A Deconvolution Method for Dynamic Contrast Enhanced MRI of Cervix Cancer based on Dynamic Contrast Enhanced CT: Improved Correlations with Biological Markers

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Introduction

Characterizing cervix cancers often includes a quantitative description of their vasculature, including perfusion. Quantitative estimation of tumor perfusion relies on consideration of the arterial form of the contrast agent bolus, the arterial input function, AIF. On the other hand, accurate estimation relies also on ultra-high speed imaging to achieve adequate temporal resolution to sample the contrast agent kinetics. An MR imaging sequence, optimal for temporal resolution and tissue contrast suffered from lack of quantitative assessment of arterial input, rendering arterial input deconvolution initially impossible and thus allowed only semi-quantitative analysis of morphologic aspects of the dynamic enhancement. Since patients also receive dynamic contrast enhanced CT (albeit with a different injection of contrast agent), an approach was developed to allow definition of a tissue residue function for tumor based on the combination of dynamic MRI (without an AIF) and CT. The overall objective is to evaluate the improvement of such deconvolution derived parameters of the DCE-MRI in correlation with invasively determined biological measures of oxygenation (mO2) and interstitial fluid pressure (IFP), both prognostic indicators, in comparison to the semi-quantitative morphologic parameters.

Methods

Dynamic contrast enhanced (0.1 mmol/kg GdDTPA, Omniscan) MRI was performed through the cervix tumors of 36 patients. Dynamic contrast enhanced computed tomography (CT) was performed in the same patients. While tumor enhancement dynamics are readily visualized using a single slice high temporal resolution gradient echo MRI sequence, vascular enhancement (in particular the arterial input function, AIF) is not accurately documented. In this method, healthy tissue (e.g. muscle) MRI enhancement is used to estimate the MRI AIF, by deconvolution with the muscle tissue residue function, itself determined by deconvolution of dynamic contrast enhanced CT data, which has a measurable (although different to MRI) arterial input function. The estimated MRI AIF is then used to estimate the tumor residue function by deconvolution of the MRI-measured tumor signal change. This yields parameters of the tumor residue function derived from MRI. A 2-parameter model-based deconvolution (exponential function with amplitude, A, and decay rate, k) is used throughout to estimate residue functions. For comparison, non-deconvolved MRI measures of enhancement in tumor (peak, initial slope) were also compared with the biological markers, median oxygenation (mO2) and interstitial fluid pressure (IFP) obtained by multiple invasive samples.

Results

Using this method, MRI-derived deconvolution parameters, A and k both correlated highly significantly with invasive measures of tumor oxygenation, mO2 (A: $r = 0.70$, $p<0.01$; k: $r=0.65$, $p<0.01$). This compares with weaker correlations for the peak enhancement measure ($r = 0.09$) and the initial slope ($r = 0.16$). Importantly, the decay rate parameter, k, also correlated significantly with invasively sampled interstitial fluid pressure ($r = 0.38$, $p<0.05$), while measured parameters did not (peak: $r = 0.01$; initial slope: $r = -0.19$).

Conclusion

Using dynamic contrast enhanced CT to estimate the residue function of healthy tissue, e.g. muscle, allows estimation of the AIF of dynamic contrast enhanced MRI. With this estimated AIF, deconvolution of the measured MRI signal changes in tumor can be performed to obtain non-invasive estimates of important non-invasive prognostic indicators, oxygenation and interstitial fluid pressure that are significantly better than using morphological parameters of the measured MRI signal enhancement alone. This approach illustrates the combination of imaging technologies in such a way as to harness the separate desired characteristics of spatial and temporal resolution, soft tissue contrast and vascular sampling. Ongoing studies address the appropriate MR imaging sequence that has adequate temporal and spatial resolution, while permitting quantitative estimation of intravascular contrast concentration to obviate the CT component of this study and reduce opportunity for computationally-introduced uncertainty.