Positional Marking and Instrument Tracking using ESR.

G. J. Ehnholm[1], M. Lindström[1], M. Seppälä[1]
[1]Philips Medical Systems MR Technology Finland Oy, Vantaa, Finland

Introduction: Therapeutic applications of MRI include image guided procedures and the use of MR images for planning of radiation therapy [1]. Several types of navigational devices, based on different technologies (e.g. optical, MR fiducials) for real-time tracking of surgical instruments and catheters have been developed, each with their own merits and limitations [2], [3]. For radiation therapy another need exists: Marking of points ("virtual fiducials") and exact outlining of the external patient contour in regions to be treated. For this use the tracking device must operate precisely in a rather large volume.

We have developed a system for both uses employing electron spin resonance (ESR). Here we describe its radiation therapy application.

Methods: The ESR system comprises a probe with electronics. The probe has a small crystal of radical-ion N-methylpyridinium.(TCNQ , volume ca. 0.7 mm3) in a 1 mm OD send/receive coil forming a tuned circuit with a Q-value of ~20. The coil (1-2 turns) is inside a 2 mm OD copper shield, which is soldered to the end of a flexible 2mm OD and 2 m long flexible microwave coaxial cable (Gore). The resonance frequency of the sample at the used field (0.23T) is 6.54 GHz. The FID is excited by a 50 ns pulse from the electronics unit, which also receives it through the same cable. The T2 is ~1 microsecond, and the repetition rate of the sequence is 2.5 microseconds. The FIDs are first averaged in the electronics unit by a digital signal processor, and subsequently analyzed to extract the value of the resonance frequency.

The MRI scanner uses a simple gradient sequence with four events: No gradient, x-gradient, y-gradient, z-gradient, repetition time 16 ms. A trigger pulse is sent to the ESR electronics unit for each repetition, which answers by sending back the corresponding probe frequencies. Using special sw the scanner calculates the x, y, and z positions of the probe from the frequencies obtained with the corresponding gradients active, minus the one without a gradient. In this way the positions become independent of the field homogeneity as long as its value is within the range of the ESR electronics ($\pm$ 0.3% of center field). The useful range for the probe is thus set by gradient linearity rather than by field homogeneity.

The scanner plots the acquired position values in real time (62.5 points /sec) as a trace on top of the image shown in the display. Gradient nonlinearity is modeled using a series of spherical harmonics functions of order 3,5,7, and 9, and corrected using an iterative method.

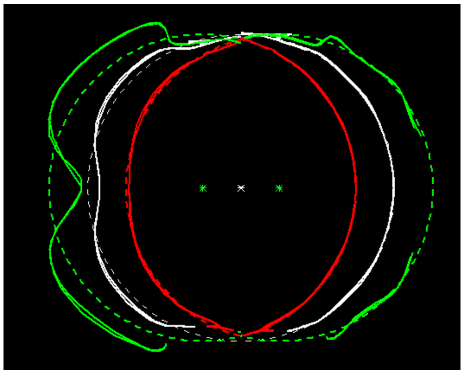

Fig.1. Circ. Segments, displaced by 0 and $\pm$5 cm from magnet center, respectively.

Results: The system was tested by measuring position along segments of 40 cm dia circles (dashed lines in Fig.1). Measured raw data is shown on the left and corrected on the right (solid lines). The correction algorithm worked within 24 cm from the imaging center. In Fig. 2 we simulate contouring the outline of a patient being scanned by placing two cylindrical phantoms each having a diameter of 22.5 cm side by side and wrapping a 4 mm ID nylon tube around them. The ESR probe was inserted into the tube and slid through it. The trace formed by the probe points, superposed on the MRI image (Field Echo, TE= 8 ms) is shown in the Figure, raw data on the left, corrected on right.

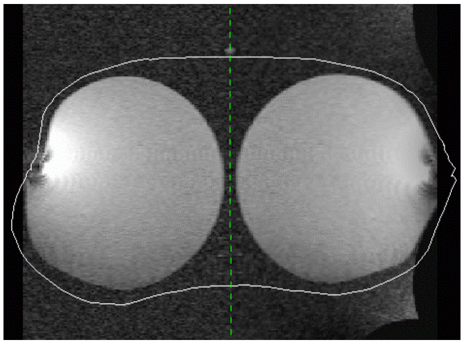

Fig.2. Water phantoms, 22.5 cm dia.

Conclusion: An ESR based navigator for marking and outlining the patient when preparing images for radiation therapy simulation and planning is described. It extends the useful volume of the magnet for marking significantly. Adding a 11th order term to the spherical harmonics and using ESR to calibrate it should further increase precision.

References:

[1] Chen L., Price RA Jr, Wang L, Li J, Qin L, McNeeley S, Ma CM, Freedman GM, Pollack A, "MRI based treatment planning for radiotherapy: dosimetric verification for prostate IMRT", *Int. J. Radiat. Oncol. Biol. Phys.* 60(2), pp. 636-647, 2004.

[2] Gesine G. Zimmermann-Paul, Mark E. Ladd, Thomas Pfammatter, Paul R. Hilfiker, Harald H. Quick, and Jörg F. Debatin, "MR versus Fluoroscopic Guidance of a Catheter/Guidewire Sys.: In vitro comparison of Steerability", J. Magn. Reson. Imag., 8(5), pp. 1177-1181, 1998.

[3] Michael Burl, Glyn A. Coutts, Ian R. Young, "Tuned Fiducial Markers to Identify Body Locations with Minimal Perturbation of Tissue Magnetization", Magn. Res. Med., 36, pp. 491-493, 1996.