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Milliamperage Requirements for Supramaximal Stimulation of the Ulnar Nerve with Surface Electrodes

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Monitoring of neuromuscular transmission with portable, battery-operated nerve stimulators is common anesthesia practice.[1] In 1976 Kopman[2] and Pue[3] demonstrated the safety of pregelled electrodes for the stimulation of the ulnar nerve. However, the amount of current necessary to produce supramaximal stimulation (SMS) of the ulnar nerve at the wrist with surface electrodes has not been established. Of the commercially available battery-operated nerve stimulators available in the United States, most have maximum outputs no greater than 30 milliamperes (mA). Yet our clinical experience is that currents of at least 50 mA often are required to produce SMS when using surface electrodes.

We therefore decided to determine the delivered current necessary for SMS of the ulnar nerve at the wrist when using pregelled electrodes. We hoped to define the minimum output specifications for nerve stimulators intended primarily for routine clinical use with these electrodes.

METHODS

Thirty-eight patients undergoing surgical procedures, for which the administration of a muscle relaxant was indicated by the nature of the proposed surgery, were included in the study. The study was approved by our hospital Committee on Human Research. These individuals were chosen randomly from the authors' practice. Anesthesia was induced with thiamyl sodium and maintained with nitrous oxide and halothane or enflurane. Tracheal intubation was performed following the administration of succinylcholine 0.75 mg/kg iv. The wrist

circumference of each patient studied was measured at the level of the proximal flexor crease.

Evoked isometric tension to ulnar nerve stimulation was measured with a Grass FT-10 linear force transducer and recorded. Preload on each patient's thumb was adjusted to approximately 200 g. The nerve stimulator employed was a Neuro Technology Inc. Digistim II®. The battery-operated unit has a unipolar pulse duration of 0.2 ms and a maximum output of approximately 75 mA. A digital ammeter displays the actual current delivered with each stimulus. Prior to use in this study, the Digistim ammeter was bench tested against a 1,000 ohm resistive load and found to be accurate to within ±3%. The surface electrodes employed were the NDM PNS electrodes (cat #61-2510).

The distal (negative) surface electrode was placed at the level of the proximal flexor crease of the wrist. Each electrode pair was placed directly over and parallel to the flexor carpi ulnaris tendon, thereby insuring the close proximity to the ulnar nerve as it approaches and crosses the wrist. When single-twitch height at maximum stimulator output (65–75 mA) had recovered from the endotracheal intubating dose of succinylcholine and remained stable for at least 5 min, the study commenced. Stimulator output was increased from zero in increments of 1–2 mA, and twitch tension was recorded at each output level. When these small increases in current no longer produced observable changes in evoked tension, the increments were increased in 5-mA steps until maximum output of the stimulator was reached.

RESULTS

Figure 1 is the response curve for patient 9 and is typical of the results obtained during this study. The initial threshold for stimulation (ITS) was defined as first clearly visible twitch above background noise. ITS the pen deflection on the polygraph usually amounted to 1–2 mm, when full twitch height was 40 mm or more. For any given patient, determination of the exact current required to achieve supramaximal stimulation (SMS) is not a simple process. There was rarely a precise end point at which an increase in delivered current no longer elicited a measurable rise in twitch tension. The steep phase of the response was characterized by large changes in twitch
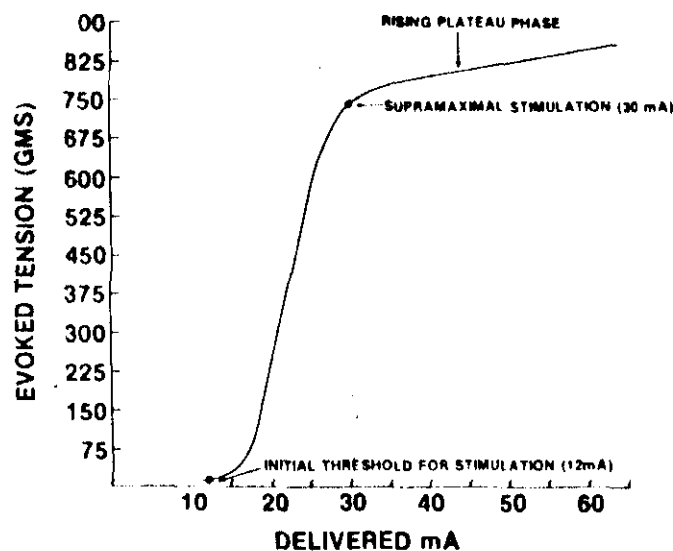
FIG. 1. Representative mA-evoked tension response curve (patient 9).

