DCE-MRI DEFINED SUBVOLUMES OF A TUMOR FOR THERAPY ASSESSMENT

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Purpose

Analyzing the physiological parameter (PP) maps derived by fitting the dynamic contrast enhance magnetic resonance imaging (DCE-MRI) time series data to a pharmacokinetic (PK) model provides a useful tool for diagnosis and therapy assessment. However, using PK models to calculate the underlying physiology of a tissue of interest is time consuming and may involve a series of uncertainties (1) hence affecting the accuracy, reproducibility and repeatability of the PP. Also, the PP derived from the PK models may not accurately reflect the underlying physiology due to oversimplification in the PK models (2) and lack of physiological validation. The previous work has shown that an early reduction in the subvolume of the brain metastatic tumor with high cerebral blood volume predicted tumor response to radiation therapy (3). Hence, we aim to develop a model-free approach for delineating the response-driven subvolumes (3) of a tumor by directly analyzing the DCE-MRI data for therapy assessment and for adaptive treatment.

Method

DCE-MRI images were acquired prospectively from twenty patients who had brain metastases (45 lesions in total) and were treated by the whole brain radiotherapy (WBRT). All DCE curves from all lesions are normalized, temporally aligned and then concatenated to construct an N x T matrix wherein N denotes the total number of DCE curves. The principle component analysis (PCA) was then applied to generate T principle components (PCs). The projection coefficient maps of a lesion from the first M principle components that had the 99% energy of the original signals were calculated. To delineate the tumor subvolumes, we assigned each voxel of the tumor a probabilistic membership function belonging to a set of classes relating to the value of the projection coefficients (pc_i) and then calculated the related subvolumes. Changes in each pc_i-defined subvolumes of the tumors from pre-RT to 2 weeks (2W) after the start of WBRT were evaluated for differentiation of responsive, stable and progressive tumors using Mann-Whitney U test. Performance of the newly developed metrics for predicting responsive tumor to WBRT was evaluated by Receiver Operating Characteristic (ROC) analysis and compared with the subvolumes derived from the physiological parameter maps (3) and conventional metrics such as changes in gross tumor volume (GTV) or mean of the regional cerebellar blood volume (rCBV) or transfer constant (K^{trans}).

Results

Our results showed that the projection coefficient maps obtained from the first three principle components ($PC_{1\text{-}3}$) contain almost all response-related information of the DCE curves (Fig. 1). Our results revealed that a change in the subvolume of tumor with the high area under the DCE curve, relating to the first principle component, is the main factor to determine the response (area under the ROC curve (AUC) = 0.83) while the third component which corresponds to the derivative of the enhancement rate has a complimentary role (AUC = 0.88) (Fig. 2). In other word, we observed greater decrease in the subvolume of a tumor with the high area under the DCE curve and low derivative of the enhancement rate in responsive tumors than the stable ones ($p < 0.0018$), progressive lesions ($p < 0.0053$) or non-responsive tumors, either stable or progressive, ($p < 0.0005$). Our results also showed that both PCA-defined and physiological-defined tumor subvolume introduce better metrics for therapy assessment and guidance than the conventional metrics including a change in GTV and mean of the rCBV and K^{trans}.

Discussion & Conclusion

The PCA-defined subvolume of a tumor could predict the tumor response to therapy similar to the physiological-defined one. The PCA-defined subvolume can be delineated more quickly by decomposing the DCE curves of a tumor to the PCs, for supporting clinical decision making.

Reference

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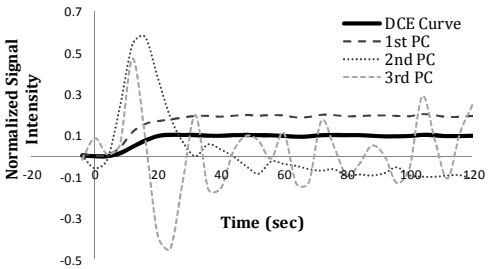

Fig. 1. An example of a typical DCE curve for a brain metastatic lesion and the first three principle components (PCs) resulted after applying PCA to the DCE-Matrix. The coefficient maps achieved by projecting the DCE curve onto these components relate to the area under the DCE curve, enhancement rate and the first derivative of the enhancement rate, respectively.

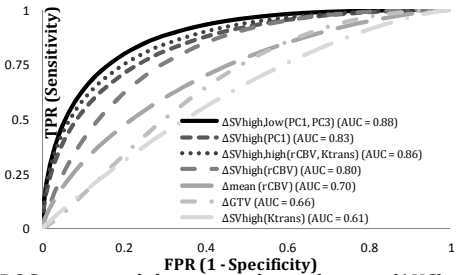

Fig. 2. ROC curves and the area under each curve (AUC) of different metrics for predicting responsive tumors; ΔSV: change in tumor subvolume from pre-RT to week 2; high/low: subvolume with high or low projection coefficient/physiological parameter value, GTV: gross tumor volume; rCBV: regional cerebellar volume; K^{trans}: transfer constant.