Anesthesiology
60:464–466, 1984

Evaluation of Peripheral Nerve Stimulators and Relationship to Possible Errors in Assessing Neuromuscular Blockade

K. C. Mylrea, Ph.D.,* S. R. Hameroff, M.D.,† J. M. Calkins, M.D., Ph.D.,‡ C. D. Blitt, M. D.,§ L. L. Humphrey¶

Voltage and current output characteristics were measured on six commercially available peripheral nerve stimulator devices. The results are evaluated as possible sources of variability in peripheral nerve stimulator function and neuromuscular blockade assessment. The authors found significant differences in output voltage waveform and in maximum current into a 470 ohm load (21.4 to 128 mA.). Output current decreased from 25 to 88% in the different devices, with a load impedance increase from 470 to 10,000 ohms. Due to the variability in peripheral nerve stimulation units and the decrease in current output at higher load impedance, less than supramaximal stimulation is possible with erroneous interpretation of neuromuscular blockade. (Key words: Equipment: nerve stimulator. Neuromuscular transmission: nerve stimulator.)

NEUROMUSCULAR BLOCKING DRUGS commonly are used during anesthesia and surgery, and monitoring of neuromuscular blockade (NMB) is desirable to help determine drug requirement and to help assess reversal of NMB.

NMB monitoring requires observation of muscle twitch in response to motor nerve stimulation by a peripheral nerve stimulator (PNS). Typically, a PNS impuse is delivered via electrodes (surface or needle) to the ulnar nerve at the wrist or to the facial nerve lateral to the orbit. Assessment of NMB may be influenced by factors such as stimulus strength, location of electrodes, tissue and electrode impedance, and interpatient variations.[1] For example, twitch response to train-of-four stimulation has beeen shown to vary with PNS electrode site (ulnar *vs.* facial nerves) and electrode type (needle *vs.* surface).[1]

* Associate Professor, Department of Electrical and Computer Engineering; Adjunct Associate Professor, Department of Anesthesiology, University of Arizona.

† Assistant Professor, Department of Anesthesiology, University of Arizona.

‡ Assistant Professor, Department of Anesthesiology, Adjunct Assistant Professor, Department of Electrical and Computer Engineering, University of Arizona.

§ Professor, Department of Anesthesiology, University of Arizona.

¶ Engineering Technician, Department of Radiology, University of Arizona.

Received from the Department of Anesthesiology, University of Arizona, Tucson, Arizona. Accepted for publication November 2, 1983.

Address reprint requests to Dr. Mylrea: Department of Electrical Engineering, University of Arizona, Tucson, Arizona, 85721.

In this study we investigated the output current and voltage characteristics of six commercially available PNS units. The results are evaluated as possible sources of variability in PNS function and NMB assessment.

Methods

Voltage and current output characteristics were measured on six PNS devices (Burroughs Welcome, Dupaco 54120, Neurodyne Dempsey ST-4, Output FB 800, and Professional Instruments NS 2 and NS 3).** Features of the PNS units are listed in table 1. Voltage waveforms for the maximum output setting into a 1K ohm load for each PNS unit were photographed. Output voltage and current were measured using a high-input impedance (10 M ohm) storage oscilloscope at each PNS amplitude setting with a series of fixed noninductive resistances: 470, 1K, 10K, and 100K ohms and infinite resistance (five devices only). The resistances were selected to span the range of expected and measured *in vivo* impedances for surface or needle electrodes. For other than square wave pulses, the maximum voltage was recorded. All units were fitted with a new battery prior to testing.

Results

The time-dependent voltage waveforms from the six PNS units at maximum output setting with a 1K ohm load are shown in figure 1. Pulse widths varied from approximately 100 μs to 1.5 ms. Peak voltages varied from 20 to 100 v. Waveshapes included triangular, square, and double-peaked waveforms.

Voltages and currents from the six PNS units with the selected load resistances are shown in figure 2. The Neurodyne Dempsey PNS has two outputs, cutaneous for surface electrodes and subcutaneous for needle electrodes. The data shown are from the cutaneous output. The subcutaneous voltage and current output followed the

** Burroughs Welcome, Greenville, North Carolina; Dupaco Inc., San Marcos, California; Neurodyne Dempsey, Carson City, Nevada; Output Inc., Portland, Oregon; Professional Instruments Co., Houston, Texas.

