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Evaluation of the Accuracy and Electrical Properties of the Thai Peripheral Nerve Stimulator for Neuromuscular Blockade Assessment

Thewarug Werawatganon*,Tayard desudchit**, Jerdkul Sopavanit***, Korranis Pirompanich*, Kamonchanok Tengwongderm*, Atisatan Karin*

**Department of Anesthesiology, Faculty of Medicine, Chulalongkorn University,Thailand*

***Department of Pediatrics, Faculty of Medicine, Chulalongkorn University,Thailand*

****Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University, Thailand*

Background: Many practice guidelines recommend using a peripheral nerve stimulator during anesthesia with muscle relaxants to improve patient safety; however it is not widely available in our country. Thus, a locally manufactured peripheral nerve stimulator was designed. This study was aimed to evaluate the electrical characteristics and accuracy of these peripheral nerve stimulators.

Materials and methods: Peripheral nerve stimulators (TOF-watch and Thai locally-manufactured) were set to deliver a train of four stimulation at 50 mA currents into a resistance loads ranging from 500 to 7000 ohm which represented the range of patient skin resistance, in same standard temperature and relative humidity. The current output, stimulus duration, waveform morphology, and maximum voltage output were studied using a factory-calibrated digital oscilloscope.

Results: The stimulation was performed 66 times for each peripheral nerve stimulator. One sample t-test demonstrate the current output was higher than set current (50mA) in both models ($P < 0.001$, 2.207 [2.050-2.365] vs 3.993 [3.643-4.343] for TOF-watch and Thai peripheral nerve stimulator respectively). These small differences of the stimulus current output should not affect clinical measurement. The morphology of the stimulus performed by both models was characterized by a regular monophasic rectangular pulse at all resistance loads. However, both mean rise time (17.18 vs 6.86 microseconds) and decay time (13.12 vs 1.44 microseconds) were lower in Thai peripheral nerve stimulator ($P < 0.001$).

Conclusions: According to the electrical characteristic measurement from this study, the Thai peripheral nerve stimulator was comparable to TOF-watch and further use in patients should be studied.

Keywords: Accuracy, Electrical characteristic, Neuromuscular monitoring, Peripheral nerve stimulator, TOF-Watch.

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Introduction

In modern anesthesia era, non-depolarizing neuromuscular blocking agents have been increasingly used as a significant component in general anesthesia. There is variability in the duration of action of this kind of muscle relaxant so the effect is unpredictable without the monitor. Therefore, the residual neuromuscular blockade could be detected in up to 40% patients for up to two hours after their administration.[1]

According to many practice guidelines,[2, 3] peripheral nerve monitors should be applied and used from induction until recovery from blockade and return of consciousness to improve patient safety.[4-8] However, the popular peripheral nerve stimulator distributed in our country, TOF-Watch[9], was recently discontinued and no further maintenance anymore.[10] Due to this

Correspondence to : ThewarugWerawatganon, M.D., E-mail: thewarug@hotmail.com

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problem, we produced the "locally-made simple peripheral nerve stimulator" which will be called "THAI peripheral nerve stimulator (THAI PNS)". We aimed to evaluate the accuracy and electrical properties of the train of four stimulation delivered by this THAI peripheral nerve stimulator before to study in patients.[11]

Materials and Methods

A prototype of THAI peripheral nerve stimulator was designed and tested in the Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University (Figure 1A). The detail of the latest stable version was shown in Figure 1B. THAI peripheral nerve stimulator machine had electrical schematic diagram consisted of the control circuit and high voltage circuit (Figure 2). Reproduction of this instrument is allowed for patient benefit and the detailed diagram is available on request to the corresponding author.

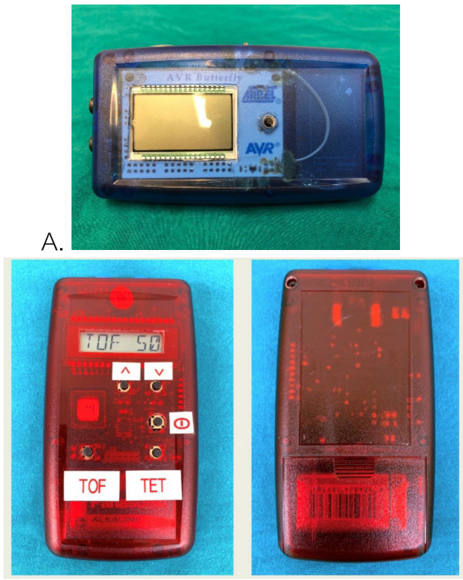

Figure 1 A. A prototype of peripheral nerve stimulator (version 1) was designed and tested in the Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University. B. The current stable version of THAI peripheral nerve stimulator, no hanging problem and low battery consumption.

