Journal of Neurology, Neurosurgery, and Psychiatry 1985;**48**:14–18

Technical note

Stereotaxis and nuclear magnetic resonance

LARS LEKSELL, DAN LEKSELL, JOHN SCHWEBEL

From the Department of Neurosurgery, Karolinska Hospital, and the Department of ORL, Huddinge University Hospital, Stockholm, Sweden, and Siemens Medical Systems, Inc, Iselin, NJ, USA

SUMMARY The application of nuclear magnetic resonance (NMR) imaging to a stereotactic method is described. The physical properties of NMR offer some important advantages such as good contrast between grey and white matter and the possibility to scan the brain in three planes and at any desired angle. Stereotactic localisation by NMR gives very satisfactory and precise visualisation of the target structures based on transaxial, coronal and sagittal scans. With the technique described stereotactic localisation is performed by the surgeon directly in the operating room.

Stereotactic surgery has been based on X-ray imaging of intracranial structures by ventriculography, angiography, computed tomography or other techniques. Now magnetic resonance offers a new approach, as an alternative to the usual stereotactic CT examinations. It has some specific advantages, such as good contrast between grey and white matter, presentation of brain sections at any desired angle and easy postoperative visualisation of stereotactic lesions.[1] It may be expected that the use of NMR imaging in stereotaxy, because of its unique physical characteristics, will open up new areas of research in deep brain surgery. Such studies are now underway in several quarters. The present paper briefly describes the adaptation of a stereotactic technique[2 3] to this non-ionising imaging method.

Apparatus

The Stereotactic Instrument. A standard instrument was used manufactured by Elekta Instrument AB, Stockholm, Sweden (fig 1). The coordinate frame can be directly accommodated in most scanners. Since it is made from aluminium alloy, tests were made at different magnetic field strengths and it was confirmed that there were no distortion or artifacts due to eddy currents in the metal. The iron feet used for fixation of the frame in the CT scanner were replaced by non-magnetic feet. In addition, the coordinate scales were revised, in order to correspond with the X-, Y-, Z-coordinate system generally used in both CT and NMR scanning and to minimise the risk of errors (fig 2).

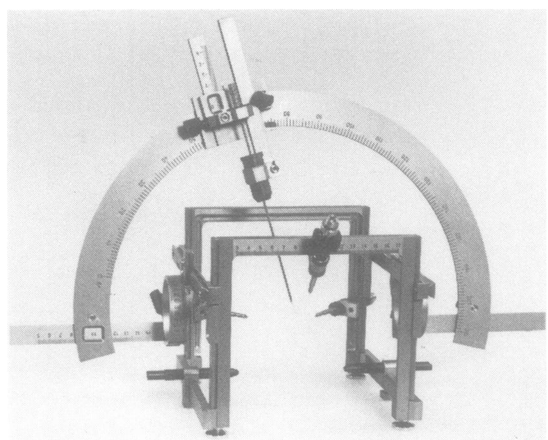

Fig 1 *The stereotactic instrument with new coordinate system and skull fixation modified for NMR.*

The Coordinate indicators. The coordinate indicator discs used during CT examinations were substituted by similar plastic discs with liquid indicators (fig 3). Following tests of various solutions vegetable oil was used, enclosed in plastic. Figure 3b shows the

Address for reprint requests: Prof Lars Leksell, Dept. of Neurosurgery, Karolinska sjukhuset, 104 01 Stockholm, Sweden.

