Development of multi sensor array electrode and programmable multi-channel electrical stimulator

S. H. Kim, G. C. Park, J. H. Kim, S.W. Baik, G. R. Jeon

***Abstract*—The multi-sensor array electrode (MSAE) and the programmable multi-channel electrical stimulator (PMCES) were developed for preliminary study to fire trigger point (TP) of the patient with myofascial pain syndrome (MPS). The MSAE has 25 Ag/AgCl electrodes arranged in the form of array (5X5) fabricated with flexible pad, which are applicable to be easily-attached to the specific curved region of human body. Each channel was to generate-various electric stimulus patterns (ESPs) by changing parameters, that is, mono-phasic or the bi-phasic of ESP, On/Off duration of ESP, the time interval between ESPs, and amplitude of ESP. The PMCES consisted of 5 channels. The PMECS hardware was composed of Host PC, programmable electric stimulus pattern generator (PESPG), and the MSAE. In Host PC, the software of the PMCES was developed in the form of graphic user interface (GUI) using LabVIEW2010 to generate ESP, to transfer the generated ESP to PESPG, and to perform the function of receiving the measured signal from the MSAE.**

Micro controller unit (MCU) was separately composed of main micro controller unit (MMCU) and sub micro controller unit (SMCU) in order to operate efficiently the PMCES. MMCU performs to drive the generated ESP by PESP editing program of PC and to control each channel of SMCU. SMCU performs the function to apply the generated ESP to the MSAE after generating ESP. Three experiments were performed using the MSAE and the PMCES as the following. First experiment was performed on four types of pattern (sine, square, triangle, sawtooth waveforms) among the ESPs edited in PC, and four patterns were displayed on PC screen. Second experiment was performed to evaluate the function for each channel of SMCU in PESPG. Third experiment was conducted on whether ESP applied from each channel of SMCU in PESPG was focused on the electrode which was set to the ground, after applying ESP being output from each channel of PESPG in SMCU to the MSAE.

***Index Terms*—Myofascial Pain Syndrome (MPS), Trigger Point (TP), Multi Sensor Array Electrode (MSAE), Programmable Multi-Channel Electrical Stimulator (PMCES), Electric stimulus pattern (ESP)**

I. Introduction

Muscle of the human musculoskeletal system, distributed in human body and accounting for 40% of body weight, is one of the most dynamic organization governing the movement and posture. Thus, muscle is one of the organs of the musculoskeletal being affected by the various functional disorders or the structural damages due to the fatigue caused by long-term excessive activity, and the sprain caused by sudden external force. The myofacial pain syndrome (MPS) is the disease with the highest onset frequency among causes of muscular pain and chronic pain in the disease of the musculoskeletal system [1].

The MPS is the pain syndrome induced in muscles and fascia, and the diseases that are sensitive to the external and internal stimulus because trigger points (TPs) occur within the neuromuscular and skeletal muscle. TPs are very sensitive tender point occurring within muscles, and some of the muscle fibers are formed as taut band. When the pressure stimulation is applied to the taut band, MPS patients feel a severe pain and the twitch response generated by muscle contraction. Then, the metastatic pain is generated. The metastatic pain occurs in various ways such as dulling, stabbing, and tingling pain. When TP is more sensitive, the metastatic pain is stronger and spreads out widely over the body [2],[3]. While TP is being generated, the articulation movement is restricted by disharmony of autonomic reflex and the muscle attenuation as well as metastatic pain [4]. In addition, the pain occurs even in the resting state as well as the motion of stretching or contracting [5]. Further, the referred pain occurs in a specific region according to the muscle that TP occurs, often accompanying by the chronic musculoskeletal diseases [6].

Different from other diseases of the musculoskeletal, the MPS cannot be diagnosed with the aid of diagnostic equipment such as X-ray, CT, and MRI. Thus, the MPS diagnosis is usually performed by patient medical history, observation of posture and gait pattern, muscle strength at pain region, the tension of muscles, the motion range of associate joint in the region where TP is suspected, and the palpation of muscle. In clinical, a taut band has been searched by palpating the region suspicious of TPs or applying tenderness to that region. When twitch response, jumping response, and metastatic pain occur, they are diagnosed as the MPS. Recently, the tender threshold has been evaluated by applying the pressure to suspected regions within the muscle using the algometer. In order to search for body heated points with disc-shape, thermography has been used in the diagnosis of the region of metastatic pain.

