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Supplemental material

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Supplemental Methods: Process of fuzzy C-means clustering

The function of fuzzy clustering is defined as follows:

\[ \sum_{j=1}^{N} u_{ij} = 1, \quad i = 1, 2, \ldots, D \]

where \( N \) is the number of clusters, which equals to 2 in our study (cystic and solid components); \( D \) is the total number of voxels in the tumor ROI; \( u_{ij} \) is the membership grade of the \( i \)th voxel in the tumor ROI in the \( j \)th cluster.

The objective function is defined as follows:

\[ J_m = \sum_{i=1}^{D} \sum_{j=1}^{N} u_{ij}^m \| x_i - c_j \|^2 \]

where \( J_m \) is the objective function; \( m \) is the fuzzy partition matrix exponent that controls the degree of fuzzy overlap and was set at 2 in our study (default setting); \( u_{ij} \) is the degree of membership of data point \( x_i \) in the \( j \)th cluster; \( x_i \) is the \( i \)th voxel in the tumor ROI; \( c_j \) is the center of the \( j \)th cluster and was calculated as follows:

\[ c_j = \frac{\sum_{i=1}^{D} u_{ij}^m x_i}{\sum_{i=1}^{D} u_{ij}^m} \]

Fuzzy clustering was performed as follows:

Step (1) \( u_{ij} \) was randomly initialized

Step (2) \( c_j \) was calculated as described above.

Step (3) \( u_{ij} \) was renewed according to the following formula:

\[ u_{ij} = \frac{1}{\sum_{k=1}^{N} \left( \frac{\| x_i - c_j \|}{\| x_i - c_k \|} \right)^{m-1}} \]

Step (4) The objective function \( J_m \) was calculated as described above.

Step (5) Steps (2) to (4) were repeated iteratively until self-improvement \( J_m \) was smaller than a specified threshold or until a specific number of iterations has been performed. In our study, the minimum improvement was set at \( 1 \times 10^{-5} \) and the maximum number of iterations was set at 100 (both were default settings).

Step (6) Each voxel in tumor ROI was classified as cystic or solid component based on the final \( u_{ij} \).