Received 15 June 1984. Accepted 29 July 1984

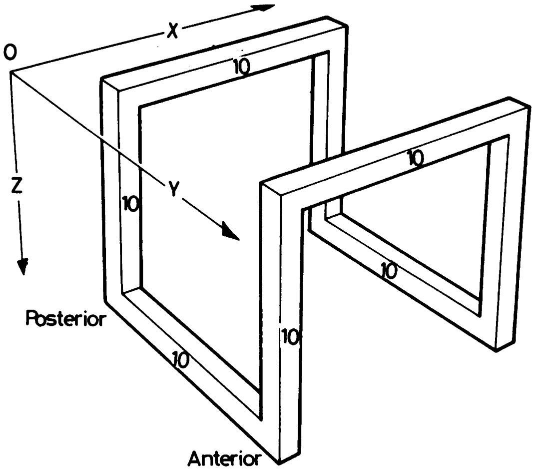

Fig 2 *Schematic view of the coordinate frame. The origin of the coordinate system is in the superior posterior corner on the right side.*

appearance of the indicators in an NMR scan. These indicators, temporarily attached to the frame during the examinations, allow the target coordinates to be derived from both transaxial and coronal scans. For localisation in the sagittal plane a similar indicator disc is attached to the top of the frame.

The NMR Adapter. The coordinate frame is attached to the NMR apparatus by an interface made of fibre glass instead of the aluminium adapter used with X-rays and in CT scanning (fig 4). The frame is connected to the adapter by the non-magnetic feet, which easily snap on and also allow quick detachment, thus precluding undue stress on the instrument. The stereotactic frame and the adapter can be used in all standard RF coils with a diameter of 30 cm or more.

The stereotactic NMR examination. A Siemens Magnetom was used. The coordinate frame is first fixed on the patient's head by three or four fibre glass pins and the NMR indicator discs are attached to the frame. During the examination the frame is held in correct position in the RF coil by means of the adapter.

The NMR scans are made in the usual way. Generally a multislice mode is used in order to simultaneously make a number of slices parallel to each other. For the localisation of the target, scans are made in two perpendicular planes, one parallel with the base plane of the coordinate frame and the other in the coronal plane. When maximal accuracy is needed the coordinates are determined also in the sagittal plane, as illustrated in fig 5. If desired additional scans may be made at the same angle to the frame as the intended surgical approach, in order to visualise the brain structures which are to be penetrated by the electrodes or other instruments during the operation.

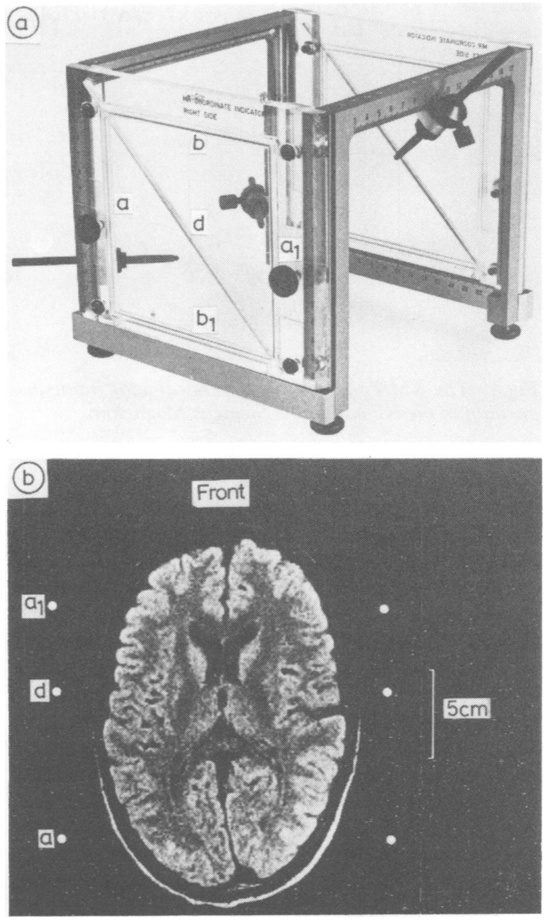

Fig 3 (*a*) *The coordinate indicator discs for NMR with channels filled with oil. The channels a, a_1, b, b_1 and d, appear as feudicials on the NMR scans as seen in figs 3b, 6 and 7.* (*b*) *Appearance of the coordinate indicators on the NMR scan. The middle feudicial on each side, that is the diagonal channel, is used for the Z-coordinate determination in the transaxial plane (the feudicials slightly retouched).*

The localisation procedure

When the desired target point has been identified in all three planes, its X-, Y- and Z-coordinates are determined according to the same principles as described previously for CT.[4] The coordinates can be determined either from the scan films or directly from the CRT screen.