In the clinical field, MPS treatments have been accomplished by diathermy, stretching and spray, ischemic compression and massage, behavior therapy, pain parenteral therapy, electric stimulus, needle and drug therapy, and etc. Among these treatments, the electric stimulus has been used as a pain therapy method from 1970's. Electrical stimulation therapy has been reported to be an effective therapeutic method for reducing the pain [7],[8]. Electrical stimulation may contribute to reduce the intensity of pain because of

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S. H. Kim, Dept. Interdisciplinary Program in Biomedical Engineering, Pusan National University, Yangsan-si, Gyeungsannam-do, Korea, 82-51-510-8119.

G.C. Park, Dept. Interdisciplinary Program in Biomedical Engineering, Pusan National University, Yangsan-si, Gyeungsangnam-do, Korea, 82-51-510-8119.

J. H. Kim, Dept. of Computer Simulation, Inje University, Gimhae-si, Gyeungsangnamdo, Korea, 82-55-320-3206.

S. W. Baik, Dept. of Anesthesiology and Pain Medicine, College of medicine, Pusan National University, Yangsan-si, Gyeungsannam-do, Korea, 82-51-510-8119.

G. R. Jeon, Dept. of Biomedical Engineering, School of Medicine, Pusan National University, Yangsan-si, Gyeungsangnam-do, Korea, 82-51-510-8119.

facilitating the process of waste products by improving blood circulation [9]-[11]. It has been also widely used in the field of human treatment and rehabilitation [12]-[15].

In pain clinic, the approximate location of TP has been searching for using the algometer and the electromyogram (EMG) for MPS patients. The treatments to alleviate the pain have been performed by putting the needle into the region of TP or applying an electric stimulus after attaching electrodes to the region that is estimated to TP. However, intensive treatment has not been achieved for TPs that are distributed in several regions of the body because these electrical stimulators have a limited number of electrodes that can be attached to the pain regions.

In this study, the multi-sensor array electrodes (MSAE) and the programmable multi-channel electrical stimulator (PMCES) were implemented for firing TPs of MPS patients. Experiments were performed using the MSAE and the PMCES. First experiment was performed to evaluate the function of PESPG for each channel of SMCU. Second experiment was conducted on whether ESP applied from each channel of PESPG in SMCU was being focused on the electrode set to the ground, after applying ESP being output from each channel of PESPG in SMCU to the MSAE. For the focusing experiment, three ESPs being output from the PESPG were connected with three electrodes of the MSAE, and then, the ground line was connected with one electrode in the MSAE.

II. METHODS

To fire TP of MPS patients, the MSAE and the PMCES were implemented in this study. The MSAE was fabricated in the form of pad arranged in an array (5 × 5) of 25 Ag/AgCl electrodes, which was made of a flexible material easily attached to the specific curved regions with flexion in human body. The PMCES was composed of 5-channels.

Specifications of ESP generated in each channel of SMCU are as follows. The sine, square, triangle, and sawtooth waveforms were generated in the basic forms of ESP. And four types of ESPs such as single twitch, tetanic pulse, train of four (TOF), and double brust stimulation (DBS) were to be generated, which have currently used as ESP in clinical field. A programmable electrical stimulus pattern generator (PESPG) was implemented to generate various ESPs for user desire. Various ESPs were to be generated in PESPG by varying parameters such as mono-phasic or bi-phasic of ESP, time interval between stimuli, amplitude of ESP, and etc. Table 1 shows the specification and function of PESPG.

Table - 1. Specification and function of PESPG

Contents	Specification
DC power supply	· Output voltage: ± 15 V, + 5 V · Maximum output current: 1 A at DC ± 15 V, 2 A at DC ± 5 V · Maximum output power: 1.5 watt when duty rate is 50% · Impedance between input and output port: 100 MΩ
Input power	· AC Voltage and frequency: 220 V ± 10%, 50 ~ 60 Hz
Type of electric stimulus pattern	· Sine, Square, Triangle, Sawtooth waveforms · Single twitch, Tetanic pulse, Train of four (TOF), Double brust stimuli · Programmable electric stimulus pattern (PESP)
Pulse duration time and time interval in PESP	· Duration time of pulse/TOF stimulation: 10 ~ 50 ms/20 ~ 100ms · Time interval between stimuli/ TOF stimuli : 10 ~ 100ms · Frequency: 1 ~ 100 HZ
Output peak to peak voltage and current in PESP	· Peak-to-peak voltage (V_{pp}): Mono-phasic (20 ~ 100 V_{pp}), Bi-phasic (40 ~ 200 V_{pp}) · Current: 1 ~ 30 mA
Enduring voltage	· Break down or enduring voltage: 1500 V/min.
Function and composition unit of main micro controller unit (MMCU)	· Function - Communication with PC and driving control of PESPG - Driving control of PESP edited by S/W in PC · Composition unit: - Communication between MMCU and PC - Memory capable of storing program code - Power supply unit for supplying a stable voltage to MMCU
Function and composition unit of sub micro controller unit (SMCU)	· Function: Generation of various electric stimulus patterns · Composition unit: - Communication between MMCU and SMCU - Signal conversion unit converting analog signal to digital PESP - Constant current unit for generating constant current signal by voltage - current conversion - H-bridge circuit for generating PESP - Amplification unit for generated PESP - Isolation unit for electrical safety of the subject
DAC	· Resolution: 8 bit · Settling time of output current: 100 ns
Electric safety	· Isolation transformer: Shield transformer