TABLE 1. Characteristics of the Six Peripheral Nerve Stimulators Tested

Characteristic or Feature	Prof Inst NS3	DUPACO	Output FB 800	Welcome PNS	Neurodyne Dempsey ST-4*	Prof Inst NS2
Single-twitch Frequencies (Hz)	1	0.1 2	0.1 0.2 1	0.1 0.2 1	none	0.2 1
Tetanic Frequencies (Hz)	50	100	50 100	50	25	50
Train-of-four	Yes	No	Yes	No	No	Yes
Battery test	Yes	No	Yes	No	No	No
Electrode test	No	No	Yes	No	No	No

* All modes are demand in nature.

ne variation with dial settings but was 0.89, 0.71, 0.55, d 0.5 of the cutaneous output at 470, 1K, 10K, and 0K ohms, respectively.

Som its produced essentially no voltage or current the lowest dial setting, and for the sake of graph clarity ese near-zero values were not plotted. The Neurodyne empsey PNS delivered large currents at low resistance ads (128 mA at 470 ohms and 90 mA at 1K ohms). All her units had maximum currents of 21.4 to 27.6 mA 470 ohms load. Decreases in current due to increasing pedance (impedance increasing from 470 to 10K ohms) ere 25, 30, 46, 48, 49, and 88% for the Output, Burughs Welcome, Professional Instruments NS3, NS2, upaco, and Neurodyne Dempsey, respectively.

Discussion

Assessment of NMB by observation of muscular reonse following nerve stimulation can be affected by veral interdependent factors. These include polarity of lectrode attachment,[2] location and type of electrodes,[3] utput rrent and voltage characteristics of the PNS,[4] nd im ance of the stimulating site.††

Current rather than voltage is the determining factor r neural stimulation. Our data show that the six PNS nits tested are neither constant current nor constant oltage in the range of impedances studied. The variability f the PNS units could result in erroneous interpretation f NMB. All units had significantly less current output t higher impedances, which could produce less neural timulation and a decreased muscular response in some ituations. It is recommended to employ a supramaximal timulus in assessing NMB. Less than supramaximal stimlation (with surface electrodes) results in overestimation f NMB.[5]

It is interesting to note that of the PNS units tested, the Neurodyne Dempsey had significantly more output current into impedances below 10K ohms when compared with the other units. Higher output current could alleviate the potential problem of inadequate stimulation with surface electrodes. However, in our opinion, the Neurodyne Dempsey did not function satisfactorily in the clinical setting because of the low tetanic frequency and the lack of the train-of-four output.

All of the other PNS units tested should function adequately in the clinical setting. Because of the electrical similarity among PNS units, one would be tempted to recommend purchase of a PNS unit based on features and cost.

A constant current PNS would be highly desirable so as to overcome variability in impedances. Our data help substantiate the clinical impression that surface electrodes may not provide reliable data during assessment of NMB because decreasing current delivered by the PNS in the face of increased impedance does not permit delivery of a supramaximal stimulus to the nerve.

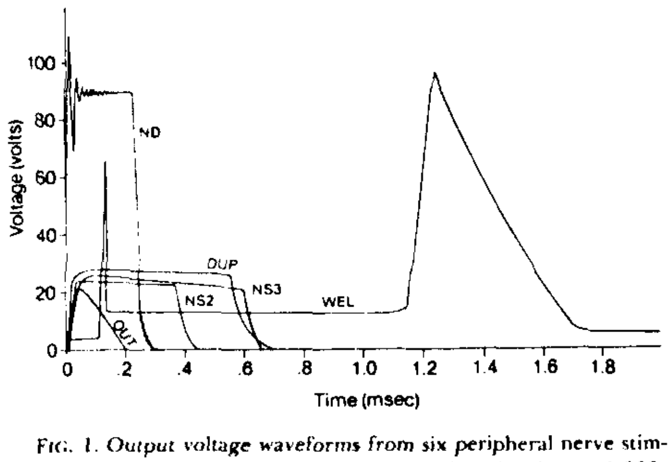

FIG. 1. *Output voltage waveforms from six peripheral nerve stimulators.* The output was obtained at maximal setting into a 1,000-ohm resistor. WEL—Burroughs Welcome; DUP—Dupaco; ND—Neurodyne Dempsey; OUT—Output; NS2—Professional Instruments NS2; and NS3—Professional Instruments NS3.

