Strong Magnets

As radiologists, we are familiar with the use of magnets to generate images that are now a mainstay of radiology. MR imaging is still evolving, with ever increasing magnetic field strengths. Nowadays, 3T magnets are commonplace, with 7-9T research systems in existence and 11T human systems under development. Most of us know that smaller bore magnets, capable of higher field strengths, are also used for MR imaging on samples ranging from humans to animals and isolated tissues down to single cells. MR spectroscopy itself, used mainly for elucidating the chemical content of materials and solutions, continues to find applications in biological research and human studies. As neuroradiologists we forget that MR imaging is only 1 part of an extensive range of applications for magnets, and that at facilities throughout the world, an astounding variety of magnet systems are being developed and applied for a wide range of uses outside the realm of clinical medicine. In this perspective, I give a short overview of some of these facilities.

Tallahassee, the capital of Florida, is located in the center of that states' panhandle, just south of its border with Georgia. In a city of about 200,000 inhabitants, between its regional airport and downtown, one finds the National High Magnet Field Laboratory (or, for short: Mag Lab). This facility comprises a group of angular, clean, bright buildings (covering over 370,000 sq ft), making it the largest facility of its kind in the world. The Mag Lab attracts about 1000 visiting scientists every year. Before the Mag Lab, the largest and most prestigious laboratory of this sort was at the Massachusetts Institute of Technology (MIT). The Boston lab was named the Francis Bitter Laboratory in 1967, and in the 1970s began its operations and obtained funding from the National Science Foundation. Today, it houses several 17.6T magnets and a 21T unit, all dedicated to research.[1] During the 1980s, 3 institutions—Florida State University (FSU), Los Alamos National Laboratory (Pulsed Field Facility), and the University of Florida—proposed the creation of Mag Lab to the National Science Foundation. To the surprise of the folks at MIT, the state of Florida was awarded the right to build what is today the most complete research ultra-high-field MR facility in the world. Completed on time, the center was dedicated by former Vice President Al Gore in June 1994. Mag Lab research includes physics, biology, bioengineering, chemistry, geochemistry, biochemistry, materials science, and engineering. It also houses the Center for Research and Learning, which serves as its education arm.

When Mag Lab opened, it housed a 27T magnet, at that time the strongest in the world. One year later, a 30T resistive magnet rivaling hybrid systems found at MIT and the Laboratoire National des Champs Magnétiques Intenses in Grenoble, France, was ramped up. In France, powerful research magnets producing continuous fields are housed in Grenoble, whereas those producing pulsed and even higher strengths are housed in the Toulouse facility (see below).[2] Similarly, the Mag Lab facility houses the continuous magnets in Tallahassee, while the pulsed systems are at Los Alamos. By 1998, Mag Lab total investment in infrastructure from all sources was US $192 million, including the creation of a resistive magnet to be deployed to the International Space Station, in addition to outside contracts such as building a 30T unit in Tsukuba, Japan, which is the highest field resistive magnet in Asia.

In 1999, Mag Lab made it into the *Guinness Book of World Records* when it built a continuous field 45T hybrid MR system. Pictures of this apparatus show it to resemble some infernal machine from Nikola Tesla's imagination (such as the ones built during his Colorado years) or, perhaps, the core of a nuclear reactor. Several stories high, this vertical magnet has a bore opening about the size of a golf ball (3.2 cm). Tiny samples of the materials to be interrogated descend into the bore via a probe. To reach such enormous magnetic strength, the magnet is of hybrid design—that is, resistive and superconductive at the same time. So in reality, it is 2 magnets in 1. The inner magnet is a resistive one surrounded by a superconductive one.

One can request magnet time by sending in a short 3-page description of a project, and a committee will decide which magnet and which facility is most appropriate for each individual experiment. Generally, researchers are granted 1-week-long periods, so they work around the clock to complete their projects during those short 7 days. Although the larger magnets are expensive to run (about US $4000–5000 per hour) magnet time is paid for by Mag Lab and is thus made available for users free of charge. Additional support such as computers, cryogenics, an electrical shop, and so forth is also available. A list of visiting scientists (including names, parent institutions, and title of project) is available on-line.[3] At the Tallahassee site most work is in the materials sciences with personnel from chemistry, physics, astronomy, or engineering departments. Most biology and medicine studies are performed at the University of Florida site. This last site also houses a Mag Lab supported high B/T facility, which conducts experiments in strong magnets at very low temperatures close to absolute zero (−273 Kelvin).

An interesting series of lectures is held at Mag Lab throughout the year, and the program and a short explanation of it are also found on their Web site. Among the different topics, one can find a vodcast by Sir Harry Kroto, a Nobel Prize winner for chemistry, chatting about great minds of the 16th and 17th centuries. Most interesting, he states that we are not in the midst of a scientific revolution but rather of a technical one. Mag Lab has received many accolades and does not rest on its laurels; this year they completed construction of the highest field strength (36.2T) resistive magnet in the world.

