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Minimally Invasive Deep Brain Stimulation Using Intracranial Stents

Kaitlin Hall
Department of Electrical and Computer Engineering
University of Utah
Salt Lake City, UT, USA
kaitlin.hall@utah.edu

Cynthia Furse
Department of Electrical and Computer Engineering
University of Utah
Salt Lake City, UT, USA
cynthia.furse@utah.edu

David Hasan
Department of Neurosurgery
University of Iowa
Iowa City, IA, USA
david-hasan@uiowa.edu

***Abstract*— Deep brain stimulation is a multipurpose therapy indicated for a host of neuropsychiatric disorders including treatment resistant depression, Parkinson's disease, and refractory epilepsy. However, current systems require invasive surgery and have a high risk of complications. This paper explores an alternative solution using non-invasive electrodes and an implanted intracranial stent. A comparison of active stimulation and passive stimulation at 915 MHz is presented.**

Keywords—deep brain stimulation, intracranial stent, external electrodes, major depressive disorder (MDD)

I. Introduction

Major depressive disorder (MDD) is a global health crisis afflicting more than 300 million people around the world. Despite holistic treatments of psychotherapy and antidepressant medications, up to 40% of MDD sufferers experience treatment resistant depression (TRD), enduring months of drug trials without any positive benefit. Clinical studies suggest that deep brain stimulation (DBS) is effective at producing a rapid reduction or even remission of TRD. Furthermore, these clinical studies indicate that the antidepressant effects of DBS can be maintained long-term [1], [2].

Despite the promising benefits of DBS for a host of neuropsychiatric disorders, today's DBS systems require open brain surgery to place the electrode deep in the brain, as well as surgery on the chest to place the battery pack [3]. Numerous complications are possible, including electrode migration, fracture, or malposition; infection and intracranial hemorrhage; and hardware-related failures [4]. One approach to reduce the risk of complications is to reduce the amount of hardware required in the DBS system. Previous research has proposed the use of active intra-arterial stents that have been designed, with wires attached, to stimulate areas of the brain that are near brain vasculature [5]-[7]. These are the same stents that are used to support vasculature suffering an aneurism. They are inserted through the vein/artery in a minimally invasive surgical procedure, which is much simpler than DBS surgery.

This research expands on previous work by comparing an active stent (wire and battery remain connected to the stent) [6] to an alternative DBS system which is wireless and would eliminate the need for the internal battery pack and open brain surgery. This proposed method places an arterial stent near the target area. Electrodes or antennas outside the head would deliver electromagnetic fields to the head, and the metal stent would act as a re-radiator to augment the fields and focus them on the region to be stimulated. We explore three types of stent configurations – an active stent (wire / battery connected), a passive straight stent stimulated by electrodes outside the head, and a passive curved stent (representative of a stent placed in the curved vasculature in the head).

II. Simulation Environment

A human head analog was created in CST Microwave Studio. The model was constructed of cubic tissue layers of brain, skull, fat, and skin overlaying each other. A hollow steel cylinder modeling an intracranial stent was implanted in the center of an artery located at the center of the brain tissue layer. A cross-sectional view of the model is shown in Fig. 1. A dispersive model of each biological material's dielectric properties was generated from [8] and loaded into the material library in CST, enabling field characterization from 1 MHz to 2450 MHz. In this work, we focus on the results obtained at 915 MHz.

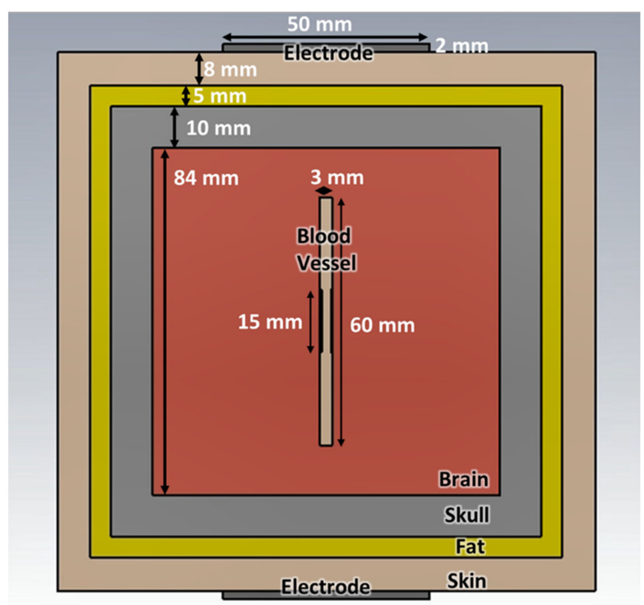

Fig. 1 Human head model for passive deep brain stimulation using an intracranial stent and external electrodes.

