Minimally Invasive Intracranial Robot (MINIR)

Rao P Gullapalli[1], Michael Kolz[2], Mingyen Ho[3], George Makris[1], Alan B McMillan[1], Marc Simard[2], and Jaydev P Desai[3]
[1]Magnetic Resonance Research Center, Department of Diagnostic Radiology & Nuclear Medicine, University of Maryland School of Medicine, Baltimore, MD, United States, [2]Department of Neurosurgery, University of Maryland School of Medicine, Baltimore, MD, United States, [3]Department of Mechanical Engineering, University of Maryland College Park, College Park, MD, United States

Introduction: Many patients cannot undergo primary surgical resection of their brain tumor and therefore are destined to a poor outcome and premature demise. Two most important reasons include an unfavorable location of the lesion, usually deep or otherwise inaccessible to conventional neurosurgical techniques, often seen with metastatic disease that places the patient at an undue risk for complications from complex brain surgery and general endotrachial anesthesia. A general solution that would overcome these problems would involve a "minimally invasive" neurosurgical intracranial robot (MINIR). Here we describe the development of a multi-digited MINIR that can be deployed through a narrow 'corridor' to approach and resect tumor, and will be capable of operating outside the 'line-of-sight', all under continuous MR imaging guidance.

Materials and Methods: A multi-degree-of-freedom MINIR with sufficient work volume and suitable actuation and control strategy to perform complete tumor electro cauterization was developed for use in the MRI environment.[1] Shaped memory alloy (SMA) actuators were used to actuate the various joints of the robot shown in Fig 1. The robot consists of revolute joints that are actuated by SMA wire. Two probe tips allow for electro cauterizing the tumor. The hollow core design of the robot allows for the passage of electrical wiring that can be used to actuate individual SMA actuators and activate electrocautery. Compatibility of the MINIR was tested both on phantoms and in the brain of the pigs. Gradient echo images with high temporal resolution were used (TE/TR/flip=4.0ms/5.0ms/25^{o}) when testing on gel phantoms doped with gadolinium. Image distortion and temporal signal to noise of the images was computed with no activation and during activation. To test the performance of MINIR in brain tissue, omentum was harvested from the peritoneal cavity of three Yorkshire pigs and implanted into the brain so as to 'induce a tumor' using conventional aseptic general surgical and neurosurgical techniques. The omentum thus implanted served as the tumor and provided a distinct contrast in comparison with the rest of the brain. The choice of omentum was also justified as it could be liquefied during the electrocautery procedure and can be drained. Structural T1-weighted images were obtained followed by dynamic images of the MINIR both in the actuated and non-actuated state. Effect on signal to noise and image distortion were assessed followed by a general assessment of the maneuverability of MINIR.

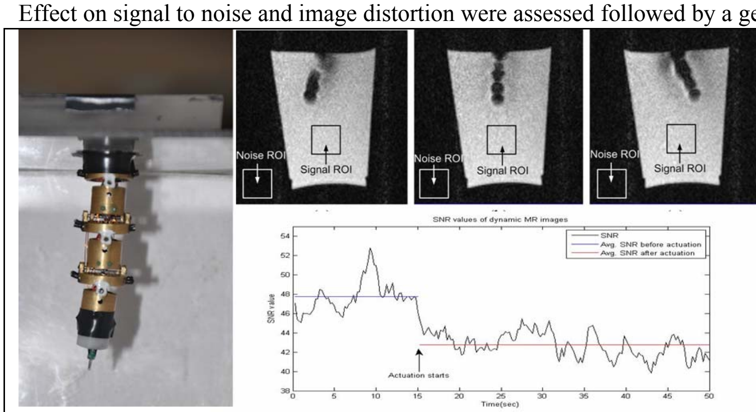

Figure 1. Picture of MINIR (left). Top right shows the MR images of MINIR within a gelatin phantom as it spans from left to right. The bottom graph shows the changes in signal to noise in the image as measured in the square ROI before and during the actuation. A minimal loss of signal is observed during actuation.

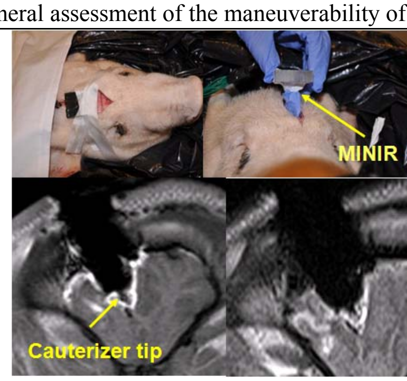

Figure 2. Top images show the bur hole made on the skull of the pig and the introduction of the MINIR The bottom images show T1-weighted and FLAIR images respectively. The MINIR tip can be seen clearly on both images with minimal artifacts. Bright signal around the MINIR is from the implanted omentum.

Figure 3. Blue arrow shows the opening made to incorporate omentum (bright signal shown by green arrow). The MINIR was introduced from the same opening actuated to target the 'tumor'. Shown here are images as the MINIR spans from the left to right. The MINIR tip (yellow arrow) can be clearly seen with minimal distortion.

Results: Figure 1 shows the MINIR and its operation in a gelatin phantom. As can be seen from this figure, each of the digits of MINIR can be easily distinguished even as it is being actuated. Spanning of the robot from left to right demonstrates no noticeable interference artifacts and very minimal B0 related signal loss (depicted by loss in signal in the phantom). As can be seen in the figure the drop in signal to noise in the overall image during the activation process is minimal (normal SNR 47.8 vs. 42.8 during actuation). The residual Bo signal loss around the MINIR is likely due to a few sharp edges that induce susceptibility artifacts from each of the brass digits. Figure 2 shows a picture of the MINIR and its introduction into the brain of the pig. Also shown in this figure is a T1-weighted MR image of the pig brain with the bright omentum that was introduced during the neurosurgical procedure providing a clear target for MINIR. There is minimal distortion of the MINIR tip on both the T1-weighted and FLAIR images. Figure 3 shows in vivo images of the pig brain with the actuated MINIR spanning from the right side of the 'tumor' to the left under real-time imaging. Notice the clear depiction of the electro-cauterizer without any distortion or signal loss, a very important and necessary feature for image guided neurosurgical interventions.

Conclusions: The prototype of a minimally invasive intracranial was successfully implemented and tested with minimum distortion and loss in image signal to noise. Future developments will focus on tracking the tip of the MINIR to enable navigation to effectively target the tumors.

Reference: Ho et al. Towards a Meso-scale SMA-Actuated MRI-Compatible Neurosurgical Robot", IEEE Transactions on Robotics, IEEE transactions in robotics, in press (NIHMSID # 320788)