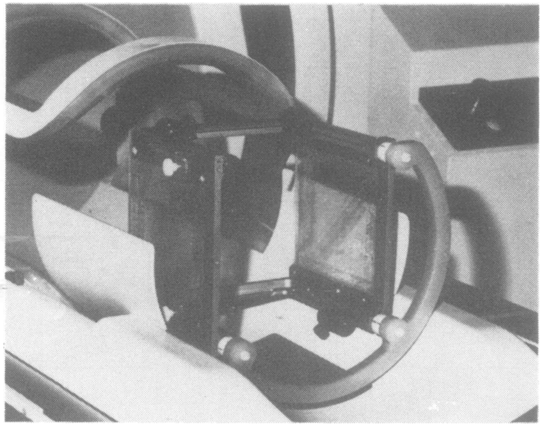

Fig 4 *The NMR adapter and the coordinator frame in position in the RF coil of the Siemens Magnetom.*

Fig 5 *Sagittal NMR scan showing the feudicials obtained by means of an indicator disc on top of the frame.*

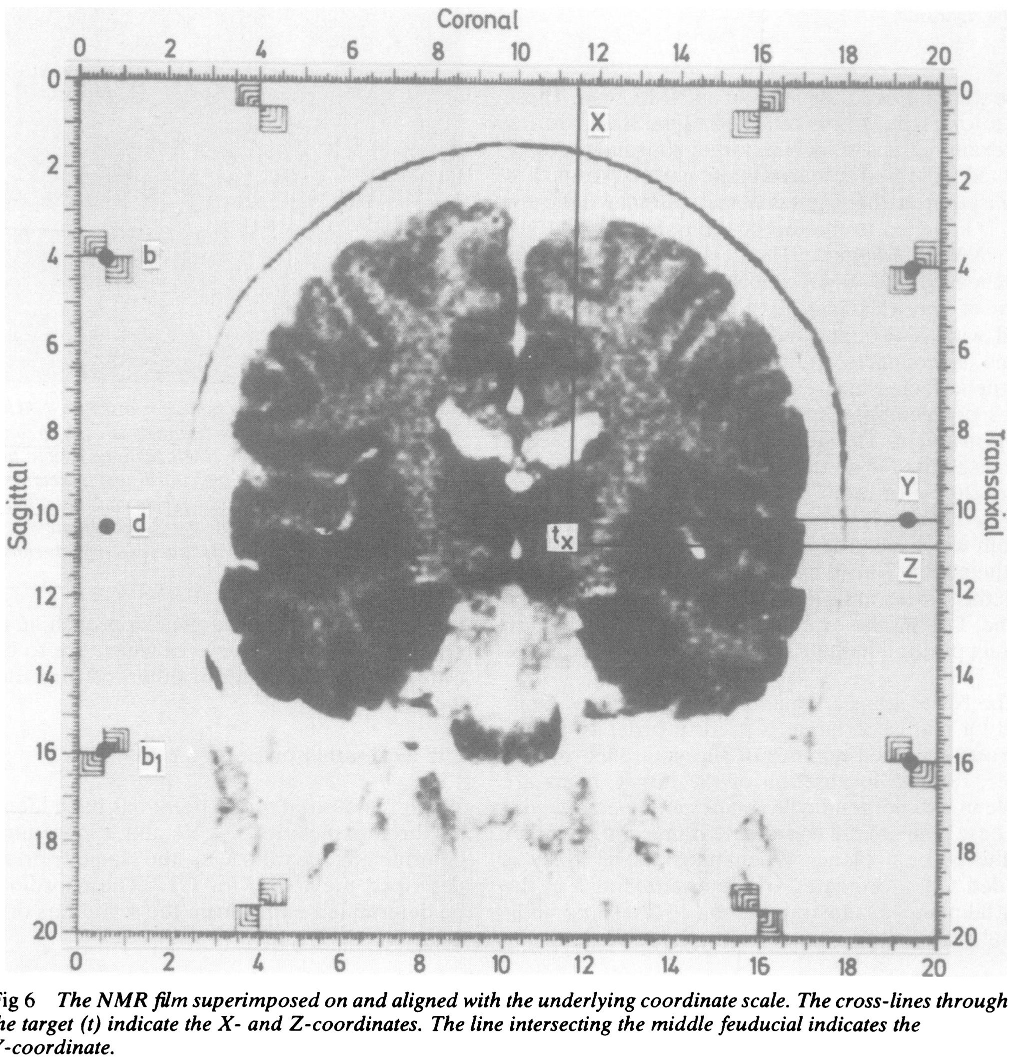

Fig 6 *The NMR film superimposed on and aligned with the underlying coordinate scale. The cross-lines through the target (t) indicate the X- and Z-coordinates. The line intersecting the middle feudicial indicates the Y-coordinate.*