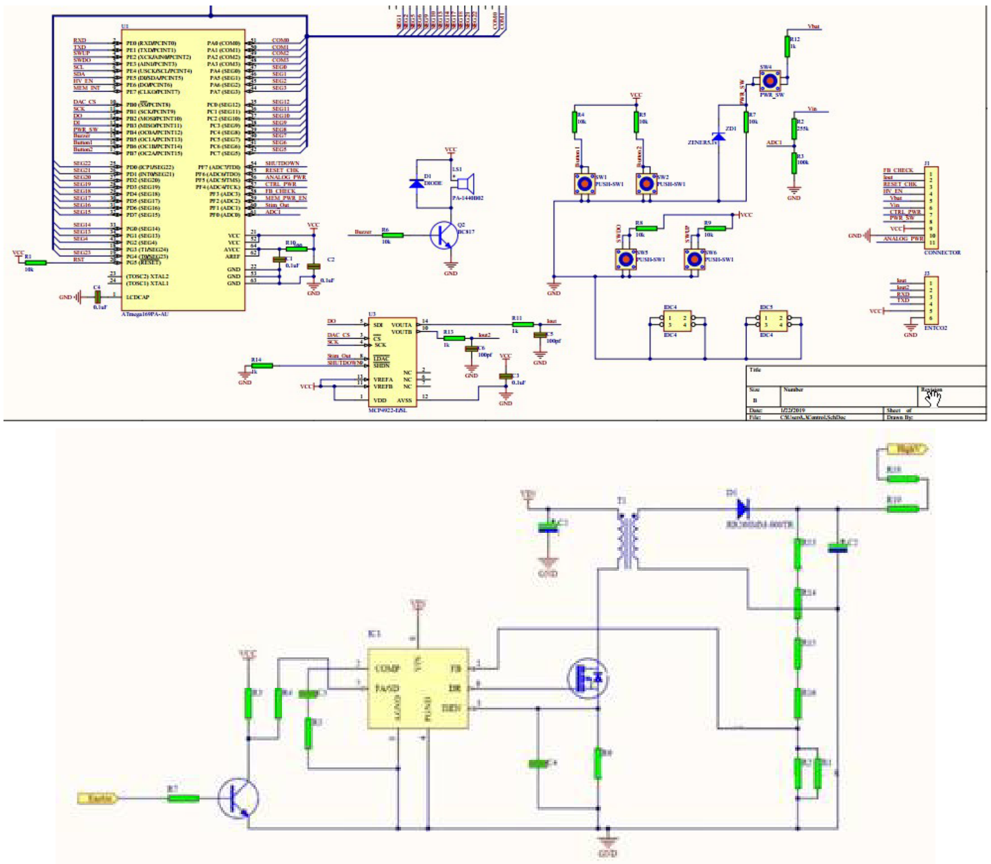

Figure 2 The control circuit and high voltage circuit in THAI peripheral nerve stimulator machine respectively.

Peripheral nerve stimulators (TOF-watch and THAI PNS) were fitted with fresh batteries and set to deliver a train of four stimulations at 50 mA current into a series of high-tolerance resistance loads. We hypothesized that "There was no difference in the accuracy of constant delivered current output (mA) from THAI peripheral nerve stimulator from the set current value 50 mA". The primary objectives were to evaluate the accuracy of the actual current output of stimulation from THAI PNS and TOF-Watch compared with the set current value. The secondary objectives were to evaluate the suitability of stimulation waveform morphology from both peripheral nerve stimulators. We measured the electrical properties of TOF Watch and THAI PNS with the factory-calibrated oscilloscope (figure 3). We increased the resistance load from 500, 600, and 700 until 7000 ohms which represented the range of patient skin resistance. The study was conducted in the control environment, standard room temperature (20-25oc), standard relative humidity (%RH 35-55), shielding for the electrical and magnetic field.

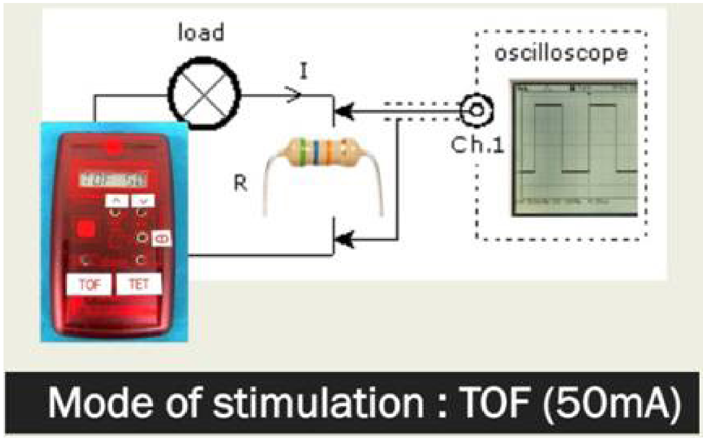

Figure 3 The nerve stimulator was connected in serial to the resistance load and the oscilloscope.