III. Active Stent Stimulation

The first simulation mirrors what has been done in previous literature by attaching a wire to the end of the stent to supply power [6]. This topology is similar to that in Fig. 1, but the external electrodes are replaced with a wired connection to the stent, shown in Fig. 2a. A 100 mA current source was used as a maximum input signal, and the electric field pattern was calculated. We observe in Fig. 2b that the fields concentrate around the stent in a dumbbell shape that is mostly concentrated in the artery and less in the surrounding brain tissue.

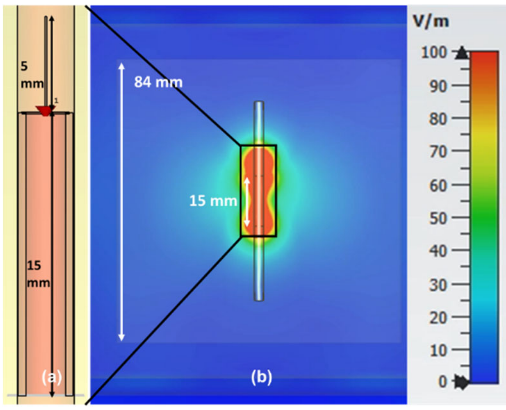

Fig. 2 Electric field distribution for the actively powered stent shows that the fields are mostly concentrated in the artery and the immediate tissue.

IV. Passive Stent Stimulation

A passive stent, shown in Fig. 1, could use external electrodes (in this case, with a 0.5 W excitation signal) to transmit fields into the body, where they could concentrate on the tips of the stent. We observe from the electric field distributions in Fig. 3 that a significant portion of the signal is absorbed in the skin and fat layers located immediately next to the exciting electrode. The electric field that makes it into the brain tissue is insufficient for stimulation. However, comparing Fig. 3a (no stent) with Fig. 3b (implanted stent) indicates that the presence of the stent enhances the electric field intensity.

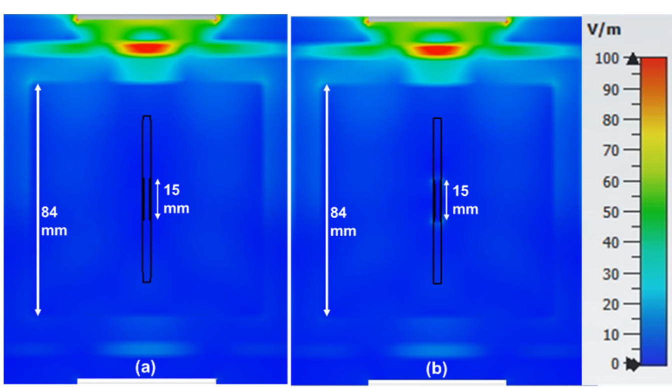

Fig. 3a electric field distribution in the absence of the stent and 3b with the implanted stent.

This effect is further enhanced when a bend in the vasculature and stent is added as seen in Fig. 4. This suggests that we may be able to take advantage of natural curvature within the vasculature of the brain to further enhance the field strength without the presence of a direct wired connection.

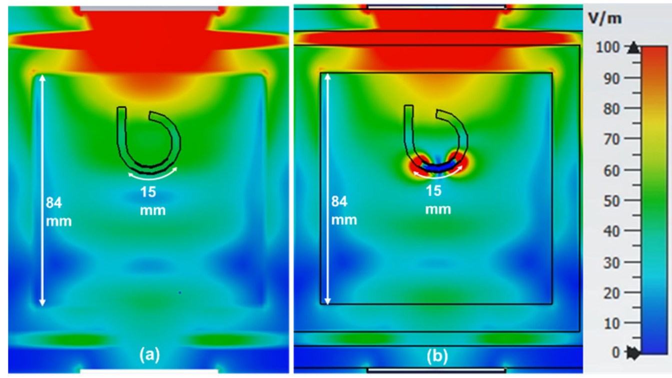

Fig. 4a Electric field distribution without the stent and 4b with the implanted stent.

V. Conclusion

In this paper, we see that the active stent provides the best electrical stimulation, however it has the disadvantage of requiring an internal wire and battery pack. The passive straight stent did not provide strong enough field augmentation. In future work we will try different external electrode or antenna configurations or changes to the stent. The curved stent, however, had significant field enhancement, potentially sufficient to enable stimulation. In all cases, the conductive blood plays a significant role and cannot be neglected.

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