Fig. 1 shows the block diagram of system consisting of the MSAE and the PMCES implemented in this study. Commercial Ag/AgCl electrodes were placed in the horizontal and vertical placement of 5 × 5 in the MASE. The size is designed as follows. Horizontal and vertical size is 95 mm, electrode diameter is 10mm, and distance between electrodes is 12 mm. The PMCES was composed of Host PC and PESPG. Each function is as follows. First, in Host PC, the system software was developed in the form of graphic user interface (GUI) using the LabVIEW2010 (LabVIEW, National Instruments Corp., USA) to perform the function of transferring the generated PESP to PESPG, and to receive the function of measured signal from the MSAE. Second, SMCU was composed of driving unit for ESP generated by the editing program of PC, MMCU for controlling each channel of SMCU, and SMCU for performing ESP function per each channel. SMCU was composed of digital to analog converter unit (DACU), current to voltage converter unit (CVCU), constant current unit (CCU), H-bridge circuit unit for outputting of bi-phasic ESP, amplification unit for firing H-bridge circuit, and isolation transformer unit for electric safety.

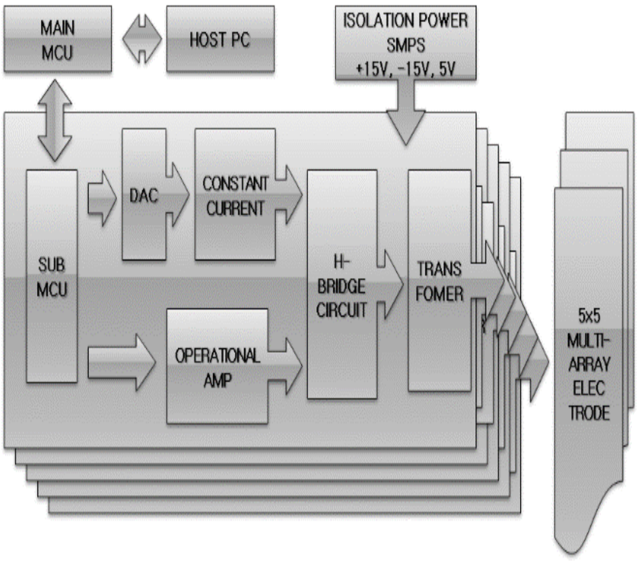


Fig. 1. Block diagram of PMCES and MSAE.

III. Implementation of MSAE and PMCES

A. *Implementation of the MSAE*

The MSAE was implemented to fire TPs of the MPS and chronic pain patients. As shown in Fig. 2, 25 Ag/AgCl electrodes was placed in the horizontal and vertical 5×5 arrays in the MSAE. The width and length of electrode are 95 mm, the diameter of the electrode is 10 mm, and the distance between the electrodes was 6mm. The MASE pad was fabricated by a flexible silicone material to allow the easy attachment of the MASE to various regions of human body that TPs exist. Ag/AgCl electrodes with gel were used to reduce the contact resistance between the electrode and the skin. Snap electrodes were used to connect the probe of Ag/AgCl electrodes with the top of the MASE. The back area was divided into adhesive pad and electrode area. To reduce electrical resistance between electrodes, and to maintain the minimum distance between electrode and probe, component elements at the back side of electrode were designed as shown in Fig. 3.

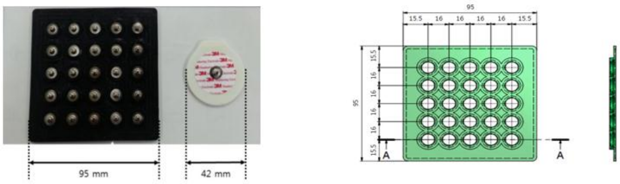


Fig. 2. Appearance and design drawing of MSAE: (a) appearance, (b) design drawings.

