

The future of magnetic resonance-based techniques in neurology

European Federation of Neurological Societies Task Force

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Magnetic resonance techniques have become increasingly important in neurology for defining:

- 1 brain, spinal cord and peripheral nerve or muscle structure;
- 2 pathological changes in tissue structures and properties; and
- 3 dynamic patterns of functional activation of the brain.

New applications have been driven in part by advances in hardware, particularly improvements in magnet and gradient coil design. New imaging strategies allow novel approaches to contrast with, for example, diffusion imaging, magnetization transfer imaging, perfusion imaging and functional magnetic resonance imaging. In parallel with developments in hardware and image acquisition have been new approaches to image analysis. These have allowed quantitative descriptions of the image changes to be used for a precise, non-invasive definition of pathology. With the increasing capabilities and specificity of magnetic resonance techniques it is becoming more important that the neurologist is intimately involved in both the selection of magnetic resonance studies for patients and their interpretation. There is a need for considerably improved access to magnetic resonance technology, particularly in the acute or intensive care ward and in the neurosurgical theatre. This report illustrates several key developments. The task force concludes that magnetic resonance imaging is a major clinical tool of growing significance and offers recommendations for maximizing the potential future for magnetic resonance techniques in neurology.

Introduction

Magnetic resonance imaging (MRI) is a safe, non-invasive method for imaging based on the distribution of small, highly mobile molecules in tissue (Hashemi and Bradley, 1997). The most common form is proton MRI, which generates images based on the distribution of water and lipids. The imaging experiment can, in principle, also be applied to other nuclei such as sodium, fluorine and phosphorus. However, the sensitivity (and therefore the image resolution) for different nuclei varies. Only nuclei of atoms such as hydrogen, fluorine and sodium can be used to give relatively high-resolution images. Lower sensitivity means that a minimum practical voxel size for imaging phosphorus, for example, is approximately 1000

times greater ($3 \times 3 \times 3 \text{ cm}^3$ vs. $1 \times 1 \times 1 \text{ mm}^3$) than for imaging protons.

Magnetic resonance imaging in neuroscience currently is used for the analysis of:

- 1 brain, orbits and spinal cord or (less commonly) large peripheral nerve or muscle structures and their changes in size or shape;
- 2 pathological changes in tissue structures and properties; and
- 3 functional activation of the brain during sensory or motor tasks or with cognitive processing.

This has been an area of remarkable growth in hardware, imaging strategies and data analysis (Table 1). One area of advance in hardware has been in the design of gradient coils, allowing improved speed of data acquisition and spatial resolution. New magnets are being constructed at ever higher magnetic fields to further increase sensitivity. Specialized magnet designs (e.g. 'open magnets') at lower fields are making the possibility of purpose-built magnets a reality, e.g. for the neurosurgical theatre.

A major area of development in analysis of magnetic resonance imaging data is in the explicit integration of data from different types of MR experiments and integration of magnetic resonance data with other imaging techniques providing very different data, e.g. PET (Toga and

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Table 1 Newer magnetic resonance imaging hardware, techniques or reagents expected to form the basis for future applications of MR techniques in neurology

Hardware, technique or reagent	Importance for neurological applications of MR
Higher field MRI systems (>1.5T)	Increased signal-to-noise ratio for imaging, allowing higher spatial resolution, particularly for spectroscopy Increased contrast-to-noise ratio for FMRI
Digital image analysis	Quantitative interpretations of size, shape and signal changes; development of objective measures of pathological changes Post-processing optimization of sensitivity and specificity
Diffusion-weighted MRI	Early detection of tissue damage (e.g. stroke) Mapping white matter projection tracts and pathological damage to them
MR angiography (MRA)	Non-invasive, three-dimensional descriptions of arterial and venous flow Detection of large- to medium-sized aneurysms
MR perfusion imaging	Mapping microcirculatory blood flow and volume in tissue Defining tissue 'at risk' of ischaemic infarction, regions of brain metabolically hypoactive, or those with abnormally increased blood volume due to an inflammatory disorder (e.g. AIDS)
Magnetization transfer imaging (MTR)	Determined by interactions between tissue water and macromolecules and can be sensitive rather specifically to particular types of pathological change, e.g. demyelination
T1 or T2 relaxometry	Increases sensitivity to forms of pathological changes (e.g. mesial temporal sclerosis) Provides a quantitative index of change that is potentially reproducible precisely between centres
Magnetic resonance spectroscopy (MRS) or spectroscopic imaging (MRSI)	Provides measures of relative tissue metabolite concentrations over volumes of less than 1 cm ³ to larger sizes, depending on the specific molecules being studied Proton MRS measures brain N-acetyl aspartate, a marker of axonal integrity Phosphorus MRS is sensitive to tissue pH and bioenergetic state: applications include establishing tissue viability (e.g. post-hypoxic-ischaemic insult) and tissue characterization (e.g. tumours)
Functional magnetic resonance imaging (fMRI)	Uses a small signal enhancement accompanying increases in the relative proportion of oxygenated blood to map regions of the brain that become active during somatosensory, motor or cognitive tasks performed during the imaging Potential applications of this new technique already seem apparent in differential diagnosis, pre-surgical mapping, definition of treatment responses and understanding mechanisms of functional recovery
Contrast agents	To better define large vessels, tissue perfusion, blood volume or impairment of the blood-brain barrier Traditional agents such as gadolinium – DTPA are rapidly removed from the circulation, whereas newer agents such as coated iron particles can remain circulating for prolonged periods, potentially allowing dynamic measurements of tissue perfusion and blood volume

