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Review

Magnetic Resonance Imaging: Present Position and Future Prospects

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MAGNETIC RESONANCE imaging (MRI) is now widely accepted as the technique of choice for imaging the brain and spine [1, 2]. The technique is of considerable value in imaging the head and neck, musculoskeletal system and pelvis. It is of much less value in the imaging of the abdomen, for which ultrasound and computed tomography are generally preferred. The technique is of some value in imaging the mediastinum and for breast imaging, but not for the lung [2].

Magnetic resonance (MR) machines have traditionally been constructed around a magnet, which is the largest and most expensive single item in an MR system, and has dictated the form which machines have taken. A new range of magnets is being produced with much improved access to the patient. These range from the completely open horizontal disc magnets, similar in configuration to a gamma camera, to much shorter cryomagnets (of length less than 1 m) as well as to radically open designs which provide access for a surgeon between two separated magnetic rings (the 'double doughnut') [3]. Prototypes and commercial versions of these systems are now available, and even more radical flat-bed designs, with totally open access to the patient above a table are under consideration. These systems provide new options for placing whole body machines in intensive care units and operating theatres.

At the other end of the scale, very small purpose-designed systems about the size of an average television are now available. These are suitable for imaging limbs and can be installed in offices or outpatient facilities without difficulty.

Within an MRI system, additional time-varying magnetic fields are necessary to select slices and spatially localise the signals that are detected by the system's receiver coils. Over the last 5 years, there has been a move to self-shielded gradient coils, which essentially consist of two partially opposed coils so that there is a magnetic field around the patient, but not the surrounding magnet. This reduces eddy currents induced in the magnet and improves machine performance. In addition to the change to self-shielded gradients, the gradient strength available has doubled. This provides options to image faster, to detect signals earlier, to improve angiography and to use gradient intensive techniques such as diffusion weighted imaging. In fact, the specification of gradient strength is almost as important as the main field strength in assessing the capabilities of a system. The main implications for this have been new options and approaches for imaging the abdomen and pelvis. It is easier to obtain images during a breath-hold and thus reduce artefact due to respiratory motion.

Development of receiver coils has taken two main forms, either as phased arrays in which small coils are combined to produce a net benefit, or as internal coils placed in body orifices. These internal coils greatly improve the imaging of local structures. Phased arrays are now available for imaging the abdomen or pelvis [4] as well as the brain [5]. The main result of this work has been a further improvement in image quality and new applications in the pelvis.

Internal coils were first used for imaging the prostate, but a wider variety is now available for imaging the anus (Figure 1) [6], vagina and uterine cervix [7]. Fixation is important and combinations of internal and phased array coils are now being used. Considerable improvement in resolution and contrast has been achieved.

New faster pulse sequences are being routinely employed, such as the rapid acquisition with relaxation enhancement (RARE) [8], rapid acquisition gradient echo [9], gradient and spin echo acquisition [10] and echo planar imaging [11]. They can reduce imaging time by a factor of 2 or 3, or provide a much wider range of options so as to tailor the MR examination to the clinical requirements. Abdominal imaging has particularly benefited from these improvements [12, 13]. Most of these faster forms of imaging are available in two-dimensional form, but some are being developed in three-dimensional form. This is a particularly efficient way of imaging, and enables information to be displayed in any plane for surgical and radiotherapy planning on a workstation.

The three-dimensional form of imaging has a further benefit for precise registration of serial images. Comparison of changes on two-dimensional images is frequently limited by the fact that slices are obtained at slightly different levels and angles. This produces anatomical differences which may be greater than the changes being sought. After obtaining three-dimensional images, it is possible to reslice and realign the second set with sub-mm accuracy to match the first so that

