TWITCHER: A DEVICE TO SIMULATE THUMB TWITCH RESPONSE TO ULNAR NERVE STIMULATION

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ABSTRACT. Objective. To design and fabricate a device to simulate evoked thumb adduction in response to ulnar nerve stimulation. **Methods.** We implemented a computer-controlled, motorized thumb (TWITCHER) that responds to ulnar nerve stimulation by an unmodified peripheral nerve stimulator. Clinically realistic response patterns are generated for both depolarizing and non-depolarizing muscle relaxants and three modes of stimulation (single twitch, train-of-four, tetanus). **Results.** The device has been used in a full-scale patient simulator for the last six years. **Discussion.** TWITCHER has been well received by participants in simulation exercises including the use of neuromuscular blocking drugs.

KEY WORDS. Simulation, peripheral nerve stimulation, neuromuscular blockade, thumb adduction.

INTRODUCTION

Full-scale patient simulators [1–3] are now in use in over 40 sites worldwide. The ability to observe the onset and decay of the action of neuromuscular blocking drugs enhances the clinical realism of the simulator when used in anasthesia-related exercises. We describe the engineering design of a device which simulates evoked thumb adduction in response to ulnar nerve stimulation.

MATERIALS AND METHODS

Engineering objectives

The overall engineering design objective was to physically simulate the thumb twitch response of a patient to electrical stimulation of the ulnar nerve by a peripheral nerve stimulator (PNS) to enhance the clinical realism of the patient simulator. The thumb twitch simulator (TWITCHER) was designed to:

1. Operate in real time (no noticeable time delay between the stimulus and the response).
2. Interface directly to an unmodified PNS.
3. Discriminate stimulus current level (no response if stimulus current is too low).
4. Differentiate between three electrical stimulation modes (single twitch, train-of-four, tetanus).
5. Respond appropriately to the type of neuromuscular blocking drug (depolarizing or non-depolarizing).
6. Allow visual (movement) and tactile (force) assessment

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The University of Florida owns and licenses human patient simulator technology. Royalties received by the University of Florida are distributed in part to the inventing team, which includes Drs. Lampotang, Good and Gravenstein.

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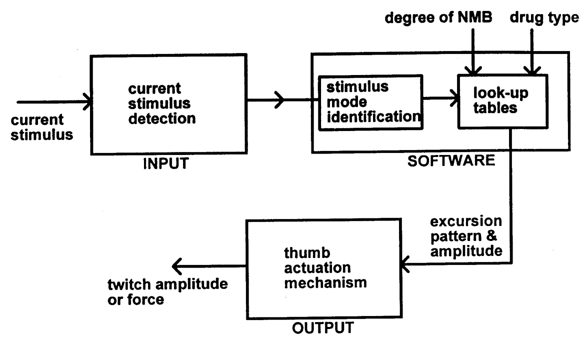

Fig. 1. The high level block diagram of TWITCHER.

of the degree of neuromuscular blockade (NMB). During tactile assessment, the movement of the thumb is blocked by the clinician's hand and the force generated by the thumb is estimated.

7. Modulate degree of thumb excursion and force to at least 10 different amplitudes of twitch response.
8. Be generic (usable with any kind of PNS; not brand- or model-specific).
9. Be modular (usable both in a full-scale patient simulator and in a part-task trainer).

Implementation

A standard, commercially-available PNS (Model NS-2CA, Professional Instruments, Houston, TX) was used to develop and test TWITCHER. One essential engineering objective was real-time identification of the stimulus mode so that the thumb responds appropriating for a given stimulus. In commercial PNSs, the time interval between each current pulse is unique for each stimulus mode: 1 or 10 seconds for single twitch, 0.5 seconds for train-of-four, and 0.02 or 0.01 seconds for 50 Hz and 100 Hz tetanic stimulation, respectively. Therefore, this unique time interval between current pulses in each mode was used to identify the stimulus mode in real time. Each current pulse in all modes (single twitch, train-of-four, and tetanus) is a square wave of 250 microseconds duration.

As shown in the high level block diagram (Figure 1), the three main components of TWITCHER are the input module, the control software, and the output module.