Fig. 3. Probe arrangement and design drawing of MSAE: (a) probe arrangement, (b) designed drawing at the back side of electrode.

B. *Hardware implementation of the PESPG*

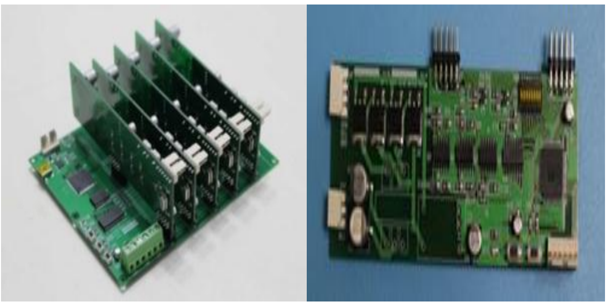
Hardware of the PESPG was composed of power supply unit and MCU. The MCU consisted of MMCU and SMCU. SMCU consisted of DAC, CVC, H-bridge circuit, amplification unit for triggering H-bridge circuit, and isolation transformer unit. Function and implementation methods for each unit are as follows.

B-1. Power supply unit

A constant voltage source (CVS) was produced for supplying a stable voltage to the PMCES. Switching power supply was fabricated using power module (PW-30-3CX, Semipowertec. Co., Korea). The specification of CVS was as follows. The input voltage was the power supply (220 V, 50/60 Hz), the output voltage was ±15 V DC and +5 V DC, and the maximum output current was set to 1A in ±15 V DC and 2 A in +5 V DC. For the electrical safety of a user and the circuit, the isolation impedance between input and output was set to 100 MΩ, and the enduring voltage was set to 1500 V/min, respectively.

B-2 Micro controller unit

In order to efficiently control the PMECS, MMCU board and SMCU board were separately implemented from MCU. The communication with PC and the function of driving the PESP edited by system software in PC were to perform MMCU board. To perform these functions, MMCU board was composed of communication unit for communicating with PC, memory unit capable of storing the program, power supply unit for supplying a stable voltage to the system. MCU and SMCU board were implemented as shown in Fig. 4. SMCU board was to perform the function of generating various ESPs. For this, SMCU board was composed of DACU for converting the programmed ESP to an analog signal, CCU for generating a constant current signal by converting voltage to current, H-bridge circuit for generating PESP, amplification unit for the generated PESP, isolation unit for electrical safety of the subject, electrode unit for applying ESP via the electrode attached to TPs region of human body, and MMCU for controlling SMCU board.



(a) (b)

Fig. 4. PCB of one MMCU and SMCU with five channels: (a) MCU and SMCU board, (b) SMCU board.

B-3 DAC and CVC

A high-speed 8 bit digital to analog converter (DAC, 0800LCN, Motorola Co., USA) was used for outputting ESP from MMCU to SMCU. DAC was selected because it generated an analog output current within 100 ns and had the low power consumption (33 mW) at ±15 V and the robust to the noise. DAC output was converted to the voltage through CVC designed by using operational amplifier (OP Amp).

B-4 Constant current source

A constant current unit (CCU) module (RCD-24-0.50, RECOM POWER Co., USA) was used to generate a constant current stimulus pattern. CCU has a range of voltage range of 4.5 ~ 36 V, output voltage of 2 ~ 32 V, and maximum output current of 500 mA. Output voltage from DAC can adjust the output current using CVC because it controls the function for an analog dimming. The voltage range used for dimming was 0.13 V in On current and 4.2 V in Off current, the resolution was 12 mA/0.1V, and the adjustment range of current was 0 ~ 500 mA. Fig. 6 shows the printed circuit board (PCB) of implemented CCU.

Fig. 5.PCB of implemented CCU.

B-5 H-bridge circuit unit

For a fast control and response of PESPG, H-bridge circuit was implemented using a fast switching power MOSFET device (IRF740, STMicroelectronics, Korea). This device was adapted to generate various PESPs changing in fast time (ms) because it had the drain-source voltage (V_{DS}) of 400 V, and the gate driving voltage of 10 V, and the time difference of 17 ns between turn on time and cross over time. The bi-phasic PESP was to be output using H-bridge circuit consisting of four IRF740 devices. In addition, the polarity (mono-phasic or bi-phasic) of PESP, On/Off time and the period of pulse, the time interval between stimuli, and the frequency were to control through MOSFET gate of H-bridge circuit in SMCU. A designed H-bridge circuit is shown in Fig. 6.

