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MRI: Time Is Dose—and Money and Versatility

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MRI examination time is equivalent to x-ray CT radiation dose. Just as we limit dose for CT examinations, we suggest that MRI examination time should be limited. Making MRI examinations shorter would make them less expensive, enable more MRI examinations because more people could be imaged, and extend the range of diagnostic procedures that can be done routinely by MRI.

Spatial resolution for x-ray CT is governed by signal, noise, and contrast among adjacent tissues, which can be characterized by a contrast-detail-dose plot [1]. More dose gives better photon counting statistics. This in turn leads to higher signal-to-noise ratio (SNR), improved contrast-to-noise ratio (CNR), and better discrimination among tissues with slightly different x-ray opacities.

However, radiation dose is limited in medical x-ray imaging. Because of that, many additional protocols and studies cannot be done, even though additional imaging might provide information about the patient that could affect the treatment outcome.

Manufacturers have developed advanced multidetector row CT scanners with improved collimated x-ray sources and multidetector row arrays that can deliver the allowed dose for specific image types in subseconds [2]. Most CT examination time is spent positioning and aligning the patient.

MRI is fundamentally limited by the simple fact that maximum magnetization of the spin system, in this case the hydrogen protons in body tissues, is established by the strength of the static magnetic field in the MR scanner. Maximum signal is obtained when the magnetization is tipped 90° into the transverse plane from the direction of the static magnetic field. Yes, there are important pulse sequence factors that can increase or decrease SNR and CNR (further discussed below). But there is no way to speed up the process by, say, increasing the radiofrequency power. Better SNR and better CNR are achieved by imaging for longer time, and averaging the (noisy) signals, in which case SNR and CNR are proportional to the square root of time.

Thus, for image quality, *time* plays the role in MR that *dose* serves for CT, and *contrast-detail-time* curves for MRI [3,4] are the analogue to *contrast-detail-dose* curves for CT [1].

We suggest that there is a further connection: limiting the time to carry out an MR examination is equivalent to limiting a CT examination to stay within an allowed dose.

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We have done brief surveys at Johns Hopkins and some surrounding MRI practices in Baltimore and find that routine imaging times for a wide range of examinations vary from 20 to 60 minutes. Each protocol frequently includes 5 or more pulse sequences.

So what makes 20 to 60 minutes of imaging time, plus at least a few minutes of patient handling, the right length for an MRI examination? We have discussed this question with many physicians and MR scientists, and there is indeed general agreement: nobody knows why. In fact, there are practices that do examinations in 10 to 15 minutes, but some of them say that they are doing “the basics”; that is, they would do more if they could, but they are deliberately being minimal and cheap. We have seen people who have developed individual, fast pulse sequences who add more pulse sequences to their protocols until they push their examination times into the range of 20 to 60 minutes.

It would seem that long MRI examination times are a consequence of a strength of MR, the many parameters—T1 and T2 relaxation times, proton density, diffusion, perfusion, flow, and others—that go into making MR images and the huge array of pulse sequences and range of variables—voxel dimensions, slice thickness, flip angles, number of echoes, spin echoes, gradient echoes, echo time, repetition time, and more—constituting these pulse sequences. All these possibilities are an incentive to do more and see more. The actual 20-minute to 60-minute times may be set by a sensitivity to what patients can tolerate when they are stuck in a small, noisy tunnel.

How can we approach this “optimization” problem and get the best answer? First, we have to acknowledge that the MRI process is so complicated that there aren’t going to be perfect protocols and that we cannot answer the questions raised using purely analytic methods. We can certainly learn a lot from the steady advance of MRI sequences and clinical practice over the past 30 years. To paraphrase Garrison Keillor, we are going to have to look for a “pretty good” solution. Our outline of pretty good is shown below:

Pretty good MRI examination principles

- Examinations should consist of 10 minutes of imaging plus 5 minutes of patient handling time, for a total cycle time of 15 minutes.
- Pulse sequences should acquire 3-D data that can be reformatted in any plane.
- Pulse sequences should acquire and use multiple echoes or use SSFP to maximize SNR and CNR.
- Optimized multicoil arrays should be used to maximize SNR.
- Prescan and scanner parameter adjustment (RF transmit amplitude, RF receive gain, tuning) should be kept to <30 seconds per patient.
- Scans should be done using a high-quality imager at fields ≥ 1.5 T.