†† Hameroff SR, Mylrea KC, Calkins JM, Brown RS, Lemay BJ. Tissue resistance effects in neuromuscular blockade monitoring. Fourth Annual Meeting of the Bioelectromagnetics Society, Los Angeles, 1982.

21/64

TABLE 1. Characteristics of the Six Peripheral Nerve Stimulators Tested

Characteristic or Feature	Prof Inst NS3	DUPACO	Output FB 800	Welcome PNS	Neurodyne Dempsey ST-4*	Prof Inst NS2
Single-twitch Frequencies (Hz)	1	0.1 2	0.1 0.2 1	0.1 0.2 1	none	0.2 1
Tetanic Frequencies (Hz)	50	100	50 100	50	25	50
Train-of-four	Yes	No	Yes	No	No	Yes
Battery test	Yes	No	Yes	No	No	No
Electrode test	No	No	Yes	No	No	No

* All modes are demand in nature.

ne variation with dial settings but was 0.89, 0.71, 0.55, d 0.5 of the cutaneous output at 470, 1K, 10K, and 10K ohms, respectively.

Som its produced essentially no voltage or current the lowest dial setting, and for the sake of graph clarity ese near-zero values were not plotted. The Neurodyne empsey PNS delivered large currents at low resistance ads (128 mA at 470 ohms and 90 mA at 1K ohms). All her units had maximum currents of 21.4 to 27.6 mA 470 ohms load. Decreases in current due to increasing ipedance (impedance increasing from 470 to 10K ohms) ere 25, 30, 46, 48, 49, and 88% for the Output, Burroughs Welcome, Professional Instruments NS3, NS2, upaco, and Neurodyne Dempsey, respectively.

Discussion

Assessment of NMB by observation of muscular response following nerve stimulation can be affected by several interdependent factors. These include polarity of lectrode attachment,[2] location and type of electrodes,[3] utput rent and voltage characteristics of the PNS,[4] nd in ance of the stimulating site.††

Current rather than voltage is the determining factor or neural stimulation. Our data show that the six PNS nits tested are neither constant current nor constant oltage in the range of impedances studied. The variability of the PNS units could result in erroneous interpretation of NMB. All units had significantly less current output t higher impedances, which could produce less neural timulation and a decreased muscular response in some ituations. It is recommended to employ a supramaximal timulus in assessing NMB. Less than supramaximal stimulation (with surface electrodes) results in overestimation of NMB.[3]

It is interesting to note that of the PNS units tested, the Neurodyne Dempsey had significantly more output current into impedances below 10K ohms when compared with the other units. Higher output current could alleviate the potential problem of inadequate stimulation with surface electrodes. However, in our opinion, the Neurodyne Dempsey did not function satisfactorily in the clinical setting because of the low tetanic frequency and the lack of the train-of-four output.

All of the other PNS units tested should function adequately in the clinical setting. Because of the electrical similarity among PNS units, one would be tempted to recommend purchase of a PNS unit based on features and cost.

A constant current PNS would be highly desirable so as to overcome variability in impedances. Our data help substantiate the clinical impression that surface electrodes may not provide reliable data during assessment of NMB because decreasing current delivered by the PNS in the face of increased impedance does not permit delivery of a supramaximal stimulus to the nerve.