tension for small changes in stimulator output. The current required for supramaximal twitch stimulus (SMS) was distinguished as the point on the response curve where twitch response failed to increase significantly despite the application of additional current (fig. 1). Increases in delivered current beyond SMS elicited some minimal rise in twitch tension in most patients studied, but an endpoint at which those increases failed to elicit a rise in twitch tension rarely could be demonstrated. This area of the curve (fig. 1) was defined as the rising plateau phase.
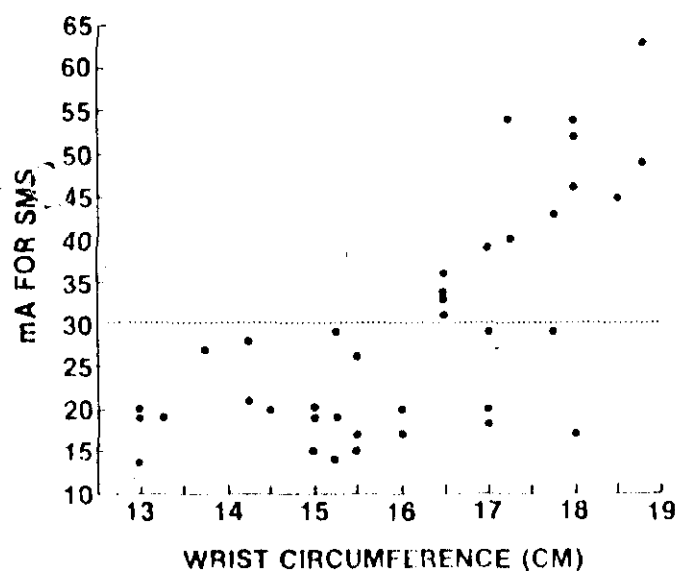

FIG. 2. Delivered current necessary for supramaximal stimulation (SMS) of the ulnar nerve as a function of wrist circumference. Thirty milliamperage assures SMS only at wrist circumferences of 16 cm or less.
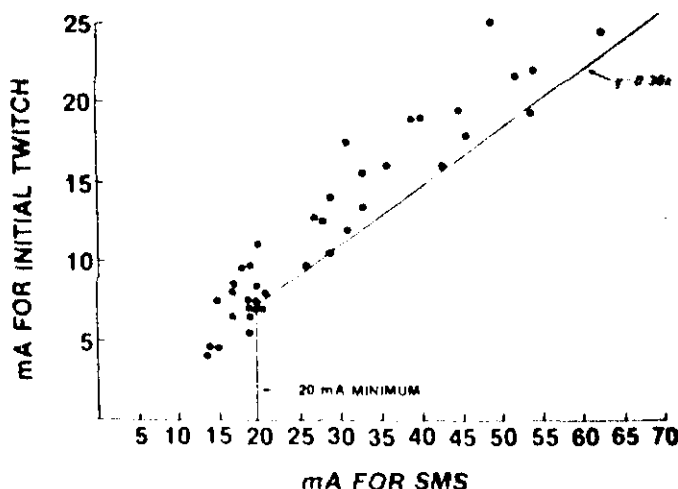

FIG. 3. The relationship between current necessary for SMS as a function of current required for evoking the first detectable twitch (ITS). If at least 20 mA is delivered, and if the current is 2.75 times that needed for the production of ITS, then all patients will receive supramaximal stimulation.

Wrist circumference did not correlate with the current required for SMS (fig. 2). If wrist circumference was less than or equal to 16 cm, then 30 mA was always capable of producing a SMS. As wrist circumference increased beyond 16 cm, more mA usually was needed for SMS. Of the 38 patients studied, 19 patients had wrists larger than 16 cm and 14 of them needed over 30 mA to achieve SMS. Five of the 14 needed between 40 and 50 mA, and 4 of those 14 required in excess of 50 mA for SMS. The scattergram (fig. 2) illustrates the poor correlation between SMS and wrist circumference, thus precluding the accurate prediction of currents needed for SMS from wrist circumference alone.

