Clinical Implementation of Functional Magnetic Resonance Imaging Technology

a report by
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Largely considered a research tool, functional magnetic resonance imaging (fMRI) has been around since the early 1990s, when the Medical College of Wisconsin, the Massachusetts General Hospital, and the University of Minnesota independently published their findings demonstrating the Blood Oxygen Level-Dependent (BOLD) contrast mechanism. Widely accepted, the BOLD technique formed the basis for most fMRI research in the next decade. As more research was conducted and papers published, fMRI quickly became the hot topic of neuroscientists, who saw it as an opportunity to learn more about how the brain 'really works'. The technology seemed to have potential in countless applications, ranging from lie detection and neuro-marketing, to preoperative brain mapping and assessment and management of neurological disorders.

It has now been almost 15 years since the introduction of fMRI, and the hype about its potential and vast array of applications continues to grow. However, even after being widely publicized and praised as the neuro-imaging tool of the future, there has yet to be a widespread and general acceptance of fMRI technology in the clinical environment. We have to question why fMRI is taking so long to transition into clinical practice, and what is being done today to facilitate its introduction into the new arena.

Challenges Associated with Implementing and Using fMRI

One of the main reasons why fMRI has not emerged as an imaging tool of choice and why it is not as readily available in hospitals as position emission tomography (PET), MRI or computed tomography (CT) has to do with the complexity associated with implementing and using fMRI in a clinical setting. To understand why, it is important to know what is required to perform functional MRI exam. Several critical pieces need to be in place to implement fMRI effectively, and all pieces must be carefully coordinated in order to obtain high-quality results and benefit from an fMRI exam.

Defining Clinical Applications and Designing Testing Paradigms

First, to conduct clinically useful fMRI, it is necessary to define an application and create the clinical content around it. For example, if a neurosurgeon wants to know the location of eloquent cortex in relation to a tumor prior to performing a surgery, then preoperative planning is the application. In this case, motor and language tasks may be used to localize the specific functional areas of the brain. However, if the application is to monitor the effect of a specific therapeutic treatment on a patient with Parkinson's disease, the tasks may need to activate the basal ganglia and other regions of the motor cortex (areas typically affected by Parkinson's disease).

Based on the chosen application, specific tasks, or stimulation paradigms, need to be designed to activate the regions of the brain that are of interest in the context of the exam. To perform fMRI it is essential to employ carefully designed psycho-physical testing paradigms, which are used to precisely measure neural activity of a patient. These paradigms can range from simple block design tasks to more complex event-related tasks. Block design paradigms compare periods of activity (e.g. finger tapping, or attending to a flashing checkerboard) with rest, and do not involve complex cognitive processes. There are several advantages to using block design paradigms, including their good signal to noise ratio, fast run time, and robust and consistent signal for sensory-motor activities. Event-related paradigms, on the other hand, can be used to look at more complex cognitive processes, such as executive function, memory, speech, or motor planning and decision-making processes. These paradigms are suitable when examining complex cognitive processes as individual events or instances, or to examine how brain activity evolves over time. However, these paradigms are significantly more challenging to design and implement.

Once the application and the paradigms have been selected, the next challenge is to implement the paradigms in an actual imaging procedure that can be

used for patient testing. To do this, precise timing and synchronization of the paradigm and MRI acquisition is crucial. Design expertise must include an understanding of the desired application, the timing constraints, quantity of data required to be statistically and qualitatively valid, and a complete understanding of hardware and software used to implement the task. In order to design and implement these paradigms, it is neccesary to put together an 'fMRI team' that includes various skill sets, including neuroscience, neurology, or neuropsychology, and computer science.

Designing a Turnkey Data Acquisition System

One of the important elements of clinical fMRI implementation is the hardware. As with any imaging modules, the right hardware components are needed to perform successful and high-quality fMRI examinations. Basic fMRI hardware consists of a central computer, a stimulus delivery system, and a patient response device. The central computer, which would typically be located in the MR control room, interfaces with the MR scanner. It sends the stimulus to the patient, collects patient responses, and pulls anatomical and functional images and behavioral data from the MR scanner. The stimulus delivery system and the response device are located in the scanner room. The stimulus system can include audio, visual, or tactile stimuli, and is used to present the stimulus to the patient. The response device, usually in the form of a specialized joystick or keyboard, is used by the patient to respond to the stimulus. All of the components inside the MR room need to be MR compatible or radio frequency (RF) shielded and optically isolated to reduce interference with the RF and magnetic fields. This will minimize artifacts in the images, and will ensure the safety of the patient and MR technologist.