Mazziotta, 1996). Along with these developments has been use of quantitative techniques for interpretation of magnetic resonance imaging data, rather than relying on qualitative changes appreciated by 'eye'.

This report identifies and illustrates several areas of applications development of magnetic resonance in neurology. It is not intended as a review of the subject area, but rather to establish a context for the Task Force *recommendations* in the concluding section.

Advances in structural measurements of the brain and spinal cord

There have been advances in structural brain and spinal cord imaging that likely will become part of routine clin-

ical practice over the next decade (Table 1). One of the most important has been in the development of tools for quantitative interpretation of changes in size or shape (Wang and Jernigan, 1994; Filippi *et al.*, 1996). This has been a particular area of interest in, for example, epilepsy and Alzheimer's disease research (Jack *et al.*, 1992; Cendes *et al.*, 1993; Fox *et al.*, 1996a; Fox *et al.*, 1996b; Fox and Freeborough, 1997; Fox *et al.*, 1997).

A major problem in developing pharmacological treatments of patients with both of these disorders is to identify markers that allow disease progression to be followed with high precision. It was demonstrated early (indeed from initial pathological descriptions) that Alzheimer's brains show more rapid atrophy than the brains of normal controls. There is evidence that this atrophy may occur prefer-

entially in particular parts of the brain. A number of workers therefore have demonstrated in pilot studies how atrophy measured non-invasively by brain imaging can be used as a marker of disease progression (Filippi *et al.*, 1995; Fox *et al.*, 1996a; Fox *et al.*, 1996b; Fox and Freeborough, 1997; Fox *et al.*, 1997). In such cases, changes in brain size are inferred from changes in position of tissue contrast edges in the images. At present, general application of these techniques is limited by variations in signal intensities between scanners and by other image artefacts. Robust approaches to post-acquisition correction of these artefacts are being developed that will be essential for general implementation of these methodologies (Tofts, 1998). Precise measurements of brain and spinal cord atrophy may prove useful for monitoring the progression of diseases other than neurodegenerative disorders, e.g. multiple sclerosis (Losseff *et al.*, 1996; Losseff and Miller, 1998). There is particular excitement concerning this work because of strong correlations between clinical indices of progression and measures of brain or spinal cord atrophy (probably a consequence of the importance of axon loss in determining functional impairment) (Matthews *et al.*, 1998).

These and similar approaches can be extended for analysis of changes in lesion size and shape (Binkofski *et al.*, 1996; Lee *et al.*, 1998). These potentially allow precise detection of even small volumes of lesion growth or shrinkage. This promises to be very useful, for example, in analysis of disease activity in multiple sclerosis, where, in addition to net lesion volume change, the dynamics of lesion change can be characterized with separate measurement of volumes of lesion growth and loss. In combination with fast imaging techniques (e.g. echo planar imaging) that reduce degradation of image quality with motion, newer pulse sequences providing improved tissue contrast and higher resolution with increased signal-to-noise ratio from better radio frequency coil technology (e.g. phased array coils) and higher-field instruments, sensitivity to pathological changes also is improving substantially. These developments are likely to extend the usefulness of MRI in evaluation of spinal cord disease particularly.