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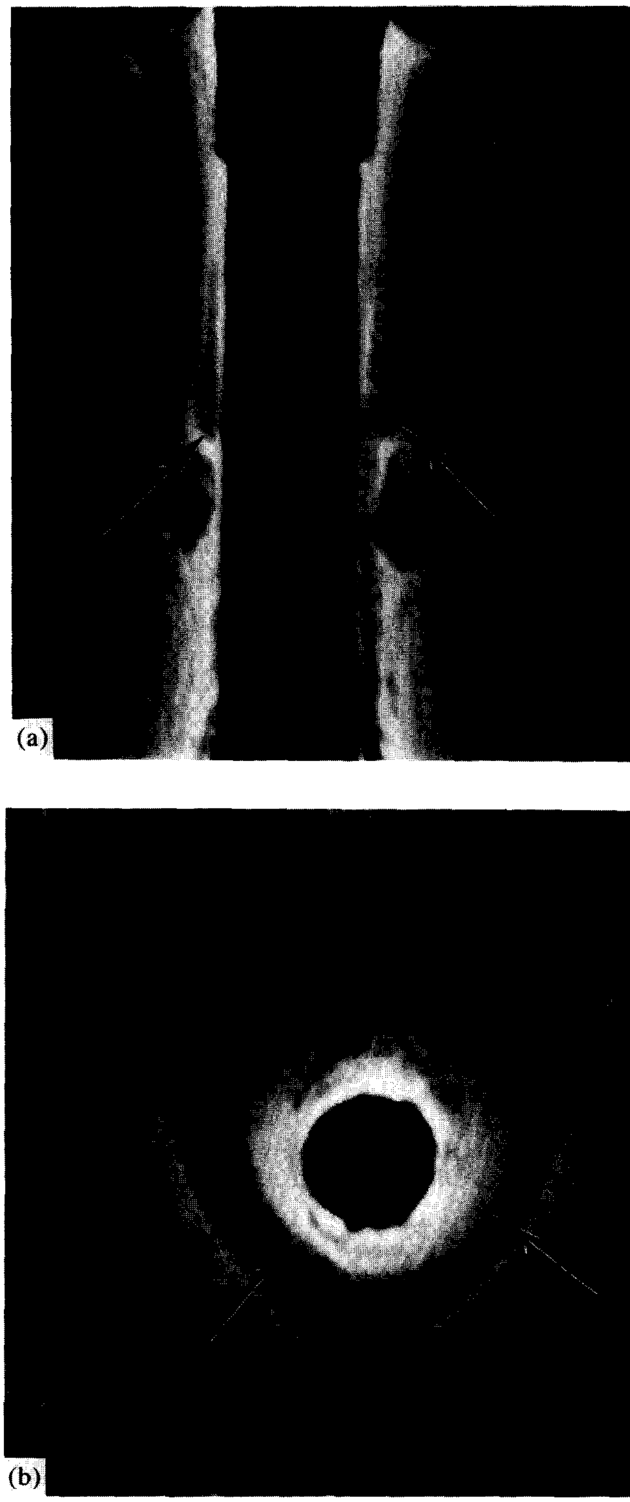

Figure 1. MRI of the anus using an internal coil. Excellent anatomical detail is seen in the coronal (a) and transverse (b) planes. The internal sphincter is clearly visible (arrows).

the two sets of images can be compared in detail and small changes can be detected either directly or on subtraction images (Figure 2) [14]. While the techniques required for this have been known for several years, their implementation is new, and they may be of considerable importance in assessing response to therapy.

Magnetisation transfer sequences are now becoming available on a routine basis. By applying a radiofrequency pulse off resonance, effects due to protons bound in proteins can be detected. These otherwise 'invisible' hydrogen nuclei contribute to tissue signals and when their contribution is eliminated, the general signal from many tissues is reduced. This is of value in reducing the background signal from tissues in MR angiography. It can also help identify lesions with a short T1 and produce more effective contrast enhancement [15, 16]. Some degree of tissue characterisation may also be achieved with this technique.