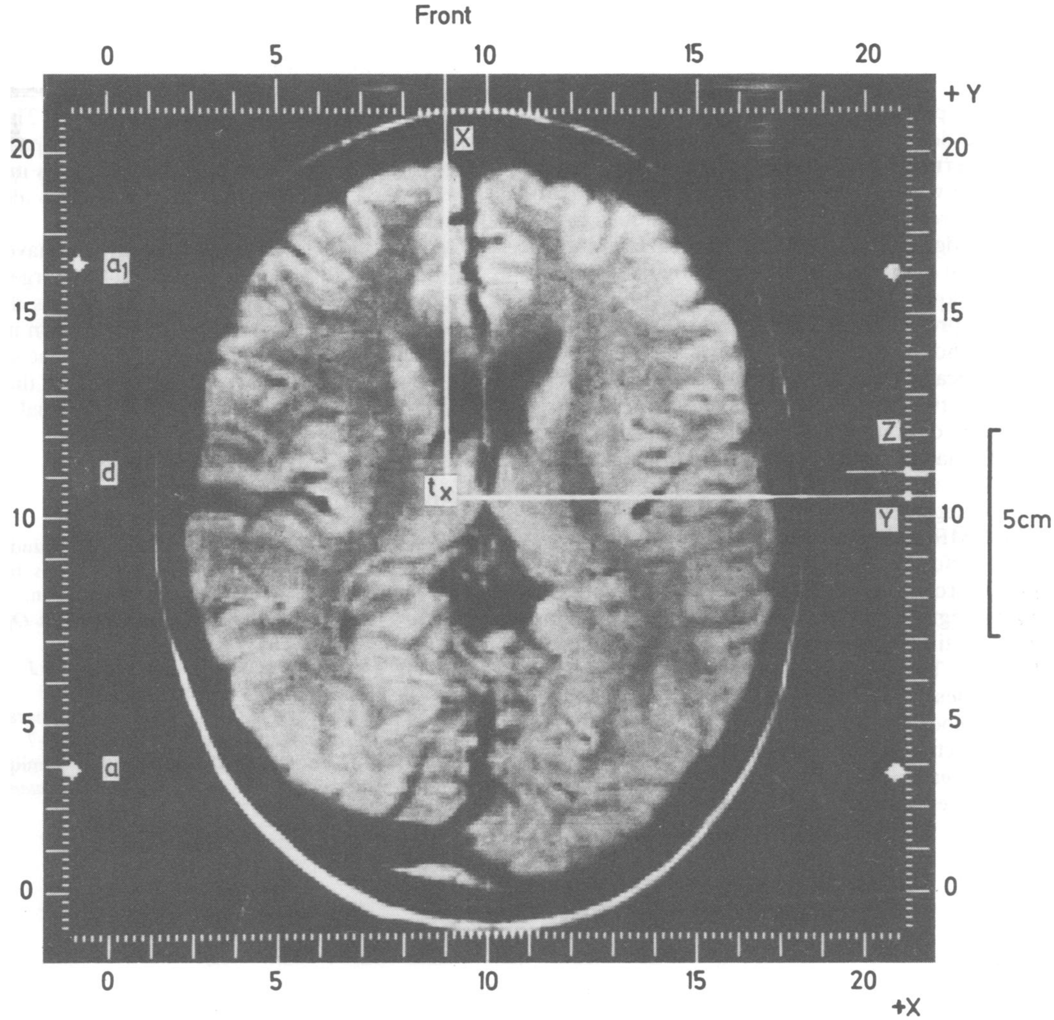

Fig 7 *The localisation procedure performed directly on the CRT screen by means of the millimetre scale incorporated in the computer software.*

Coordinate determination from the scan films. The film is superimposed on a semitransparent perspex disc with engraved coordinate scales. The disc and film are placed on top of a viewing box. The magnification of the engraved scales correspond with that of the scan and when the four feuducials on the film have been correctly aligned with the underlying scale, the X-, Y-, and Z-coordinates of the target are read off directly with the aid of a crossline ruler (fig 6).

Coordinate determination from the CRT screen. If a similar millimetre scale is displayed in correct relationship with the frame, the localisation procedure can be performed in the same way directly from the CRT screen of the NMR console. When the coordinate scales on the screen have been correctly aligned with the scan the target coordinates are rapidly obtained by placing the cursor on the target (fig 7). The three lines X, Y and Z are then automatically displayed and indicate the target coordinates on the respective scales. The software program can also display the target coordinates on the screen. The required computer software has been designed by Siemens Medical Systems.

Discussion

The development of nuclear magnetic resonance has made the depth of the brain visible to the surgeon with hitherto unattainable clarity and the method lends itself well to stereotactic work. To what extent NMR will replace other imaging techniques cannot yet be judged. However, for optimal stereotactic localisation of the target, compatibility with all imaging techniques, NMR, CT, angiography etc is a desirable prerequisite and the present system fulfills this demand.

In clinical practice brain imaging can now be divided in two parts: the diagnostic neuroradiology and the preoperative stereotactic localisation procedure. The latter is part of the therapeutic procedure. It is the surgeon's responsibility and should be closely integrated with the operation.