A limitation to all of these techniques has been the continued reliance on manual definition (segmentation) of lesions and of different tissue classes based on visual identification of borders between contrast edges in the images (Clarke *et al.*, 1995). Such analysis has a degree of subjectivity and inter-observer variability that leads to significant imprecision. It is also extremely time-consuming. New strategies based on both analyses of signal intensities across the image and Bayesian analyses based on prior information regarding brain structures have been used successfully in initial attempts to provide automated segmentation. This work is continuing and may offer

much more precise and objective measures of changes in individual brain structures.

The development of probabilistic descriptions of neuroanatomical variations across the population offers a powerful new strategy for identification of differences between populations, for example between those containing a specific genetic trait (Krams *et al.*, 1997) and over time (Thompson *et al.*, 1996; Thompson and Toga, 1997; Le Goualher *et al.*, 1999; Thompson *et al.* 2000). Related methods allow analysis of group image data for determining lesion distributions (Narayanan *et al.*, 1997). Remarkably small differences in brain structures can potentially be defined using these techniques (May *et al.*, 1999).

Imaging pathology in the brain, spinal cord and vessels

A primary goal for development of clinical MRI has been that of better characterization of pathological changes. There have been a broad range of new MR techniques introduced in the last five years that promise improved sensitivity and increased information for detection of pathological changes in the brain (Table 1). Perfusion imaging can be used to assess blood flow in a tissue (Detre *et al.*, 1994; Jezzard, 1998). This can be used to identify areas of impaired blood flow or to assess areas of altered blood volume. Changes in blood volume appear to be early markers of diffuse inflammatory processes, for example HIV encephalopathy (Tracey *et al.*, 1998). Areas of perfusion deficit have been shown to be substantially larger than areas of irreversible tissue damage in early stroke, suggesting that they may be used to assess the amount of tissue 'at risk' (Warach *et al.*, 1995; Baird and Warach, 1998; Barber *et al.*, 1998; Rordorf *et al.*, 1998; Tong *et al.*, 1998; Neumann-Haefelin *et al.*, 1999). Development of arterial 'spin-tagging' methods promises the potential for quantitative perfusion methods without the use of an exogenous contrast agent (Jezzard, 1998).

Diffusion imaging can provide novel information regarding tissue state. Decreases in water diffusion provide one of the earliest and most sensitive markers of ischaemia, for example, (Moseley *et al.*, 1990; Hossman and Hoehn-Berlage, 1995; Albers, 1998). Quantitative assessment of changes in the apparent diffusion coefficient can be useful in timing the pathology and in early objective assessment of the extent of damage. With anisotropy of diffusion of water in projection axons relative to interstitial water, diffusion imaging has proved to be a relatively specific marker of matrix damage or destruction (Christiansen *et al.*, 1993; Horsfield *et al.*, 1998). Improvements in methodologies offer the prospect for magnetic resonance 'tractography', an assessment of anatomical connectivities between neocortical areas via white matter projec-

tion axons (Basser *et al.*, 1994; Makris *et al.*, 1997, 1999; Conturo *et al.*, 1999).

The relaxation properties of water molecules in tissue, although less specifically understood, can be used to provide further empirical information on pathology. Relaxometric methods have been developed that allow precise high-resolution measurement of both T1 and T2 values across brain tissue within clinically acceptable examination periods. T2-relaxometry is sensitive to characterization of subtle abnormalities of cellular architecture in multiple sclerosis (MacKay *et al.*, 1994) or temporal lobe epilepsy, for example (Jackson *et al.*, 1994).

Magnetic resonance spectroscopic imaging allows observation of the distribution of the nuclei in small molecules in the brain other than water (Rudkin and Arnold, 1999). These 'biochemical maps' can be used to probe more directly molecular correlations of pathological change in the brain. Some of these biochemical markers can be interpreted relatively specifically in terms of the underlying pathological change. N-acetyl aspartate, for example, is found only in neurones and their processes in the adult brain, and therefore can be used as a marker of neuronal loss or metabolic dysfunction (Moffett *et al.*, 1991). New developments in MRSI are allowing increased spatial resolution, particularly with higher field MRI imaging systems. In addition they are allowing acquisition from larger volumes in multislice or volume-based MRSI (Kruse *et al.*, 1994; Adalsteinsson *et al.*, 1995). Clinical applications currently include the differential diagnosis of mass lesions, differentiation of radiation necrosis from tumour recurrence, and helping to establish prognosis after global hypoxic-ischaemic insults. Techniques of analysis are being developed that allow extension of these methods to direct observation of neurotransmitters including glutamate and GABA (Rothman *et al.*, 1992a, b; Petroff *et al.*, 1996a, b). Increases in spatial resolution are being facilitated by improvements in both hardware and post-acquisition analysis (Styles, 1991).