Note: CNR = contrast-to-noise ratio; RF = radiofrequency; SNR = signal-to-noise ratio; SSFP = steady-state free precession.

Ten-Minute Imaging and Fifteen-Minute Cycle Times

Many individual pulse sequences making up MRI protocols last about 5 minutes, so 10 minutes would allow 2 different pulse sequences or perhaps 3 if we squeeze a bit. It will also be helpful to use parallel imaging [5,6] to speed up image data acquisition.

3-D

Imaging protocols now frequently use multislice 2-D imaging to cover a volume. This is often done with in-plane resolution substantially finer than the slice thickness. Therefore it is often deemed necessary to repeat, say, a transaxial 2-D multislice scan in the coronal and sagittal directions to look at the target region in different planes, thus tripling the image acquisition time. Three-dimensional sequences have certain technical problems (eg, a larger dynamic range of signals [7] and Fourier leakage [8]), but manufacturers have done a good job of solving these problems.

Multiple Echoes and Steady-State Free Precession

It is important to maximize SNR and CNR. Fundamental to that goal is exploiting all useful available signal. In the early days of MRI, often a single spin or gradient echo per excitation was used to form an image. However, once the transverse magnetization is generated, it decays with time constant T2. So more signal can be generated by using multiple spin or gradient echoes. These multiple echoes can be associated with multiple phase encoding steps to acquire further image information. This was most successfully integrated into MRI by rapid acquisition with relaxation enhancement (RARE) and its many descendants and improvements (eg, turbo spin echo, fast spin echo, SPACE). Steady-state free precession takes individual signals in rapid succession, with time intervals comparable with multiple spin echoes, and has SNR and CNR comparable to that of multiple-spin echo sequences. These two approaches are likely to be the general classes of pulse sequences that give maximum SNR and CNR per unit time, sometimes called SNR or CNR efficiency [8].

Optimized Multicoil Arrays to Maximize SNR

This is fairly obvious but essential. Volume coils for excitation may be acceptable, indeed preferred, but should not be used for maximum receive sensitivity.

Prescan Minimization

The number of prescan procedures, and the time they take, has been steadily decreasing, which is good. Once the transmit amplitude has been determined for an initial pulse sequence, it should not be changed for subsequent pulse sequences. Patients should be positioned using the laser marker alone, and the field of view should be generous enough so that a scout image is not needed. Tuning should not be necessary. It is possible to minimize such instrumental tweaks.

Ten-Minute Scan and Fifteen-Minute Examination: The Project

Given that many, if not most, pulse sequences last about 5 minutes, it will be possible to do 2 to 3 of these in the 10-minute imaging period. Optimization should be done one protocol (focusing on a specific imaging procedure) at a time. A protocol following the guidelines above should be used first on normal volunteers. A number of parameters should be varied separately and jointly and the resulting images studied to find the relative merit of various combinations and to create SNR and CNR surfaces as a function of these multiple parameters.

We have not listed, nor do we know, all the details of such a search. However, we are confident that with cooperation among physicians, physicists, and system engineers, these relative merits can be quantified.

High-Quality Imager

Signal-to-noise ratio and CNR are roughly proportional to static magnetic field strength. Considering that we are suggesting time restriction, it is therefore desirable to use a system operating at ≥1.5 T.

Our suggestions will be most easily implemented for simple morphologic imaging. Doing everything in 10 minutes, including enhanced imaging techniques (biochemical imaging, enhanced contrast imaging, diffusion, and more) will be challenging.

The Payoff

The amortization of the MRI system, facilities rent, and technologist costs are a substantial part of MR examination costs. Changing the MRI paradigm by speeding up examinations by a factor of 2 to 3 could significantly reduce those costs and make MRI examination charges more comparable with CT charges. Numerous examinations that are now done by CT instead of MR because of lower CT costs and faster CT examinations, even when MR conspicuity is equal or better, could switch to MR and have the additional benefit of saving radiation dose.

We need to reduce medical costs and run a leaner, more efficient medical process. Shorter MR examinations would contribute to this goal. More (cheaper) MR examinations could be an important contribution to diagnosis and to medical cost containment.

The Conversation

We would be happy to hear views from scientists, engineers, and physicians on how to make MRI as efficient and cost effective as possible. Let's discuss!

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