Perfusion: DSC & DCE Basics & Analysis

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Quantification of physiological parameters from contrast agent bolus tracking data is essentially a two-step procedure: In a first step, the time-resolved signal intensities are converted into time-resolved contrast agent concentrations by employing MR signal theory. The second step aims to derive the relevant parameters from the time-resolved concentrations by means of tracer-kinetic theory. Dynamic Susceptibility Contrast MRI (DSC-MRI) and Dynamic Contrast Enhanced MRI (DCE-MRI) are two strategies that exist for retrieving contrast agent concentrations.

Dynamic Susceptibility Contrast MRI

In DSC-MRI the first passage of a rapidly injected contrast agent bolus is dynamically monitored. The contrast-agent is confined in the intravascular compartment in the brain if the blood-brain-barrier is intact. The contrast agent increases the transverse relaxation rate of the water proton spins, leading to a signal drop as it passes through the vascular system.

It is normally assumed that a linear relation between the change in the transverse relaxation rate, ΔR_2 estimated from the measured signal, *S(t)* and the concentration of the contrast agent, *C(t)* exists i.e.:

$$-\left(\frac{1}{TE}\right)\cdot log\left(\frac{S(t)}{S_0}\right) = \Delta R2 = k\cdot C(t), \quad [1]$$

where S_0 is the pre-bolus baseline signal, and *TE* is the echo time, and *k* is the constant of proportionality. In most practical applications, the proportionality constant *k* is unknown and assumed to be equal for both tissue and blood [1].

The basic tracer kinetic model is given by:

$$C_t(t) = CBF\ R(t)\otimes AIF(t) = CBF\int_0^t R(\tau - t)AIF(\tau)\,d\tau, \quad [2]$$

where *CBF* is the cerebral blood flow, $C_t(t)$ is the concentration time measured in a tissue. The residue function, *R(t)*, describes the fraction of tracer still present in the vasculature at time *t* after an infinitely short injection of tracer. The *AIF*, arterial input function, is the concentration-versus-time curve in a tissue-feeding artery. The cerebral blood flow can be determined by deconvolution, as the initial height of the product of *CBF* and *R(t)*, due to the fact that R(0)=1.

The cerebral blood volume (CBV) is derived from the ratio of the areas under $C_t(t)$ and *AIF(t)* respectively,

$$CBV = \frac{\int_0^t C_t(t)dt}{\int_0^t AIF(t)dt} \quad [3]$$

The mean transit time (MTT) is calculated by using the central volume theorem i.e. MTT=CBV/CBF [2]. MTT can also be calculated using Zierler's area to height relation [3]:

$$MTT = \frac{\int_0^\infty R(t)dt}{\max[R(t)]} \quad [4]$$

Dynamic Contrast Enhanced MRI

In DCE-MRI dynamic imaging with a T1w sequence following intravenous injection of a partially diffusible tracer applied to situations with BBB leakage is performed [4].The presence of the contrast

agent leads to an increase of the longitudinal relaxation rate and the concentration C is proportional to the contrast-induced change in longitudinal relaxation rate, i.e. $C=(1/r_1)\cdot\Delta R_1$ where r1 is the longitudinal relaxivity of the contrast agent.

To extract relevant parameters from experimental data, curve-fitting approaches are often employed. Since a large number of unknown parameters might generate unreliable estimates, pharmacokinetic models used in DCE-MRI must be relative straightforward. It is therefore common to include the effects of several physiological parameters into one model parameter. The volume transfer constant K^{trans} is such a combined parameter. The tracer uptake rate in tissue can be expressed as

$$\frac{dC_t}{dt} = K^{trans}\left(C_p - \frac{C_t}{v_e}\right), \qquad [5]$$

where C_t is tissue tracer concentration, C_p is tracer concentration in arterial blood plasma and v_e is the fractional extravascular extracellular volume. The physiological interpretation of K^{trans} depends on the relationship between capillary permeability and blood flow.

The differential equation in Equation 5 has the following solution (if C_p=C_t=0 at t=0):

$$C_t(t) = K^{trans}\int_0^t C_p(t')e^{-\frac{K^{trans}}{v_e}(t-t')}dt' \qquad [6]$$

The equation states that the acquired dynamic change in tissue concentration is modelled as a convolution of an exponential kernel and arterial blood or plasma concentration curve (i.e. AIF). If the blood volume cannot be neglected, an extended model is often applied by employing an additional term in Eq. 6, including the fractional plasma volume v_p and the arterial plasma concentration over time [4].

$$C_t(t) = v_p C_p(t) + K^{trans}\int_0^t C_p(t')e^{-\frac{K^{trans}}{v_e}(t-t')}dt' \qquad [7]$$

References

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