The Effect of Partial Volume on the Calculation of the Magnetisation Transfer Ratio (MTR)

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Theory

MTR is commonly defined as

$$MTR = (Bu - Bw)/Bu = 1 - Bw/Bu \qquad (1)$$

where Bw and Bu are the signals from the MT-weighted and un-weighted images, respectively. For a voxel containing only brain tissue (white or grey matter), (1) gives the MTR for brain. In CSF, MTR is zero. We now consider a voxel which contains a proportion of brain tissue, p, ($0 < p < 1$), the rest (1-p) being CSF. The signal in the un-weighted image is,

$$Su = pBu + (1-p)C \qquad (2)$$

where C = the signal from a voxel that is full of CSF, and the signal in the MT-weighted image is

$$Sw = pBw + (1-p)C \qquad (3)$$

Ma, the apparent MTR in the presence of partial volume, is calculated from the equivalent of equation (1):

$$Ma = 1 - Sw/Su$$

$$Ma = 1 - (pBw + (1-p)C)/(pBu + (1-p)C) \qquad (4)$$

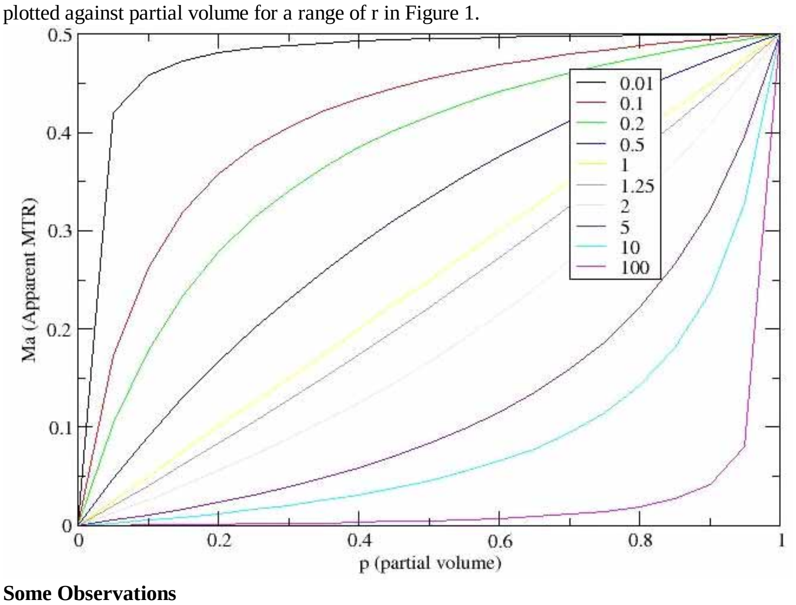
Dividing top and bottom by Bu gives:

$$Ma = 1 - (pBw/Bu + (1-p)C/Bu)/(p + (1-p)C/Bu) \qquad (5)$$

If we now define r = C/Bu as the ratio of signal in an un-weighted image of a pure CSF voxel and a pure brain voxel then r defines the intrinsic contrast (pd-weighted or T1-weighted) of the underlying image sequence. We can also define Mb = 1-Bw/Bu as the MTR of a pure brain voxel. Mb represents the amount of MT-weighting of the sequence. We can then write (5) as

$$Ma = 1 - (p(1-Mb) + (1-p)r)/(p + (1-p)r) \qquad (6)$$

Now we can compare Ma to the true MTR value, Mb, as p varies, using a typical value of Mb(=0.5). The apparent MTR, Ma, is plotted against partial volume for a range of r in Figure 1.



Some Observations

Almost any sequence that measures MTR will underestimate MTR as partial volume effects increase. The line r=0.01 would be for a sequence with very low CSF intensity which would return an accurate value of MTR until p is small. r=10 would give a very poor estimate of MTR for a wide range of partial volumes. r=1 also represents the change in signal with partial volume of an un-weighted scan: sequences which have line below and to the right of r=1 actually amplify the effect. r=1.25 corresponds to a typical 3D-MTR sequence, and it can be seen that it slightly amplifies the effects of partial volume.

Conclusions

MTR sequences underestimate MTR in the presence of partial volume with CSF. If a group of normal controls are compared to a group of patients who have atrophic brains, then an apparent drop in MTR in the patient population will be measured. This effect must be considered a confound for MTR imaging.