Input module

The leads from the PNS are attached to electrode pads that are already prepositioned over the ulnar nerve area on the mannequin's forearm (P/N: IVR-3100, Medical Plastics Laboratory, Gatesville, TX). The input module consists of a voltage divider that converts each current pulse from the PNS into a voltage pulse of corresponding amplitude (Figure 2). The values of the resistors used in the voltage divider are set such that at supramaximal stimulation (setting of "10" on the Life Tech NS-2CA PNS) with fresh batteries, 50–70 mA of current are reported as the output current on the numeric display on the NS-2CA. If the amplitude of the resultant voltage pulse is above an adjustable reference voltage (the sensitivity threshold to elicit a twitch), a hardware interrupt is generated on an I/O bit in an 80535-based microcontroller board (DACS – Data Acquisition And Control System – board) [4]. If the pulse amplitude is below the threshold, there is no twitch response. The reference voltage is adjusted by manually turning the "twitch threshold adjustment potentionmeter" in Figure 2. The potentiometer is adjusted so that there is no twitch when the current level knob on a NS-2CA PNS with fresh batteries is at a setting of "3" or less, on a scale of 0–10. As the batteries in the PNS lose their charge, a higher setting on the current knob will be required to evoke a thumb response, just as in the real situation. Causes of low current stimulus include low current output setting on a PNS, a low or exhausted battery level, leads connected to the wrong outlet (low current outlet) on a PNS and leads disconnected from the electrode pads.

Control software

The control software is written in "C" (Archimedes 8051 cross compiler, Archimedes Software Inc., San Francisco, CA) and accomplishes two main functions: stimulus mode identification and determination of twitch response according to look-up tables (Tables 1 and 2). The type of muscle relaxant (depolarizing or non-depolarizing) and the degree of NMB (0–100% in steps of 10%) in effect during the simulation are inputs to the look-up tables and are communicated to the single board computer via a serial port.

Using a real-time clock, the software keeps track of the elapsed time between the interrupts generated by each current pulse (of sufficient amplitude) from the PNS. Thus, the stimulus mode is positively identified only after the second electrical current pulse is detected. For tetanic stimulation, the second pulse arrives within 0.02 seconds so that there is no noticeable delay as the stimulus mode is identified. However, for train-of-four and single twitch stimulation, there will be a noticeable delay before the mode is identified if one waits for

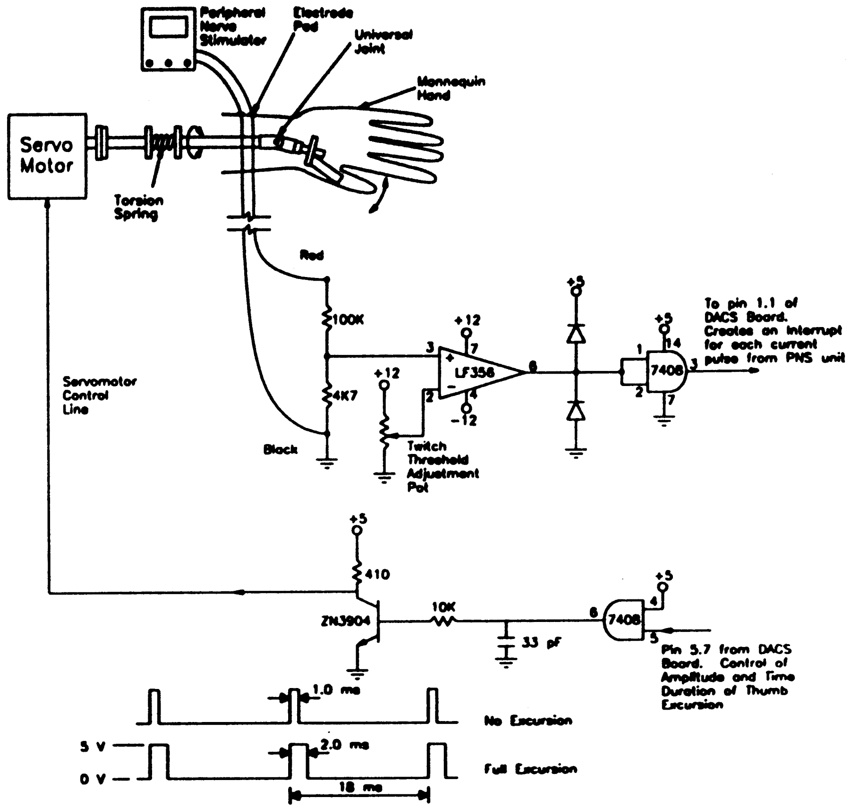

Fig. 2. The detailed schematic of TWITCHER.

