Investigating Electromagnetic Interference in Intraoperative Monitoring and a Telemetric Solution

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***Abstract* — Intraoperative neurophysiological monitoring (IONM) is commonly used as an attempt to minimize neurological morbidity during spine surgery. Transcranial motor evoked potentials (TcMEPs) are one of the signals commonly monitored as part of IONM, in which the motor cortex of the subject is stimulated with electrical pulses and the evoked potentials are recorded from the regions of interest. Our pilot investigations demonstrated that this cumbersome wired system is vulnerable to electromagnetic interference (EMI) produced by other operating room (OR) equipment.**

By eliminating lengthy recording wires can we potentially remove the EMI induced in the IONM signals; hence, we are proposing the development a telemetric system to acquire TcMEPs. The proposed wireless system can potentially be used to reduce the preoperative setup time, unclutter the operation room for surgical staff, and reduce wire-related risks for patients during the operation.

***Index Terms* — Wireless intraoperative monitoring, Electromagnetic interference, Transcranial motor evoked potentials.**

I. Introduction

Intraoperative neurophysiological monitoring (IONM) is commonly used in a number of surgical procedures including neurological, orthopedic, and vascular surgeries. IONM is used to examine the integrity of the spinal cord, peripheral nerves during surgery, and reduce the risk of neurological morbidity. IONM relies on various electro-biological signals such as transcranial motor-evoked potentials (TcMEPs), in which the patient's cerebral motor cortex is transcranially stimulated with electrical pulses, the evoked responses are recorded from the distal limb muscles. If the evoked potentials disappear or show any significant deviation from baseline measurements, the surgeons are immediately alerted of possible neurological compromise and they can take corrective actions to prevent a permanent neurological deficit. Despite the critical role of the IONM and in particular TcMEP, currently–available systems to acquire such signals suffer from various limitations and more importantly are vulnerable to electromagnetic interference (EMI).

A typical IONM session requires up to 40 to 60 lead wires, typically 1.5–2.5 m in length, for stimulating and acquiring signals during spine surgery. There are three major concerns with the current wired systems. First, it takes significant time to set up such a large number of electrodes and verify all the proper connections, because of the multitude of wires laying across the operating room (OR) on the floor or hanging over other equipment. Second, the numerous lengthy lead wires limit the maneuverability of the surgeons, nurses and staff during the long hours of operation, contributing to a cumbersome surgical area in the OR. Finally and most importantly, the EMI caused by many monitoring and supporting equipment surrounding the operating bed in the OR, affects the signal integrity of the evoked potentials. Therefore, we hypothesized that substituting the long lead connection wires with telemetric communication technology can solve the interference problem.

According to the best of our knowledge, the only telemetric system developed for acquiring TcMEPs was established by our group [1]. However, the previous system was capable of acquiring from only a single channel at a time, a disadvantage compared to the wired system, and it utilized an analog transmitter that still can be affected by EMI.

In this proposal, we first investigated and document EMI on a standard (wired) IONM acquisition machine. Then we developed a wireless system that can record IONM signals wirelessly. Finally we tested our developed wireless system, side by side a conventional wired system to demonstrate that the EMI does not affect the wireless system.

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II. Methodology and System Configuration

Identifying and Quantifying EMI: We visited Texas Scottish Rite Hospital for Children (TSRHC) in Dallas and investigated the EMI caused by equipment in an OR and effects on TcMEPs. We generated pseudo-IONM signals with signal generator and utilized a gold standard IONM system (Cadwell Cascade™) to acquire the signals. Testing methods for investigating the EMI effects were designed based on the American National Standards Institute recommendation (ANSI C63.18) [2]. The EMI effects were restored during the visits and interference effects were analyzed based on the changes in the amplitude, frequency and signal to noise ratio.

Wireless IONM Acquisition: The wireless system comprised a front-end and a back-end. The front-end consists of an analog board, an ADC, a microcontroller (μC) and a 2.4-GHz transceiver. The analog board conditions the signals through a two-stage amplification and band-pass filtration. The amplified signals were sampled, digitized, put into packets, and sent by the transceiver, which utilizes Gaussian frequency-shift keying modulation. Packets were received in the back-end and sent to a computer via serial communication where a graphical user interface (GUI) displays the data in parallel panels. [3]

III. RESULTS

A- *Wireless Recording of TcMEPs in Animal Experiments*: Typical evoked potentials recorded simultaneously with the wired and wireless systems are shown in Fig. 2. The upper tracing represents the evoked potential obtained from the front limbs. The first three peaks (dashed-line arrows), with an interval period of 2 ms, correspond to stimulation artifacts. Stimulation artifacts did not appear in the hind limbs. However, the amplitudes of the potentials were generally smaller compared to those obtained from the front limbs. During IONM, baseline evoked potentials are established prior to the surgery and any significant deviation is interpreted as abnormal. Significant deviation could include sudden reduction of waveform amplitude or disappearance of the waveform. Comparing the amplitudes of the largest positive peaks (solid-line arrows) of signals from the four limbs, amplitudes of 4484μV and 4440 μV, 2911μV and 2850 μV, 1272μV and 1211 μV, 595 μV and 560 μV were obtained for the wired and wireless systems, respectively. The similar magnitudes and waveforms recorded wirelessly, validated by the wired system, demonstrated the fidelity in signal detection of the wireless system. The repeatability of the wireless system was also demonstrated on the animal model.