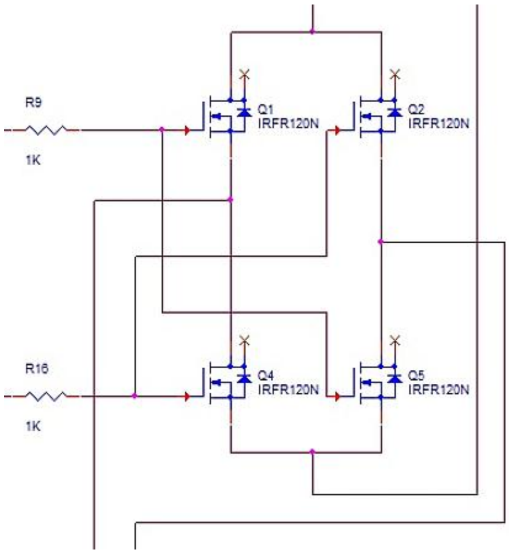


Fig. 6. Designed H-bridge circuit unit.

B-6 Amplification unit for triggering H-bridge circuit

In order to trigger IRF740 used in H-Bridge circuit, the gate of IRF740 was triggered using TL064 device after amplifying the pulse being output from SMCU. TL064 can turn on the gate of IRF740 at a high speed because it is capable of being operated at a low current (200 μA) and has a high input impedance and the slew rate (3.5 V/μs). The gate of H-Bridge circuit was triggered using IRF740 to quickly generate PESP transferred from MMCU.

B-7 Isolation transformer

For the electrical safety of patient, the output of the shielded transformer was applied to the MSAE after inputting PESP generated by H-bridge circuit into shielded transformer. The shielded transformer was isolated to protect patient, user, and peripheral circuit from the leakage current and a ground fault. The impedance/maximum voltage of the primary section and the secondary section of the shield transformer was 1000 MΩ/500 V, respectively. And the output voltage of the shielded transformer was set to 100 V_{pp} in the case of mono-phasic pulse and 200V_{pp} in the case of bi-phasic pulse, respectively.

C. System software of the PESPG

The editing software of PESP capable of generating four types of ESP in the clinical and the various PESPs in engineering field was developed. The system software was developed in the form of the GUI using LabVIEW2010 in order that PESP editing software was to interface between PC and PESPG hardware, and to edit a variety of PESPs. Fig. 7 showed the program of the developed PESPG, and Fig. 8 illustrated the square waveform of edited PESP on screen for example.

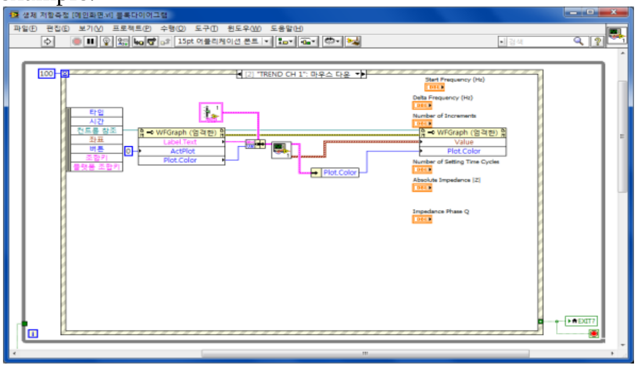


Fig. 7. PESP program developed using LabVIEW2010.

Fig.8. Square waveform of edited PESPs.

The PESP editing software was composed of communication program between PC and MMCU, generating and editing program for PESP, and input/output program of data and file of the edited PESP. The setting and calculation of all parameters related to the generating and editing of PESP was performed in PC to reduce the load of MMCU, and these results were transferred to MMCU via the serial communication. Parameter related to generating and editing of PESP was divided into ESP and PESP. ESP was divided into four types of patterns (single twitch, tetanic pulse, train of four stimulus, double brust stimulus) used in the clinical field and four types of patterns (sine, square, triangle, sawtooth) used in the engineering filed. PESP was composed to generate a variety of ESPs or the patterns combined with various ESPs. A variety of PESPs were generated by setting amplitude, mono-phasic/bi-phasic, period, frequency, On/Off time of pulse, pulse interval for each ESP and PESP to secondary parameters.

