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A Flexible Mercury-Filled Surface Coil for MR Imaging

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The use of surface coils in MR imaging allows for the possibility of obtaining images with increased signal-to-noise ratio and increased spatial resolution [1]. To obtain the maximum signal, the coil should be placed close to the region to be imaged. For rigid coils, a close fit may be difficult to obtain routinely and can lead to patient discomfort. We describe a technique for constructing flexible coils that use liquid mercury as the conductor. Mercury is the only metal that is a liquid at ordinary room temperature, and as such permits the fabrication of highly flexible coils.

Coil Construction

We have constructed a number of mercury surface coils by filling lengths of flexible plastic tubing with mercury and sealing the tube ends with plugs made from copper and epoxy cement. Figure 1 shows 33-cm and 48-cm lengths of the mercury-filled tubing so constructed; in this figure the end plugs of the 33-cm-long element have been soldered to tabs on a circuit board to form a one-loop coil. Figure 1 also illustrates the flexibility of the coil. For these coils, we used $5/32$-inch (0.4-cm) inside diameter tubing to contain the mercury and $1/4$-inch (0.6-cm) outside diameter copper tubing in making the end plugs; these dimensions are not critical. Figure 2 shows the relevant details of the end plug design, which was chosen to ensure good contact between the mercury and the copper. The copper serves as a point for soldering the coil to an electronic circuit used to tune the coil to the resonant frequency and match it to the receiver input impedance.

On the imager we are using (Philips Gyroscan), this tuning and matching is accomplished by variable capacitor diodes, contained on the circuit board shown in figure 1, and allows these operations to be done while the coil and patient are positioned inside the imager.

Image Acquisition

Data were acquired using a Philips 1.5-T Gyroscan superconducting imager operating at 0.5 T (21.347 MHz hydrogen resonance frequency) and the 33-cm coil positioned (fig. 3) to obtain an image in the region of the right temporomandibular joint. The exciting radiofrequency field was transmitted by a body coil, with the surface coil acting as a receiver only. Since the exciting radiofrequency field was in the vertical direction, there was minimal coupling between the surface coil and this field. A sagittal image (fig. 4) was obtained using a four-measurement multislice spin-echo pulse sequence with 500 msec TR and 30 msec TE; the image was acquired and reconstructed into a 256×256 matrix, with a 200-mm field of view and a slice thickness of 5 mm.

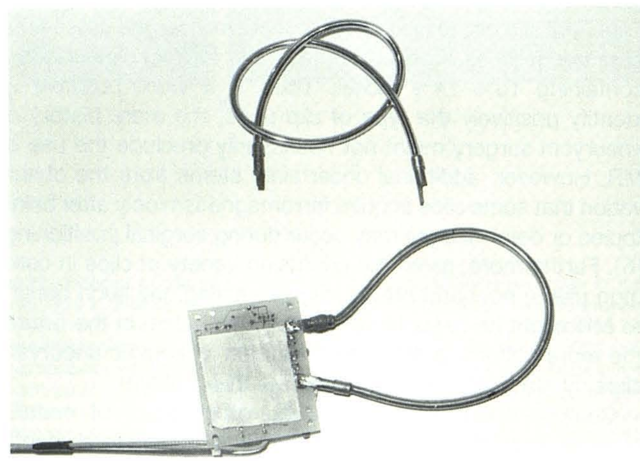

Fig. 1.—Two lengths of flexible plastic tubing, each filled with liquid mercury and sealed at both ends with copper and epoxy plugs. The two ends of one of the tubes have been soldered to a circuit used to tune and match the coil.

Discussion

The resistivity (r) of mercury is 55 times greater than that of copper, and this increase in resistance will increase the image noise. The noise, N, due to the intrinsic resistance, R, of the coil varies as $(R)^{1/2}$ [2]. However, the high-frequency current induced in the coil travels only in a thin outer layer of the conductor, parameterized by the "skin depth," D. Since R is proportional to r/D, and D is proportional to $(r)^{1/2}$ [3], we have that N is proportional to $(r)^{1/4}$. The effect of the mercury, therefore, is to increase the intrinsic noise by a factor of only 2.7. Since the resistance losses resulting from the patient must be added to the overall noise, and since this is expected to be the dominant term [4], the increase in resistance due to the mercury is not significant.