The Magnet Lab at Los Alamos National Laboratory also houses impressive equipment. Pulsed magnets there are capable of generating fields of up to 100T for very short periods of time. A single turn magnet can generate up to 300T for a 6-μs burst but is destroyed by explosives in the process of doing this. For years, magnet engineers have thought of 100T as the Holy Grail for non-destructive magnets. Materials used at these field strengths have enormous tensile strength since the strong magnetic fields result in energies equivalent to 200 sticks of dynamite.[4] Eight other magnets, the weakest being 17T, are currently functioning at Los Alamos. The facility looks exactly like what one expects to find in Los Alamos: boxy, brown, secretive-looking, nondescript buildings. Although nationally sensitive work there is off limits to the public, the Mag Lab part of the facility is open and accessible. Los Alamos National Laboratory is located in New Mexico, and the largest nearby town is White Rock; the better known Santa Fe is about 35 miles away. The entire Los Alamos site is a group of about 1800 buildings spanning 35 square miles.

The third and complementary site of this effort resides at the University of Florida in Gainesville, a city of about 130,000 inhabitants located in northern Florida about 100 miles from Disney World. The University is quite large with over 51,000 students and nearly 5000 faculty members. There the Mag Lab facility is located in the McKnight Brain Institute and involves MRI and MR spectroscopy, hence its name: the Advanced MRI and Spectroscopy (AMRIS) facility. The Institute is one of the world's biggest neuroscience research operations with a faculty of over 300. There one finds 7 magnets, including an 11T unit with a 40-cm bore and a whole-body 3T unit. Unfortunately, their Web site seems a bit anachronistic and simple and does not offer a great deal of information.

The Laboratoire National des Champs Magnétiques Intenses in Grenoble is one of the main institutions belonging to the Centre National de la Recherche Scientifique in France and is open to researchers from the 27 states of the European Union and adjacent countries such as Turkey, Israel, and others. Grenoble is located in southeast France, close to the Italian border and at the foot of the Alps, a location that has earned its nickname: the Capital of the Alps. Housed in this laboratory is a 35T magnet with a 34-mm-wide bore The Laboratoire National des Champs Magnétiques Intenses in Toulouse is found in southwest France. Because Toulouse is also known as La Ville Rose, it is not unexpected that its building has pinkish tones. There one finds magnets capable of 45T or 60T during pulses as long as 1 second in duration and of 150T–260T for only microseconds. Both of these facilities form part of the larger EuroMagnet Net II (Research Infrastructures for High Magnetic Field in Europe).[5]

Other facilities that are part of EuroMagnet Net II include the High Field Magnet Laboratory in Nijmegen, the Netherlands.[6] This laboratory is housed in a beautiful modernist building that has a curvy, sensuous façade and contains 32T magnets and is building a new 32 mm magnet which they claim will make 38 T and a hybrid one which will make 45 T. As well as an extensive magnet research and application program in many ways similar to the Mag Lab, some of their work applies magnetic levitation such as is used in magnetic levitation trains and levitation displays (used in those globes that seem to float on air). A provocative idea is that humans, if placed in a strong enough magnetic field, can also levitate. Another EuroMagnet Net II facility is the Dresden High Magnetic Field Laboratory located in Germany.[7] This facility is located in the countryside outside the city of Dresden. It is a part of a large physics campus called the Helmholtz-Zentrum Dresden-Rossendorf. Magnets 70T and above are housed in a no-nonsense, industrial-looking modern building. Laser beams allow spectroscopy at very high field strengths.

The largest similar installation in Asia is the Tsukuba Magnet Laboratories in Japan.[6] This facility was established in 1993, and today it houses 17 high-field strength magnets including resistives, hybrids, pulsed and superconducting magnets. A superconducting unit capable of producing 24T just became operational. The facility was not open to external researchers until 1998. It is under the direction of the National Institute of Materials Science, which has established a collaborative research effort with the University of Washington in Seattle.

I hope that this short editorial complements my previous one about the industry of CT scanning. It is important for us, clinical neuroradiologists, to realize that magnets are used by other researchers whose areas of interest are very different from ours. I wish to thank Dr Robert Quencer, who gave me the idea for this *Perspectives*.

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EDITORIAL

Acute Stroke Imaging: What Is Sufficient for Triage to Endovascular Therapies?

There has been much recent debate regarding the role of advanced imaging in general—and CT perfusion (CTP) in particular—in acute stroke management.[1] Typical questions include the following:

1) CT versus MR imaging: which technique is essential/sufficient/preferred for patient selection for lytic and endovascular stroke therapies?

2) Vascular/collateral imaging: is there a role for CTA or MRA in acute triage to lytic and/or endovascular stroke therapies; are they worth the time required?

3) Core or penumbra: what measures of admission stroke severity (both depth and extent of ischemia) best predict tissue and clinical outcome and the potential risks and benefits of treatment, and how can one best determine these?

4) Perfusion imaging: when is it indicated, does it have added value for acute stroke assessment, and, if so, how should