The current output (mA), morphology of stimulus waveform including following parameters: rise time (microsecond) which defined as time from 10% to 90% amplitude, decay time (microsecond) which defined as time from 90% to 10% amplitude, impulse duration (microsecond), existence of overshoot and existence of undershoot was studied using a factory-calibrated digital oscilloscope.

Data Analysis and Statistics

Accuracy of the current delivered by both peripheral nerve stimulators was analyzed by one-sample t-test for the difference from standard current setting, 50 mA. Continuous data(rise time, decay time, impulse duration) were reported as mean and standard deviation and the difference was analyzed by paired t-test. Categorical data (existence of overshoot and undershoot) were reported as numbers or percentage. All information was analyzed by Statistical Package for the Social Sciences (SPSS for Windows, version 24.0, SPSS Inc., Chicago, IL, USA)

Results

The stimulations were performed 66 times for each peripheral nerve stimulator. One sample t-test demonstrated that the current output were higher than set current (50mA) in both models ($P < 0.001$, 2.207 [2.050-2.365] vs 3.993 [3.643-4.343] for TOF-watch and THAI PNS respectively (table 1).

Table 1 Mean and standard deviation of the actual current output of each peripheral nerve stimulator.

Actual current output	THAI PNS (n= 66)	TOF Watch (n= 66)
Mean (SD) mA	53.99 (1.425)	52.207 (0.641)
Difference from 50 mA (95% CI)	3.993 (3.643-4.343)	2.207 (2.050-2.365)
P-value	P < 0.001	P < 0.001

The morphology of the stimulus obtained from both models was characterized by a regular monophasic rectangular pulse at all resistance load measurement. However, mean rise time (17 vs 6.86 microseconds) and decay time (13.12 vs 1.44 microseconds) were lower in Thai model (Table 2).

Table 2 Mean and standard deviation of the stimulus waveform morphology parameters including rising time, decay time, impulse duration, the existence of overshoot and existence of undershoot of each peripheral nerve stimulator.

Waveform morphology	THAI PNS (n= 66)	TOF Watch (n= 66)
Rise time (SD) (microsecond)	6.862 (2.650)	17.180 (2.866)*
Decay time (SD) (microsecond)	1.441 (0.322)	13.120 (0.691)*
Impulse duration (SD) (microsecond)	204.760 (0.978)	201.820 (2.887)
Existence of overshoot (percentage)	0 (0%)	0 (0%)
Existence of undershoot (percentage)	0 (0%)	0 (0%)

* P < 0.001

Discussion

We had designed a simple and practical peripheral nerve stimulator so that it will be available for use according to current practice guideline to improve anesthesia safety.[12,13] We study the electrical output property from this THAI PNS and TOF-Watch. We evaluated the accuracy of the output with the known standard value because TOF-Watch output also had some deviations from the standard which might be better or worse than THAI PNS.

Both TOF-Watch and THAI PNS resulted in the significantly higher delivered current output than set current (50 mA) (P< 0.001, 2.207 [2.050-2.365] vs 3.993 [3.643-4.343]). These small differences of the stimulus current output should not affect the clinical measurement significantly.[14] Less than 5 mA increase above 50 mA usually does not change the train of four response count, so some peripheral nerve stimulators have a dial for current adjustment at 5 or 10 mA step for train of four output.

The stimulus waveform morphology was monophasic rectangular waveform in both PNS. However, THAI PNS demonstrated more ideal rectangular due to slower rise time and decay time. This was resulted from the difference in circuit design. THAI PNS was over-designed to have power to give near ideal rectangular waveform. Both PNS gave a series of four rectangular waveforms at 2 Hz which elicited "suitable" train of four twitches for using as neuromuscular blockade monitoring.[15] For this simple THAI PNS model, the degree of the neuromuscular blockade would be evaluated by the visual or tactile response. A reliable method to record twitch movement is still questionalble.[16] Sometime it is overestimated or underestimated.

This study has limitations that it was an equipment study using resistance load to simulate patient skin resistance in the control environment. We plan to do further clinical trials later to show that THAI PNS can be safely used for neuromuscular monitoring during anesthesia. Therefore clinical application should be waiting.

Conclusions

According to the electrical characteristic measurement from this study, the Thai peripheral nerve stimulator was comparable to TOF-watch. Further study in patients for neuromuscular monitoring during anesthesia should be performed before clinical use.

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