Using Gadolinium-DTPA as a contrast agent with fast imaging, it is possible to produce maps of cerebral blood volume. There is a close correlation with histology [17]. There is evidence that triple dosage contrast agent increases the yield of metastases, but the use of magnetisation transfer can achieve a similar effect with a single dose by reducing the background tissue signal.

Two new types of contrast agents are being developed for liver imaging. The first of these is magnetic iron oxide particles [18]. These agents are selectively taken up by the Kupffer cells of the liver. They reduce the signal of normal liver and so increase the contrast with which metastases are seen. These agents have had a somewhat chequered period of development because of concern about side-effects of hypotension and lumbar pain, but are now expected to receive approval for phase IV trials. The other type of agents include Manganese DPDP, which increases the signal from normal hepatocytes and can make metastases obvious by increasing the signal difference between them and normal liver [19]. Lymphographic contrast agents are being developed [20, 21].

Particular interest surrounds the implementation of computer-assisted surgery [22]. This exploits the opportunities provided by open access magnets, faster imaging, volume imaging, registration and other techniques to display images in the operating theatre in close to real time. The imaging may be linked to the surgical procedure through ultrasound or infra-red localising devices to provide the surgeon with images in his or her co-ordinate frame. Head up displays, rapid reconstruction and other techniques, initially developed for military use, are now becoming available. The possibilities provided by laser ablation can also be linked to imaging [23–26].

Although breast imaging was among the first applications of MR, it is only recently that it has received concentrated attention [27–29]. Contrast enhancement with a gadolinium chelate is essential and malignant lesions are distinguished from benign by their earlier and higher level of enhancement. Biopsy techniques are used in association with contrast enhancement (Figure 3). The technique has been used in problem cases after mammography. These include the dense breast and the diagnosis of recurrence following surgery or radiotherapy, where effects due to treatment complicate diagnosis.

Tumour characterisation is improving, although it is far short of histological diagnosis. Primary lymphoma is notable for the fact that it does have a reduced diffusion coefficient rather than the increase found with other tumours. Measurements of regional cerebral blood volume show promise, and there may be useful differences in the rate and degree of contrast enhancement.

Advances in MRI must be seen in relation to progress with other techniques, including ultrasound (US) and X-ray computed tomography (CT) in particular. The principal