IV. Evaluation Experiment of PESPG System

A. *Evaluation experiment of the ESPG*

Experiment was performed for evaluating the editing function of the PESP. And experiment was also performed on whether the edited PESP was exactly output to each channel of the SMCU.

First experiment was performed on four types of pattern generations among ESP edited in PC. Fig. 9 shows that four types of ESPs (sine, square, triangle, sawtooth) were displayed on PC screen with 25 channels. ESP in the middle of Fig. 9 illustrated the sawtooth waveform whose parameters were set to amplitude of 0.6 V, period of 0.2 ms, and bi-phasic. A variety of sawtooth waveforms could be generated when the parameters such as amplitude, period, mono-phasic or bi-phasic, On/Off time, and frequency were varied.

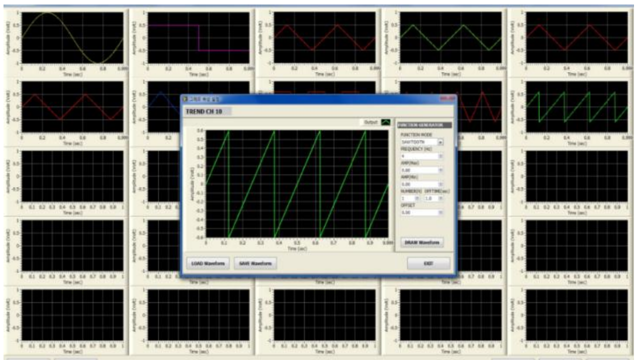


Fig. 9. An editing screen for sawtooth waveform (in middle screen of Fig. 9), and generating screen with 25 channels for sine, square, and triangle waveform.

Second experiment was performed on whether the edited PESP for each channel of SMCU was independently output, by downloading the PESP information edited in PC. Fig. 10 shows the pattern on three bi-phasic square waveform ESPs edited in PC. The output waveforms of three channels of SMCU were observed using oscilloscope.

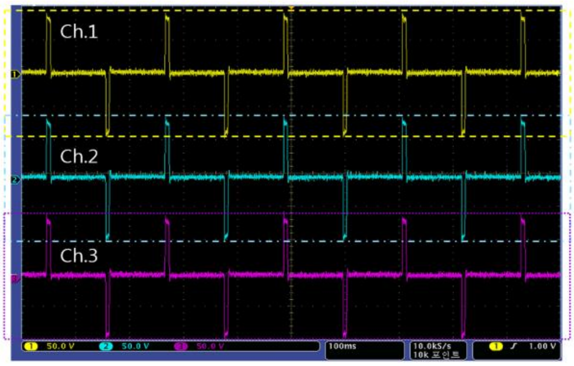


Fig.10. Output waveforms observed at three channels of SMCU.

B. *Experimental result of the focused ESP*

Experiment was performed to observe whether the square waveform ESPs output from PESPG in SMCU were focusing to the center electrode (return point in Fig. 11) of the MSAE. Parameters of ESPs output from PESPG in SMCU were set to pattern of square waveform, polarity of bi-phasic, pulse interval of 100 ms, pulse On / Off time of 10/90 ms, and pulse amplitude of 60 V on ESP editing program in PC. After setting three square waveforms of ESP on the editing program of PC, three square waveforms were transferred to MMCU. After being generated from ESPG in SMCU, these waveforms were applied to three electrodes of the MSAE.

Fig. 11 shows the experimental configuration for observing the focusing phenomenon of applied ESPs to the MSAE. The attaching positions of the MSAE on the left forearm are as follows. Three electrodes (input point 1, 2, 3) and a ground electrode (RP, return point) consisting of 5×5 electrodes were attached to the MSAE: input point (IP) 1 was attached to the position (1, 3) of the MSAE, IP 2 to the position (5, 5) of the MSAE, IP 3 to the position (5, 1) of the MSAE, and RP to the position (3, 3) of the MSAE. Here, the distance between IP 1 and RP was 24 mm, the distance between IP 2 and RP was 24 √2 mm, and the distance between IP 3 and RP was 24 √2 mm. The test point (TP) was also attached to the left carpal. And the voltage and the current between RP and TP were measured as follows. First, the voltage and the current between RP and TP were measured after an applying square waveform ESP to IP 1. Second, the voltage and the current between RP and TP were measured after simultaneously applying the same square waveform ESP to IP 1 and IP 2. Third, after simultaneously applying the same square wave ESP to IP 1, 2, and 3, the voltage and the current between RP and TP were measured using oscilloscope and multi-meter (Fluke 287, Fluke Co., USA), respectively.