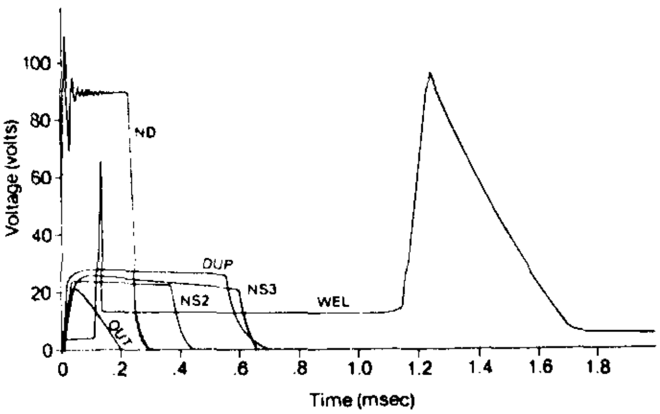

FIG. 1. Output voltage waveforms from six peripheral nerve stimulators. The output was obtained at maximal setting into a 1,000-ohm resistor. WEL—Burroughs Welcome; DUP—Dupaco; ND—Neurodyne Dempsey; OUT—Output; NS2—Professional Instruments NS2; and NS3—Professional Instruments NS3.

†† Hameroff SR, Mylrea KC, Calkins JM, Brown RS, Lemay BJ. Tissue resistance effects in neuromuscular blockade monitoring. Fourth Annual Meeting of the Bioelectromagnetics Society, Los Angeles, 1982.

97/64

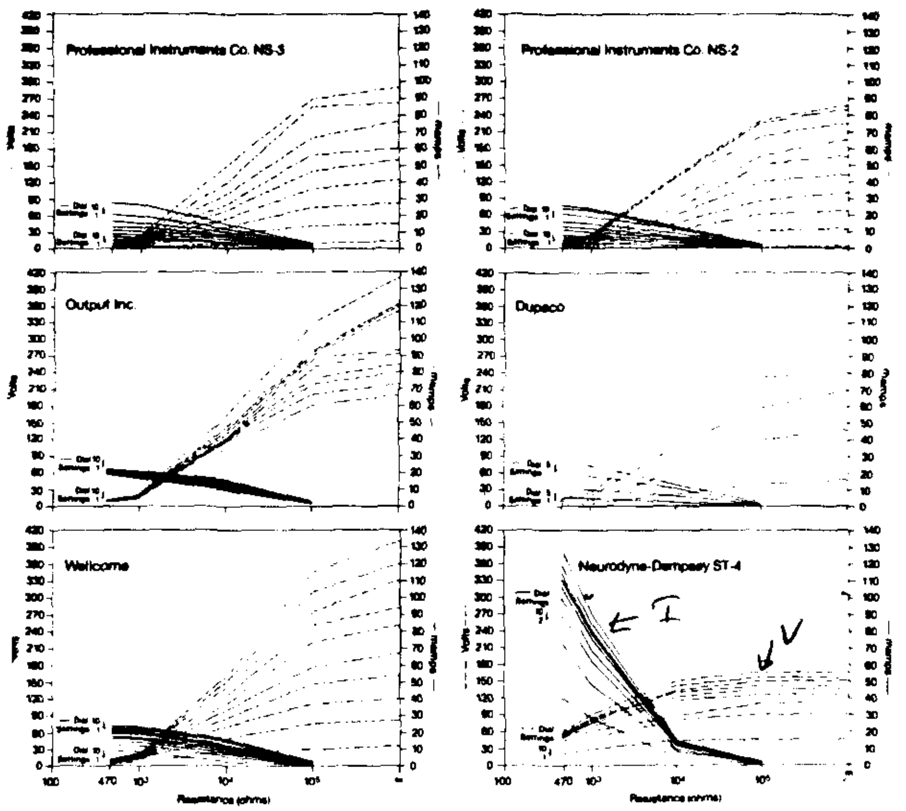

FIG. 2. Output voltage and current from the six peripheral nerve stimulators with different load resistances.

References

1. Feldman SA: Muscle relaxants, second edition. Philadelphia, WB Saunders, 1979, pp 137–152
2. Berger JJ, Gravenstein JS, Munson JS: Electrode polarity and peripheral nerve stimulation. ANESTHESIOLOGY 56:402–404, 1982
3. Stiffel P, Hameroff SR, Blitt CD, Cork RC: Variability in assessment of neuromuscular blockade. ANESTHESIOLOGY 52:436–437, 1980
4. Capan LM, Satyanarayana T, Patel KP, Turndorf H, Ramanathan S: Assessment of neuromuscular blockade with surface electrodes. Anesth Analg 60:244–245, 1981

0–100K.

01168