Water in tissue rapidly exchanges between free-, bulk water- and macromolecule- (protein and lipid) associated pools. The relative sizes of these pools, their influences on the water proton relaxation times and the rates at which the water molecules move between the pools are determined by the structure of the tissue. Magnetization transfer imaging uses radiofrequency energy to selectively saturate the magnetization of macromolecules which then interact with bulk water and thereby cause a decrease of the observable steady-state signal (Balaban and Ceckler, 1992; Wolff and Balaban, 1994). Changes in magnetization transfer (reflecting, for example, altered interactions between water molecules and macromolecules) can be very sensitive to pathological changes (e.g. demyelination) (Gass *et al.*, 1994; Berry *et al.*, 1999). With care, magneti-

zation transfer imaging can provide highly reproducible values, which can be interpreted on a quantitative index of pathological change using histogram or region-of-interest based analyses (Filippi *et al.*, 1995).

Entirely non-invasive evaluation of cerebrovascular disease has become possible in many cases because of improvements in magnetic resonance angiography, which allows accurate, non-invasive estimation of relative flow in even medium-sized arteries and veins (Bradley, 1992; Belle *et al.*, 1995; Brant and Heiserman, 1997; Graves, 1997). Aneurysms as small as a few millimetres in diameter can be reliably detected. The combination of similar methodologies with the use of intravenous contrast offers improved definition of both the arterial and the venous circulation (Parker *et al.*, 1998). Perfusion of tissue can be defined directly using gadolinium-contrast bolus-tracking or newer 'arterial spin-tagging' methods (Jezard, 1998).

New contrast agents are being developed that will allow improved definition of blood flow and blood volume. Of particular interest are the coated iron oxide particles, which offer a long circulation time contrast agent in the blood to give dynamic information on cerebral blood volume changes (Belliveau *et al.*, 1990; Bjornerud *et al.*, 1998). A novel extension of this approach has been to track specific classes of cells (e.g. monocytes) by following the distribution of contrast after allowing the cells to internalize a contrast agent such as iron oxide (Douset *et al.*, 1999). Combined use of MR diffusion imaging, contrast-based MR perfusion imaging and MR angiography allows more precise determination of infarcted tissue, tissue at risk of infarction and the site of vessel occlusion (Sorensen *et al.*, 1996). Imaging 'packages' allow acquisition of this data and high-resolution structural brain images in short time periods compatible with the demands for rapid evaluations of acute stroke patients. This could provide an improved, rational approach for selection of patients for interventions such as, for example, thrombolysis.

Functional measurements with magnetic resonance

One of the most exciting of recent developments in MRI has been functional magnetic resonance imaging (fMRI) (Ogawa *et al.*, 1990; Kwong, 1995; Matthews *et al.*, 1999). This technique uses ultrafast imaging to measure the very small changes in signal intensity that accompany local increases in blood flow with activation of local neuronal networks. The technique relies on signal differences arising from changes in water relaxation with changing proportions of oxygenated and deoxygenated haemoglobin in capillaries in, and veins draining from, a functionally activated brain (Thulborn *et al.*, 1982; Oga-

wa *et al.*, 1990). Recent advances have allowed combined fMRI and combined blood oxygenation level dependent 'BOLD' and perfusion functional activation imaging to assess the dynamics of local changes in blood oxygen utilization (Davis *et al.*, 1998; Hoge *et al.*, 1999).

These techniques allow areas of the brain involved in specific cognitive processing to be identified. This allows, for example, cortical plasticity with learning (Karni *et al.*, 1995; Toni *et al.*, 1998) or after the brain injury to be assessed directly (Cramer *et al.*, 1997; Cao *et al.*, 1998; Yousry *et al.*, 1998; Thulborn *et al.*, 1999) and facilitates pre-surgical mapping of the functional cortex around lesions, for example brain tumours (Atlas *et al.*, 1996; Herholz *et al.*, 1997). Lateralization of brain activation with language tasks also appears possible (Morris *et al.*, 1994; Desmond *et al.*, 1995; Binder *et al.*, 1997; Hertz *et al.*, 1997). Current work is focusing on determining ways in which the technique can be improved for quantitative assessment of changes in brain activation between patient groups and in individuals over time. As this becomes possible, the techniques will allow for robust approaches to functional definition of disease progression and the discrimination of functional differences between patient groups and normal controls, even in the absence of structural pathology. An exciting extension of such work would be to use the technology to assess the effects of therapeutic interventions in order to use functional criteria for appropriate dosing of new drugs.