B- *EMI Effects on Signal to Noise Ratio (SNR):* Table 2 shows the calculated SNRs for the wired and wireless systems, at different distances from the EMI sources (the temperature control unit, the C-Arm X-ray machine, and the combination of the two). The SNRs for the wired system in the proximity of the temperature control unit were considerably lower than the SNRs in the proximity of the X-ray machine.

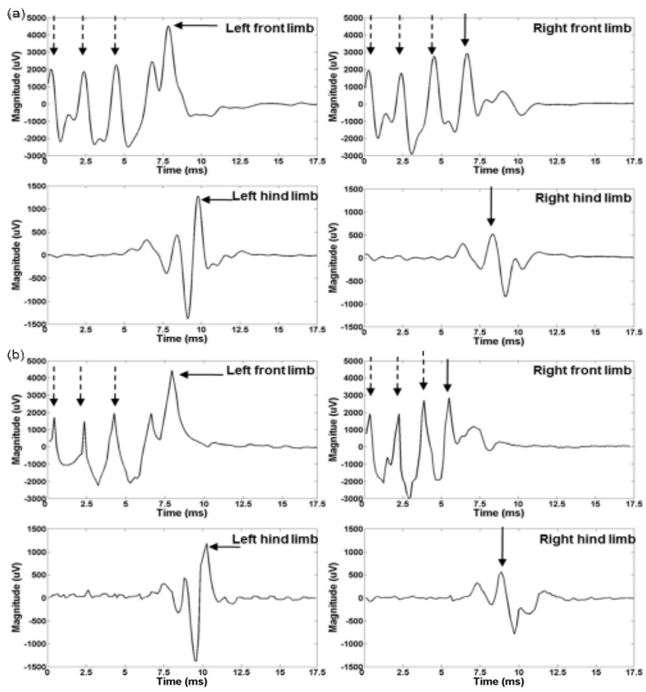

Fig. 1. Typical recording of TcMEPs with (a) wired and (b) wireless systems. Dashed-line arrows indicate the stimulation artifacts, and solid arrows indicate the largest peaks in responding signals.

		Bair Hugger		**C-Arm**		**Bair Hugger & C-Arm**	
Distance (cm)	Amplitude (μVp-p)	Wired System	Wireless System	Wired System	Wireless System	Wired System	Wireless System
0	10	-1.41	17.31	12.89	17.85	-7.74	17.44
	20	4.61	21.14	17.11	24.29	5.25	23.25
	30	8.30	25.81	19.30	25.58	7.12	25.34
	50	11.93	28.21	23.87	28.17	11.27	27.38
2.5	10	-0.82	17.18	13.39	17.65	-1.83	17.22
	20	4.76	21.30	17.70	23.87	5.85	22.73
	30	2.67	24.93	19.16	25.42	8.46	24.58
	50	12.26	29.37	24.41	28.74	12.26	27.49
5	10	-6.38	17.03	12.71	17.38	-2.50	17.24
	20	5.11	22.75	18.28	24.20	5.76	24.01
	30	8.46	25.27	19.30	25.80	8.60	25.32
	50	10.78	27.53	23.92	29.08	12.99	27.82
10	10	-0.45	17.67	14.15	17.79	-0.45	17.54
	20	8.94	23.42	18.64	24.43	8.94	23.08
	30	8.46	25.42	20.70	25.94	8.46	25.66
	50	10.78	27.88	22.21	27.98	10.78	27.56
20	10	3.69	17.42	15.12	17.85	3.35	17.58
	20	11.60	23.11	18.31	24.19	11.60	24.26
	30	13.35	25.88	20.42	26.29	14.87	25.31
	50	16.20	29.46	24.85	27.35	17.45	29.08
30	10	13.89	17.67	19.42	17.85	8.16	17.83
	20	17.84	23.42	21.34	23.85	13.62	23.56
	30	19.67	25.42	25.62	25.91	16.43	25.34
	50	21.16	27.88	—	—	18.52	28.25
40	10	17.70	17.27	20.38	18.01	13.39	17.12
	20	19.49	23.21	23.90	23.98	18.52	23.33
	30	22.06	25.83	—	—	20.56	25.69
	50	—	—	—	—	—	—

Signal to noise ratio (in dB) calculated for the wired and wireless systems in the proximity of the EMI

Career Development: Inspired by applications of microwave and wireless technology in the medical field, I would like to pursue my graduate studies after having at least 5 years in the industry under the supervision of Dr. Farajidavar and join respected companies which are conducting cutting edge research in the field of biomedical instrumentation to conduct research in wireless health, to give a better quality of life.

Conference Impression: This has been my first professional conference I attended and I was very astonished by the new technologies being develop over the world with so many collaborations. There were a couple presentations that I had no words for the applications being used. This conference motivated me to keep working until there is a great publication in which I am the author.

REFERENCES

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