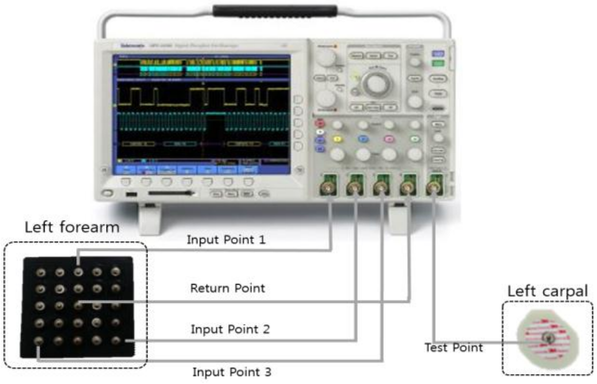
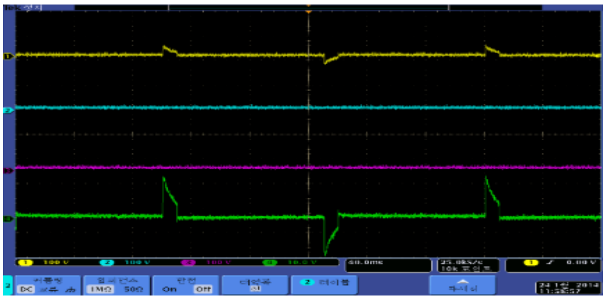
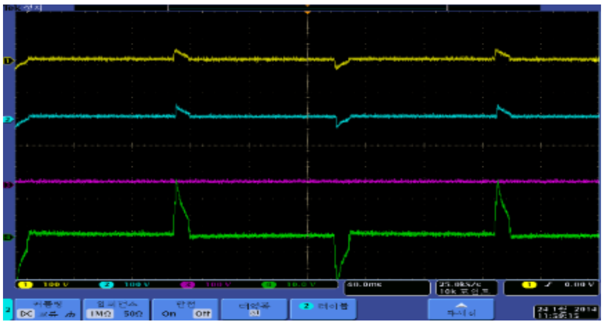


Fig. 11. Experiment configuration for observing the focusing phenomenon of ESPs applied to the MSAE.

The experimental results were illustrated in Fig. 12 and table 2. Fig. 12(a) shows the measured voltage between RP and TP after applying a bi-phasic square waveform ESP to IP 1. Fig. 12(b) shows the measured voltage between RP and TP after applying bi-phasic square waveform ESP to IP 1 and 2 simultaneously. Fig. 12(c) shows the measured voltage between RP and TP after applying bi-phasic square waveform ESP to IP 1, 2, and 3 simultaneously. As shown in Fig. 12, the voltage measured in Fig. 12(c) was observed higher than that measured in Fig 12(a) and (b). Experimental results indicated that ESPs applied to IP 1, 2, and 3 were being focused to RP simultaneously.



(a)



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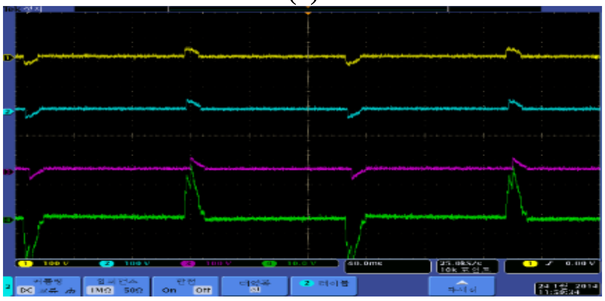

(c)

Fig. 12. The voltage measured between RP and TP after applying the bi-phasic square waveform ESP to electrodes of the MSAE: (a) when ESP is applied to IP 1, (b) when ESPs was applied to IP 1 and 2, simultaneously (c) when ESPs were applied to IP 1, 2, and 3, simultaneously.