These activation studies could be particularly important if used in conjunction with information regarding the distribution of neurotransmitter systems in the brain. Recent developments in positron emission tomography (PET) that promise mapping of receptor distributions via ligand binding, mapping of neurotransmitter synthetic pathways via incorporation of labelled precursor molecules and, most recently, semiquantitative assessment of neurotransmitter release are potentially powerful strategies to combine with these activation maps (Volkow *et al.*, 1996; Wong *et al.*, 1997; Cumming and Gjedde, 1998; Koepp *et al.*, 1998). The fMRI studies, which do not use ionizing radiation, can be repeated serially and correlated with PET studies.

The need for new technologies

Magnetic resonance techniques have considerable scope for growth in their applications in neurology (Table 1). However, if the full potential for improved healthcare and advances in neuroscience understanding are to be achieved, several challenges must be met.

Improved access to magnetic resonance technology is needed. In the clinical environment, moves away from film-based neuroradiological imaging must be accelerated. It follows that clinicians interrogating MR-based

data must be able to have access to work stations that allow easy manipulation of information for both visualization and measurement of changes in the brain or lesions. A particularly exciting possibility for this may be the use of probabilistic maps that allow quantitative comparisons between individual patient scans and normal standards (Paus *et al.*, 1996). Extension of this quantitative approach to image interpretation must be made to the neurosurgical theatre in which it will need to be interactive. Further development of techniques for monitoring of the brain during neurosurgical procedures and for interpretation of these changes with respect to the surgeon's instruments must proceed forward.

Provision of new contrast agents with an increasing range of pathological selectivity is needed. It may be possible to devise tissue-specific or cell type-specific contrast agents. These could be used in some applications in a way that might be similar to current PET metabolic tracers. Use of ^{13}C or other rare isotope nuclear magnetic resonance (NMR) techniques might eventually prove a practical strategy for some applications of this type, particularly if very high-field instrumentation becomes more widely available. Limitations on the temporal resolution and range of physiological parameters that can be probed using magnetic resonance technology may be addressed by improvements in integrating magnetic resonance and other methodologies. High temporal resolution electrophysiological methods, such as electroencephalography or magnetoencephalography, can be integrated with magnetic resonance using post-processing methods (George *et al.*, 1995; Kuikka *et al.*, 1996). Strategies have been developed for performing EEG (and even transcranial magnetic stimulation) directly in the MR magnet (Lemieux *et al.*, 1997). Combined PET and MRI have been demonstrated (Garlick *et al.*, 1997), and there is an as yet unexplored potential for linking optical imaging and MRI.

Methods for objective and quantitative analysis of brain images need to become widely used, yet currently they are largely unvalidated and are specific to individual laboratories. There is a need to develop well-tested, 'industry wide' methodologies that can be reliably used in a clinical setting. This will demand, *inter alia*, some agreement about what the primary goals for these technologies might be in a clinical setting.

Specialized magnetic resonance systems will be needed for specific neuroimaging applications. At the time of writing this report, a specialized form of instrumentation that allows intra-operative MRI in the neurosurgical theatre is already being evaluated at several centres (Gering and Weber, 1998; Jolesz *et al.*, 1998; Jolesz, 1998). Another vendor has developed a prototype ultrashort high-field magnet that will potentially provide increased sensitivity for brain applications at a lower cost, while facilitating psychophysical experimentation. Ultra-

high-field (>3–4 T) systems for magnetic resonance spectroscopy may prove practical, although there remain uncertainties regarding any risks of repeated exposure to high fields and these systems may be less well tolerated because of magnetic field-induced vertigo or phosphenes with eye movement. There are also substantial technical challenges (e.g. from magnetic susceptibility and dielectric effects) to clinical imaging at ultrahigh fields that have yet to be solved. A variety of lower field, open systems may be more ideal for structural brain, spine and peripheral nerve or muscle studies, particularly in clinics or other out-patient environments. Lower field, open designs may also prove useful tools in intensive neurological care settings where frequent scanning of unstable, ventilated patients is demanded. Increasing use of mobile systems would allow greater access to MRI technology in smaller or remote centres.