In contrast, there was a strong correlation between the current necessary to produce the first visible twitch (ITS) and that needed to produce SMS (fig. 3). Provided that a minimum of 20 mA was delivered to achieve SMS, then SMS could be assured if the delivered current was equal to 2.75 times that necessary for the production of ITS.

DISCUSSION

To properly evaluate neuromuscular function, supramaximal stimulation of the monitored nerve in question is mandatory.[1] Inadequate stimulation may lead the clinician to overestimate the degree of neuromuscular blockade present. As a result, additional neuromuscular blocking drugs may not be given, with the belief that neuromuscular blockade is adequate. Conversely, at the conclusion of a surgical procedure poor twitch response may lead to the administration of additional reversal drugs in the belief that residual blockade persists. However,

inadequate nerve stimulation also may be responsible for the apparent residual blockade. This would be especially true if control evoked responses were not observed prior to the initiation of neuromuscular blockade.

Consistent results during monitoring of neuromuscular transmission requires attention to the placement and polarity of the stimulating electrodes.[4,5] However, the principle factor underlying electrical stimulation of a nerve bundle is current density, i.e., amperes per unit area of nerve bundle.[4] Therefore, the output characteristics of the nerve stimulator being used are important. For example, the stimulator described by Zeh and Katz[6] has a pulse width of 0.6 ms and a peak current output at 1,000 ohms of 24 mA. The Myostat nerve stimulator described by Viby-Mogensen et al.[7] has a pulse width of 0.2 ms and can deliver 60 mA peak output across a 1,000 ohm load. Although the electrical energy delivered per pulse is greater with the unit of Zeh and Katz,[6] the Myostat is a more effective nerve stimulator because it generates the higher current densities needed for supramaximal nerve stimulation.

Of the 19 patients we studied with wrists greater than 16 cm in circumference, nine required delivered currents in excess of 40 mA to achieve SMS. We therefore believe that battery-operated peripheral nerve stimulators should deliver no less than 50–60 mA per pulse at all stimulus frequencies. When used with surface electrodes, currents of 20–30 mA may produce supramaximal ulnar nerve stimulation in a majority of patients, but in a significant number of normal individuals, these output levels are clearly inadequate.

We cannot explain the wide variations in delivered currents necessary for SMS between different patients. However, certain factors seem contributory. Although we took considerable care in placing the electrodes directly over the ulnar nerve, anatomic variability probably occurs. Furthermore, the depth of the nerve from the skin surface can vary between individuals. Since current density decreases rapidly as the distance from the stimulating electrodes and the responding neurons increases, delivered current at the surface electrodes does not necessarily reflect current density at the nerve bundle.

A means of monitoring stimulus intensity, in the form of a digital ammeter, incorporated into the peripheral nerve stimulator proved to be a very useful feature. The output needed to produce supramaximal stimulation can be predicted accurately (fig. 3). By visually observing a minimal twitch (TTS) in the thumb and the current necessary to produce it, then multiplying this value by 2.75, SMS predictably will be present. Because this correlation did not prove reliable at low output levels, we believe that all adult patients should be stimulated with at least 20 mA in order to assure SMS. By knowing the predicted current needed for SMS and the design limitations of the stimulator in use, the clinician will have adequate warning that his equipment may not be capable of delivering the current required to elicit a supramaximal response at the ulnar nerve.

The presence of an ammeter on the nerve stimulator also provides a method of assessing nerve stimulator function and the integrity of its connections to the patient. Technical faults such as lead wire breakage or disconnects are discovered easily by zero readings. In addition, deteriorating electrode condition (such as gel drying) or battery weakness can be discovered by progressively lower outputs measured at the electrodes.

In summary, we recommend that nerve stimulators designed for monitoring of neuromuscular function during anesthesia should be capable of delivering pulses with amplitudes of no less than 50–60 mA at all frequencies. We also feel that the inclusion of a digital ammeter into such a unit is a useful though not essential feature.

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