positive identification (i.e., the second pulse) before moving the thumb. We solved this problem by using the real-time clock to identify the first pulse in a series. If the elapsed time interval is larger than 1 second when an interrupt is received, then the pulse is internally declared to be a first pulse of unknown mode because the time intervals between pulses for single twitch, train-of-four, and tetanic stimulation are all less than or equal to 1 s. In the look-up tables, the twitch amplitude in response to the first pulse in a series is determined only by the type of a muscle relaxant and the degree of NMB currently in effect, irrespective of the stimulus mode (Tables 1 and 2). Thus, it is not necessary to know the stimulus mode for the first twitch response to a series of pulses.

The type of muscle relaxant, the degree of NMB, and the stimulus mode are used as the independent variables in look-up tables (Tables 1 and 2) programmed into the real-time control software. The dependent variables in the look-up tables are the amplitude and pattern of the twitch response (Tables 1 and 2). When used as a subsystem of the Human Patient Simulator (HPS, Medical Education Technologies, Inc., Sarasota, FL), the degree of NMB is calculated by the simulator's physiological software models according to patient parameters and the amount of muscle relaxant that has been administered. A bar code label on the syringe used to administer the drug identifies the muscle relaxant so that the variable representing the type of muscle relaxant can be set to either depolarizing or non-depolarizing. Among the neuromuscular blocking drugs programmed in the HPS, succinylcholine is the only depolarizing NMB drug; the other neuromuscular blocking agents in the simulator's formulary (atracurium, curare (d-Tubocurarine), doxacurium, metocurine, mivacurium, pancuronium, rocuronium, vecuronium) are non-depolarizing.

The look-up tables are not based on a literature search; we generated them by giving empty look-up tables to seven practicing anesthesiologists and instructing them to enter integers between 0 and 10 (inclusive) to reflect the appropriate twitch excursion for 10% increments in NMB, based on their understanding of muscle relaxant pharmacodynamics and their personal clinical experiences. Formal validation of the entries in the look-up tables will be a separate study in itself; it is beyond the scope of this technical note. Based on user response, the numbers in the look-up table appear to be

Table 1. The look-up table for desired thumb excursion in response to electrical stimulus of the ulnar nerve with depolarizing neuromuscular blockade drugs. A large excursion value corresponds to a large amplitude of motion

Blockade level (%)	Single twitch	Train-of-four	Tetanus		
			Plateau excursion	Plateau duration (s)	Slope duration (s)
0	10	10, 10, 10, 10	10	stimulus	0
10	9	9, 9, 9, 9	9	stimulus	0
20	8	8, 8, 8, 8	8	stimulus	0
30	7	7, 7, 7, 7	7	stimulus	0
40	6	6, 6, 6, 6	6	stimulus	0
50	5	5, 5, 5, 5	5	stimulus	0
60	4	4, 4, 4, 4	4	stimulus	0
70	3	3, 3, 3, 3	3	stimulus	0
80	2	2, 2, 2, 2	2	stimulus	0
90	1	1, 1, 1, 1	1	stimulus	0
100	0	0, 0, 0, 0	0	stimulus	0

Table 2. The look-up table for desired thumb excursion in response to electrical stimulus of the ulnar nerve with non-depolarizing neuromuscular blockade drugs. A large excursion value corresponds to a large amplitude of motion

Blockade level (%)	Single twitch	Train-of-four	Tetanus		
			Plateau excursion	Plateau duration (s)	Slope duration (s)
0	10	10, 10, 10, 10	10	stimulus	0
10	10	10, 10, 10, 10	10	stimulus	0
20	10	10, 10, 10, 10	10	5	2
30	10	10, 10, 10, 10	10	4	2
40	10	10, 10, 10, 8	10	3	1
50	10	10, 10, 8, 6	10	2	1
60	10	10, 8, 6, 4	10	1	1
70	8	8, 6, 4, 0	8	1	1
80	6	6, 4, 0, 0	6	0	1
90	4	4, 0, 0, 0	4	0	1
100	0	0, 0, 0, 0	0	0	0

satisfactory. From a practical viewpoint, the look-up table approach is a solution that works and is readily adjustable – as new data and insights are acquired, it will be a simple task to edit the look-up tables to reflect this new knowledge.