The role of the neurologist in neuroimaging

Particularly with the advent of functional neuroimaging, it is becoming essential for the interpretation of neuroradiological imaging to go hand-in-hand with a detailed understanding of clinical neurological or behavioural phenomena. Robust automated methods for quantitative assessment of images will allow skills in neuroscience rather than in image interpretation to be emphasized in interpretation of this data. Undoubtedly magnetic resonance techniques will become an even more integral part of assessment of patients with neurological and neurosurgical disease. However, this must be done in the context of a vigorous programme of evaluation in order for it to enhance the efficiency and quality of health care delivery. To facilitate these developments, the neurologist must be expected to play an increasingly greater role in the delivery and management of MR-based services (Brillman *et al.*, 1997) in ways previously outlined for neuroimaging in general (EFNS Task Force, 1998).

Functional magnetic resonance imaging examinations can be used as an extension of current neurophysiological investigations of the central nervous system and should be well integrated with them. The differences in contrast and sensitivity to pathology of different magnetic resonance imaging pulse sequences provide the neurologist with tools analogous to the different staining techniques used by the neuropathologist. To allow magnetic resonance techniques to develop in the neurological context, academic and clinical neurology departments need to develop new specialist posts in image analysis and magnetic resonance physics. Following the pattern of development of radiology departments over the last couple of decades, specialist expertise must be encouraged within the individual departments to develop synergy between those re-

sponsible for interpretation of the neuroscience implications of studies and those responsible for optimizing the application of studies and controlling quality. New approaches to the creation of career structures for such individuals therefore must also be put into place. Increasing subspecialist training for neurologists in magnetic resonance imaging should be provided for.

Implicit in all of this is the development of a new and enhanced academic neuroscience and healthcare delivery partnership with departments of radiology. Clearly the idea of rigidly defined ‘turf’ cannot survive in a new era in which magnetic resonance imaging is interlinked ever more closely with clinical practice.

Conclusions

On the basis of their review of the current trends in magnetic resonance methods and their applications to neurology, the Task Force have reached the following conclusions:

1 Consistent with previous Task Force recommendations (European Federation of Neurological Societies Task Force On Neuroimaging, 1998), we believe that neurologists need to be better trained in magnetic resonance imaging methods in order to become primary decision makers for defining long-term MR-based technology needs for optimal healthcare delivery, the choice of MR studies that should be performed on their patients and the interpretation of such scanning. A corollary recommendation is that neurologists should work to enhance career roles for non-clinical staff essential for maintaining and developing improved technology (e.g. specialists in image analysis and MR physics).

2 The costs and effectiveness of improved access to advanced MR imaging, particularly in acute neurological care, neurological intensive care and neurosurgical theatre settings, should be evaluated vigorously without delay. If the promise of early experience is demonstrated clearly, then national healthcare systems should make adequate provision of new resources to allow appropriate access to advanced magnetic resonance imaging methods in all neurological care centres a priority.

3 European research and national health agencies should (either directly or in collaboration with industry) encourage development and validation of improved algorithms and software for analysis of conventional and functional magnetic resonance imaging and magnetic resonance spectroscopy in the clinical setting. In the current environment, there is too little diffusion of new technologies between centres, which limits meaningful evaluation of methods and can lead to wasteful duplication of effort.

4 The potential size of the market must be emphasized to manufacturers to encourage development of lower cost

magnetic resonance systems, particularly those designed for specific neuroscience applications. Magnetic resonance applications continue to be led by technological development, much of which (particularly hardware) comes from the major imaging system vendors. Neurologists and their societies need to make greater efforts to communicate the needs and potentials for neuroscience applications of magnetic resonance.

5 Research funding bodies must be kept aware of the potential for magnetic resonance both to contribute to advances in basic neuroscience and to facilitate higher quality and lower cost healthcare. Research funding for magnetic resonance imaging studies should increase, particularly in growth areas such as MR image analysis and functional magnetic resonance imaging. Enhanced research access to state-of-the-art imaging systems should be made available. Particular encouragement should be given to those pursuing novel, imaginative and 'high risk' ideas, as well as those developing more mature research strategies.

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