Table 2 shows the measured current flowing from RP to TP. As shown in Fig. 12, the voltage and the current measured between IP 1 and RP were 60 V and 2.25 mA, respectively, after applying ESP (60 V, square waveform) to IP 1 of the MSAE. Similarly, the voltage and the current measured between IP 2 and RP were 60 V and 2.23 mA, respectively, after applying ESP to IP 2 of MSAE. The voltage and the current measured between IP 3 and RE were 60 V and 2.27 mA, respectively, after applying ESP to 1P 3 of the MSAE. The differences of measured currents are caused by differences in the skeletal muscle mass and body composition of the forearm region where the MSAE is attached. In addition, when ESP (60 V, square waveform) was only applied to IP 1 of the MSAE, the voltage and the current measured between RP and TP were 18.8 V and 1.69 mA, respectively. When same ESPs were applied to IP 1 and IP 2 of the MSAE, the voltage and the current between RP and TP were 22.0 V and 4.17 mA, respectively. When same ESPs were applied to IP 1, 2, 3 of the MSAE, the voltage and the current between RP and TP were 24.4 V and 6.77 mA, respectively. These experimental results indicated that the voltage and the current between RP and TP increased because the voltage and the current were focused to RP when ESPs were applied to electrode of the MSAE simultaneously.

Table – 2. Results of the focused voltage and the focused current from return point to test point

	The voltage and the current measured between IP and RP when square wave ESP was applied to IP 1, 2, 3			The voltage and the current measured between RP and TP when ESPs were applied to IP 1, IP 1, 2 and IP 1, 2, 3		
Electrodes	IP 1 - RP	IP 2 – RP	IP 3 - RP	IP 1	IP 1 & IP 2	IP1 & IP 2 & IP 3
Applied ESP voltage (V)	60	60	60	60	60 & 60	60 & 60 & 60
Measured voltage (V)	60	60	60	18.8	22.0	24.4
Measured current (mA)	2.25	2.23	2.27	1.69	4.17	6.77

Legend:
IP: input point, RP: return point

The experiment was performed by applying the identical ESP to the MSAE in this study. When various ESPs were applied to each electrode of the MSAE, the voltage and the current between the MSAE and RP were measured differently. This phenomenon was due to the fact that the voltage and the current were focused to RP. Thus, when various PESPs are applied to TPs, it would be possible to fire the minor TPs and the major TP simultaneously. The characteristics of minor TPs is thin and slightly hard whereas the characteristics of major TP formed with taut band is thick and solid. These TPs exist around the TP regions.

V. Conclusion

For the purpose of effectively firing TPs of the MPS patients, the PMCES capable of focusing PESP to TPs was implemented using the MSAE and PESPG. Three experiments were performed to evaluate the function of the PMCES. The experimental results are described below.

First, experiment was performed for evaluating the editing function of PESP. That is, four types of ESPs (sine, square, triangle, sawtooth) were edited by changing parameter for ESP generation in PC. When four types of ESPs were displayed on PC screen with 25 channels, it was confirmed that EPS corresponding to the setting of various parameters was generated.

Second, experiment was conducted on whether the edited PESP was independently output to each channel of SMCU, by downloading PESP information edited in PC to MMCU. In other words, when three bi-phasic square waveform ESPs edited in PC were independently output to three channels of SMCU, the patterns were observed with oscilloscope, confirming the output of square waveform ESP. However, the distortion of square wave occurred at rising and falling time is due to the time constant of RC.

Third, experiment was performed to observe the phenomenon that the square waveform ESPs applied from PESPG of SMCU was focusing to RP of the MSAE. ESPs being applied from PESPG of SMCU to the MSAE were set as follows: the pattern is square wave, polarity is bi-phasic, pulse interval is 100 ms, pulse On/Off time is 10/90 ms, and pulse amplitude is 60 V. After parameters of ESP had been set in the editing program of PC, three square waveform ESPs were transferred to the MMCU. ESPs of three identical square waveforms edited in PC were transferred to three SMCUs through the MMCU, then three square waveform ESPs generated in PESPG of SMCU were applied to IP 1, 2, and 3 of the MSAE. And then, the voltage and the current between return point (RP) and test point (TP) were measured after applying the square waveform ESP to IP 1, 2, and 3 of the MSAE. The measurement results were as follows. When ESP of a square waveform was applied to IP 1 of the MSAE, the voltage and the current were 18.8 V and 1.69 mA, respectively. When ESP of square waveform was simultaneously applied to IP 1 and IP 2 of the MSAE, the voltage and the current were 22.0 V and 4.17 mA, respectively. In addition, when ESP of square waveform was simultaneously applied to IP 1, 2, and 3 of the MSAE, the voltage and the current were observed as 24.4 V and 6.77 mA, respectively. When the number of ESPs applied to each electrode of the MSAE is increased, the voltage and the current being focused to RP are increased. In addition, the voltage and the current between RP and TP are increased due to the focusing effect of voltage and current to RP.

Thus, when various PESPs are applied to TPs distributed in TP regions of the MPS patients, it would be possible to fire the minor TPs and the major TP, simultaneously.

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