The NMR technique does not easily allow surgery to be performed directly in the scanner, in the operating room, as pioneered by Lunsford with CT,[5] but an integration of the image and the surgical procedure is still possible, with the NMR unit placed at a distance. The surgeon can use one of the two procedures described for the localisation, and determine the coordinates either from the film or alternatively directly on the CRT, by means of a separate satellite console in the operating room. The latter technique eliminates film processing and with the anatomical data stored on a floppy disc the required images can be easily reviewed by the surgeon during the operative procedure.

The present localisation technique is a simple visual method and if the surgeon wants to modify the preoperatively chosen target coordinates or to aim at other deep brain structures, this can be done in immediate connection with the operation. The accuracy depends mainly on how carefully the procedure is performed, and the risk for mistakes is minimal. The revised stereotactic coordinate scales also preclude confusion between right and left.

In the past stereotactic operations have been blind, precalculated procedures and the target localisation was usually based on more or less dependable reference structures. Now the modern imaging techniques, and particularly NMR, give the surgeon a kind of visual access to the depth of the brain which may be superior even to direct visual inspection.

References

1. Leksell L, Herner T, Leksell D, Persson B, Lindquist C. Visualization of Stereotactic Radiolesions by Magnetic Resonance. Submitted for publication.
2. Leksell L. *Stereotaxis and Radiosurgery. An Operative System.* Springfield, Thomas, 1971.
3. Leksell L. Stereotactic Radiosurgery. *J Neurol Neurosurg Psychiatry* 1983;**46**:797–803.
4. Leksell L, Jernberg B. Stereotaxis and tomography. A technical note. *Acta Neurochir* 1980;**52**:1–7.
5. Lunsford LD. Innovations in stereotactic technique coupled with computerized tomography. *Contemporary Neurosurg* 1982;**4(15)**:1–6.