The image in figure 4 demonstrates that there is no fundamental obstacle to obtaining a clinically useful image with a surface coil made using liquid mercury as the conductor, while

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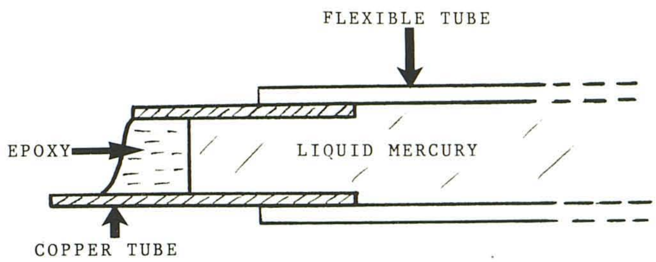

Fig. 2.—Essential details of end plug design.

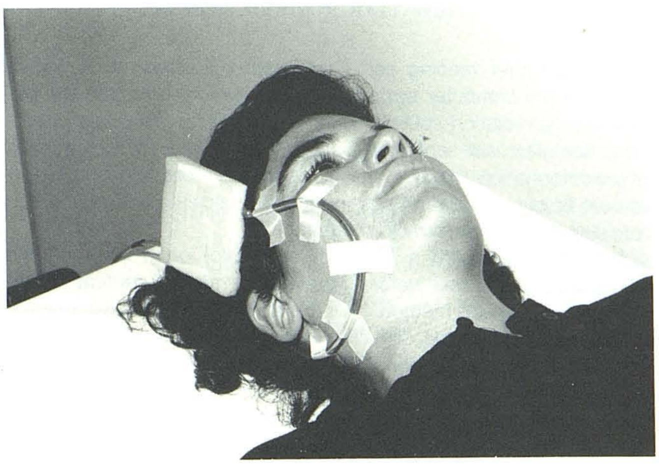

Fig. 3.—Coil positioned to obtain images in region of temporomandibular joint.

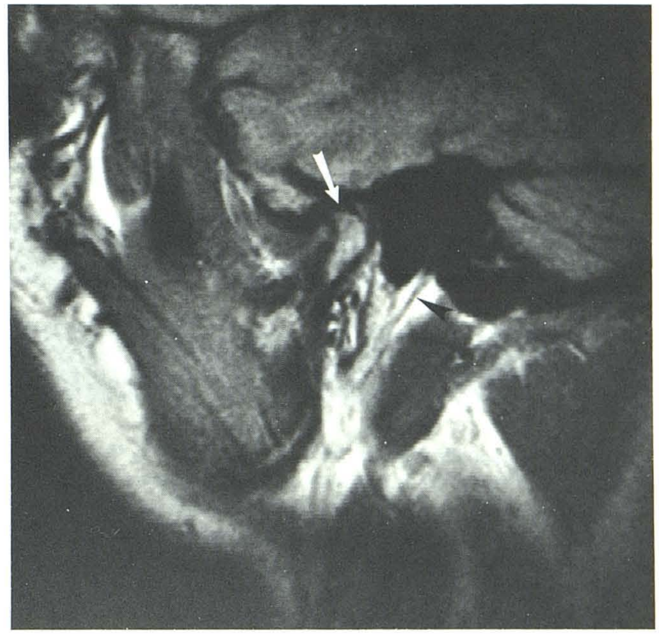

Fig. 4.—Parasagittal image of lateral aspect of temporal bone. Facial nerve is depicted as it exits stylomastoid foramen (*arrowhead*) and as it enters substance of parotid gland. Mandibular condyle and temporomandibular joint are well seen (*arrow*).

the mercury allows for more flexibility than can be obtained from a coil made of copper foil. However, the advantages, if any, to be gained through the added flexibility afforded by these coils, compared to other coils, is a question that will require a more detailed study.

Our first coil has been in use for a short period of time and we therefore have only limited experience with the long-term stability of these coils. For example, mercury is known to form an amalgam with copper, and this may at some time lead to a problem with the end plug design; if this should prove to be a problem, then aluminum can be substituted for the copper.

The great flexibility of the mercury coil may lead to problems on some imaging systems. The electronic circuit we have for tuning and matching to each patient is ideal when using a coil whose shape and hence electrical parameters may also vary. However, on imaging systems that do not have this option, or for which the dynamic range available for tuning and matching is limited, it may be difficult to obtain adequate tuning and matching.

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