Output module

A pulse width-controlled servomotor used in radio-controlled model airplanes (Model 94152, Airtronics, Irvine, CA) was interfaced to the microcontroller board and mechanically linked to move a hinged plastic rod to any of 11 positions. The hollow thumb of the mannequin forearm was placed over the plastic rod and the forearm skin pulled over the entire assembly (Figure 3).

The 80535 microcontroller board performs the pulse width modulation, using another timer with a resolution of 1/10 000 seconds. The thumb moves from its resting position to full excursion in 11 steps as the "on" time (duty cycle) of the pulse width increases from 1 to 2 milliseconds (in steps of 0.1 milliseconds) over a total cycle time of 18 milliseconds (Figure 3).

A torsion spring (120 oz.in of torque at 90° deformation; LTR-070M-01, Lee Spring Co., Brooklyn, NY) interposed between the servomotor and the thumb performs two critical functions during tactile assessment of the twitch response: servomotor protection and force generation. The servomotor has an internal controller (the "servo" part of the servomotor) that will drive the output shaft of the servomotor to the assigned position. Without a spring between the output shaft of the servomotor and the thumb (solid coupling), the output shaft is prevented from moving to its assigned possition when the thumb movement is blocked. An overload condition might result, eventually causing failure of the servomotor. By deforming, the spring allows the servomotor to move to its assigned prosition even though the thumb is blocked during tactile assessment of NMB, thus protecting the servomotor from overload.

A torsion spring generates a force proportional to its rotation from its resting configuration. Thus, with the thumb prevented from moving during tactile evaluation of NMB, the servomotor develops a force proportional to the deformation of the spring (equivalent to the amplitude of motion of the thumb if it is allowed to move) when the servomotor moves to its assigned position. The force caused by the deformation of the spring is transmitted to the blocked thumb so that the force of the response, e.g., the tetanic fade, is felt by the evaluator.

RESULTS

TWITCHER [5] met all engineering design specifications. For the last six years, it has been used as an integral part of the HPS. Because different brands and models of PNS use the same time interval between pulses in different stimulus modes, generic simulation was achieved. When tested with two other models of PNS (Paragraph, Vital Signs, Totowa. NJ; Innervator, Fisher & Paykel, Auckland, New Zealand), TWITCHER correctly identified the stimulus mode in real time and, therefore, the response of the simulated thumb was appropriate.