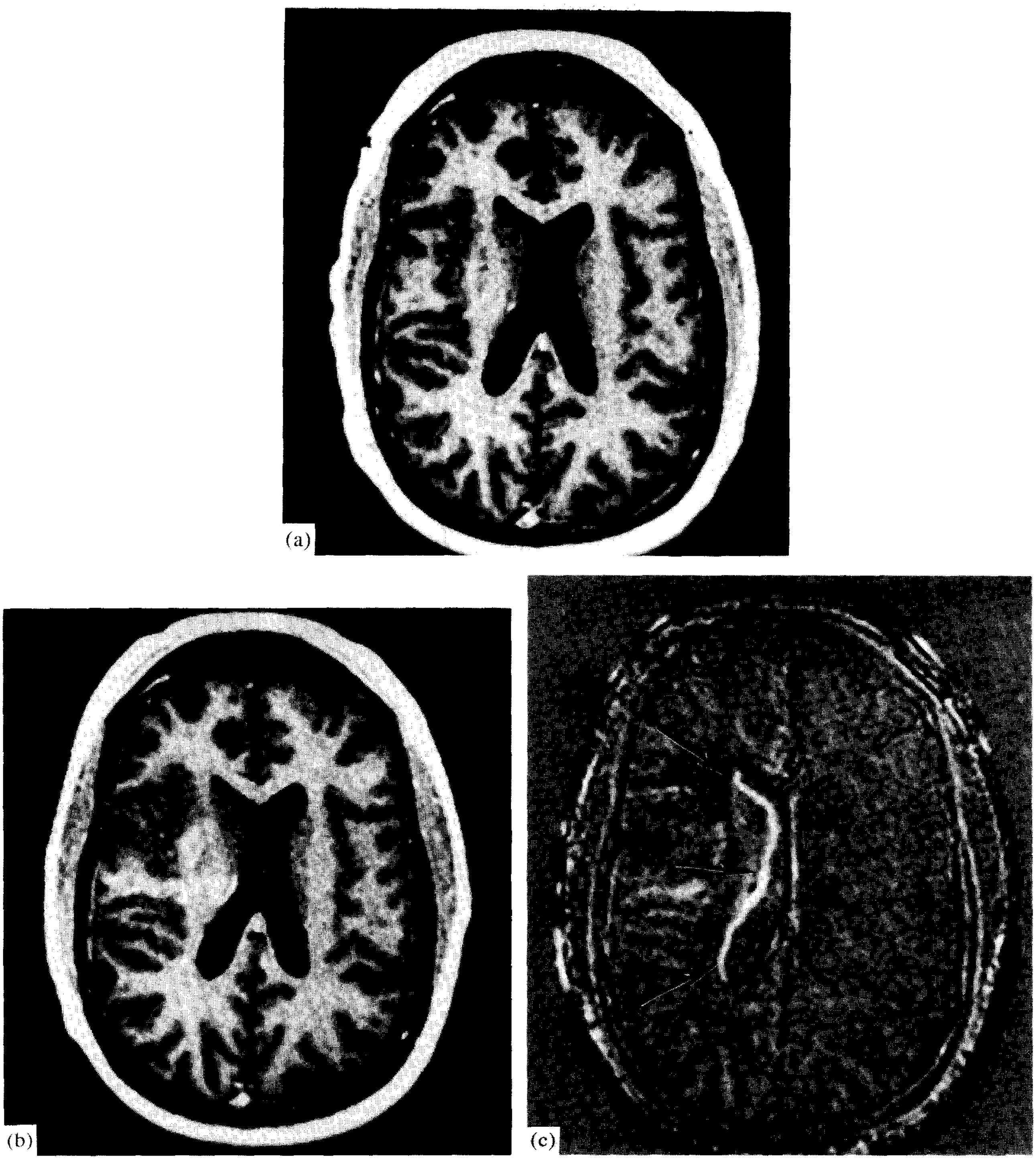

Figure 2. Astrocytoma grade III. T1 weighted scans before (a) and after (b) 4 weeks of treatment with Temozolamide and (c) registered subtraction images. The increase in tumour size is apparent as a white line in (c) (arrows).

advance with CT has been the development of spiral techniques which, when used with a contrast agent, have improved angiography and provided a three-dimensional capability. The principal benefit has been in the chest and the abdomen, where the role of CT has already been well established.

Energy mode ultrasound provides greater vascular detail than has been available previously, and new bubble contrast agents are being introduced. These also improve the visualisation of vascular structures. Advances in each of these techniques need to be compared with MRI in ongoing studies.

There has been considerable progress in methods of coregistration [30]. These are software methods used to match images obtained with difference techniques. They enable functional images obtained at low resolution to be matched to high resolution anatomical information. On a wider scale, picture archiving and communication systems (PACS) are being implemented to produce film-free sections, or whole departments in which all images are recorded and transmitted in digital form. There are problems in handling the large quantities of data involved and difficulties in reproducing

Figure 3. Biopsy: T1 weighted image of the breast showing artefact from the needle used for biopsy (white arrow).

chest and bone detail, but PACS in greater or lesser form is bound to play an increasing role in X-ray departments of the future.

X-ray departments are large employers and imaging equipment represents a significant fraction of the hospital budget. In the particular case of MR, the advent of faster imaging techniques has meant that patient throughput can be increased, without a significant increase in equipment costs, and this has been a considerable benefit to many existing departments. The greater range of systems and resurgence of interest in cheaper low field systems has also been important.

MRI continues to develop rapidly and the technique is now notable for the range of options which are available. There is no indication that development has reached a plateau as yet, but these changes must be seen in the context of other techniques [31] as well as increasing pressure to constrain costs.

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