Importance of avoiding DC in KHFAC nerve block applications

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ELECTRIC nerve block with applications ranging from blocking pain to spasticity has been achieved with a variety of waveforms in the past. Two of the most widely studied are High-Frequency Alternating Current in the kilohertz range (KHFAC) and direct current (DC) signals. While both waveforms can produce instantaneous and complete conduction block in the nerve beneath the electrode, recovery post-block has differed: nerve block achieved with *KHFAC waveforms* is *reversible* without affecting nerve conduction long-term, and generally results in complete recovery of nerve conduction in the first seconds post termination of KHFAC block waveforms. *DC signals,* on the other hand, generally cause a lasting effect on nerve conduction, especially after repeated application. DC-currents in the range from 0.1 to 0.5 mA have shown to produce complete s*hort-term nerve block with partial or complete recovery after a few (<10) applications*. The application of *continuously applied* DC waveforms, however, has been found to result in nerve block and damage at much smaller thresholds: common thresholds are 2µA for the cochlea [1], 3µA for the central nervous system (CNS) [2-3], and 6µA for the peripheral nervous system (PNS) [4]. In order to ensure the long-term safety of KHFAC applications, it is important to ensure that KHFAC waveforms are not contaminated with DC-levels beyond the mentioned limits.

I. Methods

We explored the likelihood for unwanted DC-contamination of KHFAC waveforms in two current-controlled waveform generators and two voltage-controlled waveform generators. A 1 kHz sinusoidal signal, generated by the stimulator being tested, was applied across a bipolar spiral cuff electrode suspended in 0.9% NaCl saline. The two platinum contacts each had a $1 mm^2$ surface area and provided and electrode impedance of 1.28kΩ for 1kHz sinusoidal signals. Two inline-capacitors of 1µF each were placed between the generator and the electrode. Two large inductors of 8.2H (at 1kHz) were placed on the stimulator and the electrode side of the capacitors, providing a DC-shunt. The inductors could be switched in and out of the circuit for comparison testing. Data were recorded for later offline analysis using the National Instruments USB DAQ-6258 at f_{Sample}=20kHz with both channels set as floating vs. GND. All measurements were verified using two Agilent TDS2004c oscilloscopes with 100MΩ probes, both on battery-powered floating power supplies, used to monitor the potential on the stimulator output side and across the electrode in saline.

II. Results and Conclusion

We were able to show that both, voltage-controlled and current-controlled signal generators can unintentionally add DC-contamination to a KHFAC signal at levels that could potentially produce block or damage. Voltage-controlled systems are less prone to DC-contamination than current-controlled systems. We furthermore demonstrated that large value inductors can be effective at eliminating DC-contamination irrespective of the type of stimulator, without having a significant impact on the kHz component of the waveform. Concluding this study, we were able to show the importance of a careful measurement of electrode potentials when using KHFAC waveforms to provide nerve block and present data supporting the possibility that some of the effects attributed to KHFAC could be due to DC-contamination in applied waveforms. If KHFAC waveforms are used with (unintentional) DC-contamination, then unexpected effects of neural block or even neural damage can be the result, potentially compromising chronic efficacy and/or safety of the approach.

III. References

[1] R. K. Shepherd, J. Matsushima, R. E. Millard, and G. M. Clark, “Cochlear pathology following chronic electrical stimulation using non charge balanced stimuli,” Acta Otolaryngol., vol. 111, pp. 848–860, 1991.

[2] R.J. Hurlbert, C.H. Tator, E. Theriault, “Dose-response study of the pathological effects of chronically applied direct current stimulation on the normal rat spinal cord,” J Neurosurg, vol. 79, pp. 905-916,1993.

[3] N. Islam, M. Aftabuddin, A. Moriwaki, Y. Hattori, Y. Hori, “Increase in the calcium level following anodal polarization in the rat brain”, Brain Res., 684 (1995), pp. 206–208

[4] N. Bhadra, K.L. Kilgore, “Direct current electrical conduction block of peripheral nerve”, IEEE Trans Neural Syst Rehabil Eng 12(3) 2004:313-24.

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