Until recently, there were no 'complete' commercially available fMRI systems, and researchers were forced to find their own solutions. The aforementioned fMRI team now had to expand to include the expertise of a biomedical engineer and a biophysicist. These individuals would either build the components needed in-house, or purchase them from several fMRI or MR component manufacturers, and assemble them in the laboratory.

fMRI Data Handling and Post Processing

The third component necessary to perform fMRI is the ability to process the acquired MRI and behavioral data. Using processing algorithms and statistical analysis, MRI signal changes, which correspond to specific, task-oriented stimulation need to be extracted from specific regions of interest and superimposed onto anatomical images. The processing of fMRI data is quite complex and sophisticated, especially when event-related paradigms are used. To do it successfully, the fMRI team needs to expand once again to include a data analyst and a statistician.

The team now comprises at least six individuals, combining their specific knowledge and expertise in the areas of neurology, biophysics, biomedical engineering, computer science, data analysis, and statistics to perform fMRI. There are several problems with this method. Primarily, it is costly and time-consuming to assemble and train such a team, and it may be impractical for most hospitals and imaging centers. In terms of costs, it is possible see what a healthcare facility would have to spend to establish an fMRI service. To begin with, acquiring and installing an fMRI data acquisition system can cost anywhere from US$100,000 to US$300,00 (perhaps not a significant cost compared with US$2.5–3 million already spent on an MR scanner, yet significant on its own). Once all of the equipment is in place, it is time to start bringing in and training the personnel required to perform fMRI studies. Bringing in six full-time employees, the fMRI team with necessary skill-sets, and an average annual salary of about US$80,000, yields US$480,000 annually in salaries alone. Overall, in the first year, a hospital could spend up to US$650,000 to set up an fMRI program.

The second problem arises from the potential variability in training and skill level of the staff performing the fMRI exams. Because there are no standards established for how fMRI exams should be administered, the quality of the overall results can be jeopardized, begging the question of inter-user reliability and the validity of this approach.

It is clear that fMRI is having difficulty making the transition into clinical fields. The substantial costs, combined with complex utilization and lack of reimbursement, are considerable barriers that may prevent hospital administration from taking that step. Something needs to be done to minimize the cost of performing fMRI, increase its reliability, and ultimately get paid for doing it.

Facilitating fMRI in a Clinical Environment

Several firms have developed 'turnkey' fMRI systems, eliminating the need for individuals to perform systems integration. However, due to the lack of standard stimulation paradigms and fMRI data processing

solutions, their main customer remains the researcher. To fill that void and help introduce fMRI into a clinical setting, there seems to be a need for an all-in-one fMRI solutions and service provider.

An fMRI-specialized company that provides the aforementioned components necessary to perform clinical fMRI would be attractive to a hospital or an imaging center. For example, using third-party 'plug-and-play' imaging paradigm tests for predefined clinical applications would help a hospital avoid direct costs associated with hiring the staff to develop and implement these paradigms in-house. In addition, with a third-party fMRI data-processing service, a hospital could again avoid the direct costs of keeping a statistician and a data analyst on their payroll to process and analyze the data. Instead, a hospital would attain low variable costs based on the number of times it uses the data processing service.

Using this method, a healthcare facility could easily cut as much as 70% of their direct costs, not to mention avoid the steep learning curve associated with setting up an fMRI practice. When using a third-party fMRI service, the only direct cost that a hospital would have is the acquisition and installation of the equipment. One Milwaukee-based company specializing in fMRI products and services is hoping to fill the 'fMRI boutique' niche. Neurognostics, Inc., a Medical College of Wisconsin (MCW) spin-off, has initiated a solution that enables clinicians to take advantage of fMRI technology in their fields. Neurognostics's Chief Executive Officer, Douglas Tucker, PhD, MBA, comments on the use of fMFI in the clinical community:

> *"There is a small but rapidly growing demand from clinical community to start using fMRI in their everyday practice. However, they find the technology difficult to implement and use. There is no reason to reinvent the wheel, especially when the process can take several years and hundreds of thousands of hospital's dollars. We believe there is value in having knowledge and expertise needed to set up an fMRI service easily and cost-effectively."*

Neurognostics, Inc., using the research conducted at MCW and other academic centers, developed its own product and service line to facilitate all components of the fMRI exam, including data acquisition, processing, and reporting.

Considering all the hype and excitement surrounding fMRI, it is only a matter of time before fMRI makes its way from a research laboratory into a hospital. Reimbursement polices will without a doubt help fMRI enter the clinical setting, but unless an initiative is taken to standardize and simplify fMRI technology, this exciting modality will not be able to emerge as the leading neuro-imaging tool and become a standard in patient care. However, with the help of companies like Neurognostics, who work to facilitate fMRI's implementation and use, the transition is likely to happen sooner rather than later. ■

References

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