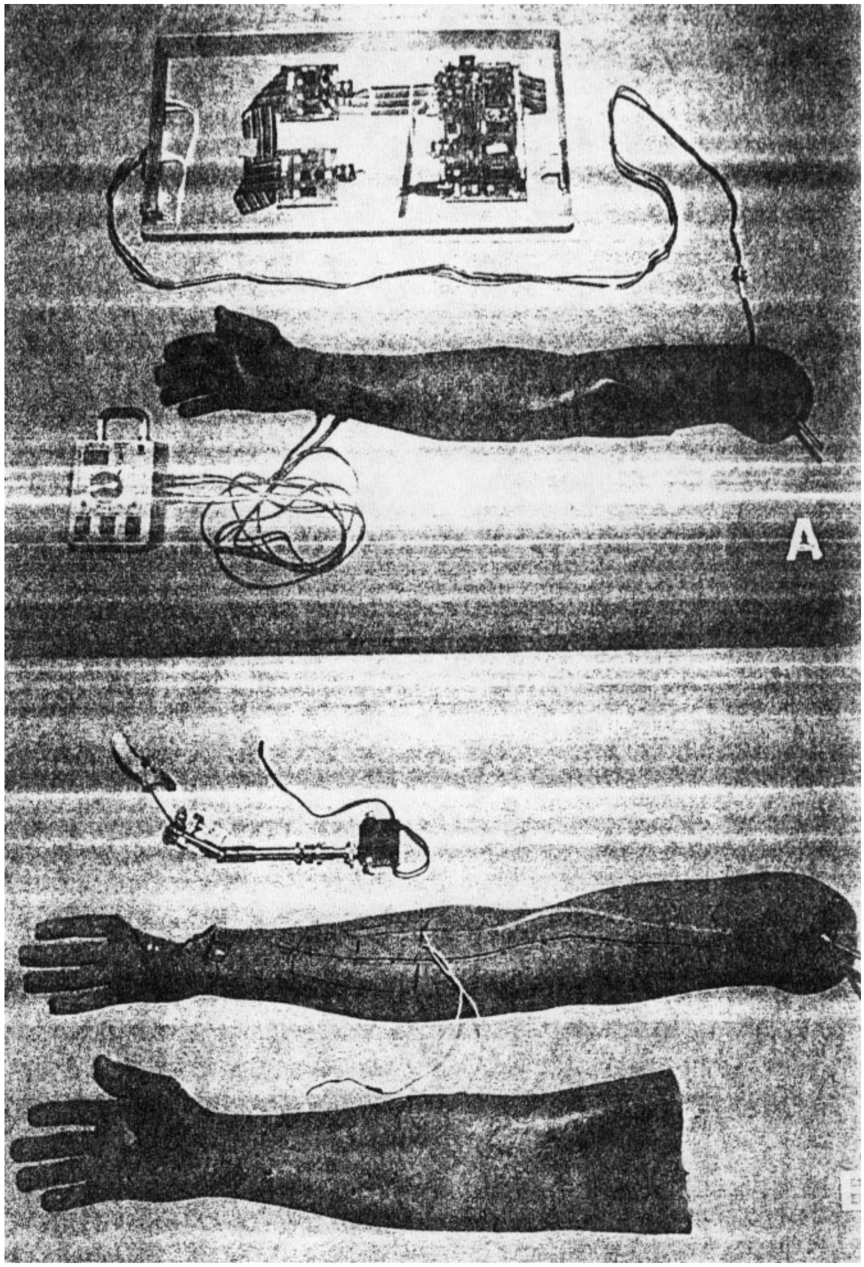

Fig. 3. (A) The assembled arm and the electronics of TWITCHER. A peripheral nerve stimulator is also shown attached to the arm. (B) The TWITCHER arm disassembled. The subassembly at the top is the servomotor/thumb linkage. The middle part is the hollow arm. Note the access panel (cutout) in the middle of the forearm for installing the servomotor/thumb subassembly inside the forearm. The bottom part is the skin with the electrode pads attached.

DISCUSSION

TWITCHER can serve as a device for evaluating PNSs because the design uses the actual current from the PNS for stimulation. During testing of TWITCHER with the NS-2CA PNS (Professional Instruments, Houston, TX), it was discovered that only three pulses were delivered instead of four during train-of-four when the batteries were low [6]. Additionally, when the output level selector switch is inadvertently flipped to the low current output position while the leads are connected to the high output side, no twitch is obtained. In a clinical environment, incorrect setting of this selector switch to the low current position might cause misinterpretation of the degree of NMB.

The degree of realism required and the method used for validation of the simulation are context dependent. If the simulation is performed for research purposes, then the look-up tables should be validated using objective force measurements. TWITCHER was designed primarily to enhance the clinical realism of anesthesia-related simulation and, as such, the validation of its response was subjective, based on the reviews by experienced clinical anesthesiologists.

Future improvements to TWITCHER should include a mathematical model of the neuromuscular junction to replace the look-up tables. If such a model is implemented, its inputs will be the magnitude and duration of the current stimulus, the patient parameters, and the drug type and dose. An advanced version of the mathematical model of the neuromuscular junction might include subtleties such as the effect of temperature, age, and drug interactions. Furthermore, the design should be extended so that the response to double burst stimulation and post-tetanic facilitation can also be appropriately simulated. An advanced version of TWITCHER should not have prepositioned leads, but should require the user to place the electrodes, thus meeting the learning objective of proper electrode placement, a significant source of erroneous readings.

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