Gadolinium does *not* increase the signal, but the speed of MRI

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You may have heard that gadolinium-based MRI contrast agents can enhance or increase the signal of tissue. This is generally a good description of what's going on. Here, however, I would like to argue why this is – strictly speaking – *not* true: contrast agents cannot really increase the signal available for MRI.

Some basic facts first: gadolinium-based contrast agents are very frequently used in clinical MRI to improve the image contrast as illustrated in the following example.

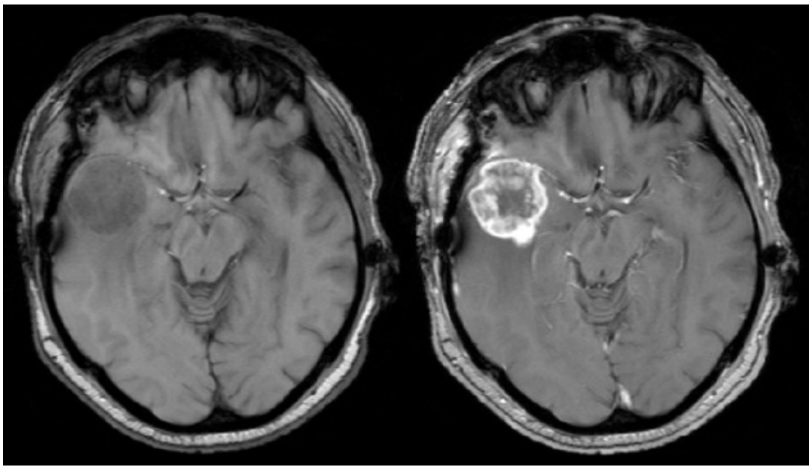

Figure 1: T_1-weighted MRI without (left) and with (right) contrast agent

An important fact about (conventional) MRI contrast agents is that it's never the contrast agent itself that is visible in MR images. Instead, the contrast agent changes the behavior of the atomic nuclei in its neighborhood – in clinical MRI, these are the nuclei of hydrogen, i. e. the protons. As a consequence, these protons now appear brighter in T_1-weighted MRI than protons which are not influenced by the contrast agent.

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So, apparently the proton signal *is* increased by gadolinium? Yes, *apparently* ... Actually, there is always a maximum signal that is available for MRI and that depends on three major factors:

- the number of available protons, which is related to the proton density ρ of the tissue: the more protons (per voxel), the higher the signal;
- the magnetic field strength B_0: the higher the field strength, the higher is also the (thermal) nuclear magnetization and, hence, the measured signal;
- the receiver coil: the more efficient the receive system (the radio-frequency coil), the higher the signal.

But the presence of a contrast agent *does not* increase this maximum signal.

Instead, we are cheating: First, we artificially decrease the MRI signal by choosing short repetition times (TR). And only afterwards, a certain part of this suppressed signal is recovered due to the influence of the contrast agent! This is illustrated in the following diagram:

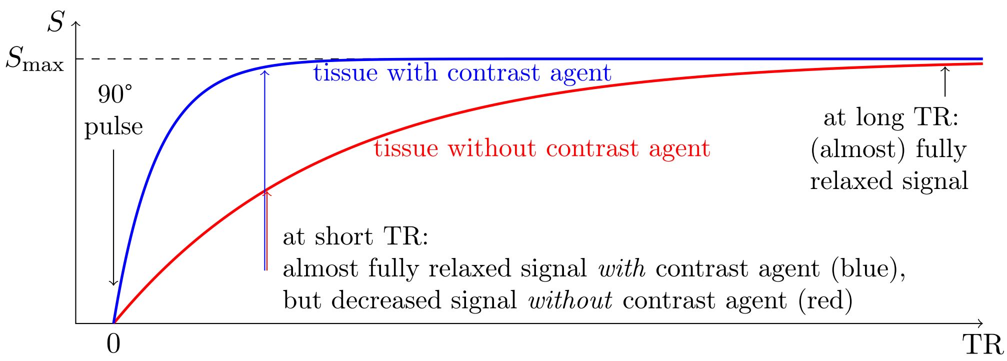

Figure 2: Effect of contrast agent on MRI signal

Obviously, the *maximum* signal, S_{max}, with contrast agent is exactly the same as the *maximum* signal without contrast agent – but we can obtain this maximum signal considerably faster (i. e, at shorter TRs). That's why gadolinium can be described to increase the speed, but not the MRI signal. In agreement with this observation, no additional gadolinium-induced signal enhancement can be found in proton-density-weighted MR images (with very long TRs). But, hypothetically, if contrast agent could be distributed homogeneously in the tissue (which in reality is not possible), then PD-weighted MRI could be accelerated by using shorter TRs without changing the contrast.

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