

MRI FOR THE THIRD WORLD

Daniel Kleppner

Whole-body magnetic resonance imaging appeared on the scene about 1980. The early pictures were crude, little more than shadowy sections of brains and hands, but they were nonetheless breathtaking because they were generated not by invasive radiation but by the feeble magnetization of precessing protons. Compared with those vague images, today's pictures are spectacular: sections of the head that show details of the brain and eye with a resolution of 5 mm^3 , or sections of the torso that vividly display the organs and can even reveal the details of a collapsed vertebral disk. Magnetic resonance imaging can not only generate images of blood vessels but in some cases measure the velocity of the blood that flows within them. Employed for spectroscopy instead of spatial imaging, the apparatus can reveal the biochemistry of tissues and even the functioning of organs. Accompanying these spectacular advances, however, are spectacular prices. A state-of-the-art mri installation costs several million dollars; its operating costs can be a quarter of a million dollars a year. But to a patient suffering from a brain tumor, mri can be priceless. To all but a tiny fraction of the world's population, however, mri might as well not exist, because its cost is out of sight.

Accompanying the progress toward ultrahigh-resolution mri and ever more ingenious diagnostic technologies is a modest but nonetheless impressive thrust toward what might be called low-resolution mri. The motivation for this thrust is that the price is also low. The diagnostic powers of this brand of mri are unimpressive compared with the state of the art, but compared with the alternative for the third world—nothing—they are outstanding. They are adequate, for instance, for deciding

whether or not a headache is the first symptom of a brain tumor, for spotting numerous other types of tumors and for revealing whether blood is accumulating between the brain and the skull following a head injury.

Most of the cost of an mri apparatus is the cost of its magnet. The signal-to-noise ratio of an mri image varies roughly linearly with the strength of the field, so that to a large extent high field is the name of the game. Modern mri machines use fields up to 2 tesla. A magnet that provides a 2-T field with an aperture matched to the dimensions of a human body is little more than a trifle compared with the magnets in the cavernous halls of CERN or Fermilab. But if the apparatus is to fit inside the hospital rather than the other way around, its construction presents a challenge. Most mri machines use superconducting magnets, though permanent magnets and electromagnets are sometimes employed. All of these are expensive, and their installation cost is frequently high. In principle a copper-coil solenoid could be used, but it would be a nightmare. The magnet would consume megawatts of power and require heroic measures for stabilization. In contrast, a superconducting magnet consumes essentially zero power, and in its persistent mode it is intrinsically stable.

The crucial step in making whole-body mri practical for poor countries is to find an inexpensive substitute for the magnet. If it were possible to operate an mri machine at a field of only 0.02 T, a relatively cheap copper-coil magnet would be practical. However, a naive estimate of the signal-to-noise ratio of an image in such a field compared, for instance, with that in a 0.5-T field yields a prohibitive loss—a factor of 70. Nevertheless, there is some reason for hope.

I learned about an effort to make mri technology available to the third world during a recent visit to Brazil. Possibly the effort is flourishing there because Brazil itself is caught between the first and third worlds. Most of the Brazilian scientists I know

are concerned about the gap, and I sense in the community a general commitment to addressing social problems one way or another. At any rate, low-field mri projects are under way at two universities that I visited, the Institute of Physics and Chemistry in São Carlos (a branch of the University of São Paulo) and the University of Pernambuco in Recife. The project in Recife is directed by Mario Engelsberg, who is my chief informant on ultralow-field mri. As he explained, the possibilities of ultralow-field mri have been known for some time. Pioneering work was carried out in 1985 by R. E. Sepponen and his collaborators at the University of Helsinki, who generated a brain image in a field of 0.02 T. Instrumentarium, a Finnish company, now produces a commercial ultralow-field mri machine. However, the potential of ultralow fields for making a relatively inexpensive whole-body imaging machine has yet to be realized.

Two factors brighten the otherwise dim outlook for ultralow-field mri. First, the longitudinal magnetic relaxation rate for protons in tissue becomes larger below 0.1 T, permitting a relatively fast pulse repetition rate and thus a larger signal in a given time. Second, because the field is small, so are its inhomogeneities. As a result, one can use smaller applied field gradients to attain the same image resolution, and this permits a narrower system bandwidth. Together, these consequences of ultralow fields reduce the loss in signal-to-noise ratio from a factor of 70 to about a factor of 8. A factor of 8 is still bad news, but it is not necessarily prohibitive. Now let's look at the good news.

A 0.02-T system can be cheap to build and cheap to operate. It is small enough to fit into an office, its installation costs are negligible, it requires only 10 kW of power, and it can be portable. It avoids special siting requirements, and it avoids the need for liquid helium that prohibits superconducting mri machines in most of the world's smaller cities. Also, there are

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important safety considerations. Near a 2-T solenoid, a wrench or other ferromagnetic object can suddenly turn into an awesome projectile. With low-field mri, however, life support equipment such as an oxygen cylinder or a monitoring device can be placed safely next to the magnet.

Finally, in some applications ultra-low-field mri is actually more sensitive than conventional mri. Much of the information in an mri image comes from the variation of the magnetic relaxation rate with the chemical environment in the tissue. It turns out that this variation is actually greater at low fields than at fields above 1 T. In one case, for example, low-field mri turned out to be superior to conventional imaging for differentiating between an acute hemorrhage and a chronic condition, that is, between new blood and old blood.

Engelsberg's project provides a case study in achieving big things on small budgets. The frame and patient carriage of an mri apparatus must be nonmagnetic. Rather than use stainless steel or aluminum, he built his apparatus from one of Brazil's most abundant nonmagnetic materials—hardwood. The coils are wound on a fiberglass form provided by one of Recife's surfboard manufacturers. Magnetic resonance imaging requires elaborate sequences of rf pulses, pulsed gradients and signal gates. In Engelsberg's machine these are generated by a microcomputer using homemade software designed with a CAD system. In fact, essentially everything is homemade except for the power supply and the rf transmitter.

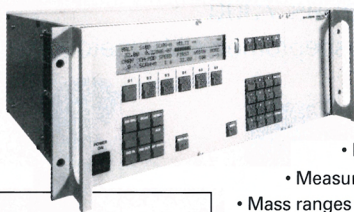
The challenge now is to convert the prototype into a commercial device. The project is being carried forward with support from the federal government and the State of Pernambuco under a program to stimulate high-technology industry. A manufacturer of medical instrumentation has been working with Engelsberg's group. The economy has recently taken a nosedive, however, and loans to industry for such ventures have become scarce. So for the moment, the project is in limbo.

Whatever the outcome of the current financial crisis, the development of mri for the world's have-not nations demonstrates that scientists don't need to settle for mere good intentions to help humanity. There are abundant opportunities for physicists with imagination, good brains, good hearts and lots of energy.

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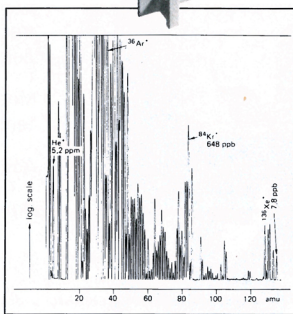
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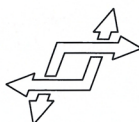
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