TV(x_{MLEM}^{n+1})$ represents the gradient of $TV(x_{MLEM}^{n+1})$, and β_{TV} represents the gradient step-size (in this work, $\beta_{TV} = 0.001$);
7: **FR step:**

$$x_{FR}^{n+1} = x^{n+1} + f^{n+1} \otimes v^{n+1}$$

in which $v^{n+1} = x^{n+1} - x_{TV}^{n+1}$ and f^{n+1} is calculated by (11);
8: **Update:**

$$x^{n+1} = x_{FR}^{n+1};$$

9: **End for**
10: **Return** The image estimate x^{n+1}.

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