A simple method for monitoring muscular relaxation during continuous infusion of vecuronium

Hideo Nagashima MD, Hung D. Nguyen MD,
Michael Conforti MD, Deryck Duncalf MD,
Paul L. Goldiner MD, Francis F. Foldes MD

There is considerable individual variation in the dose of vecuronium required for the maintenance of surgical relaxation. Therefore to provide uninterrupted relaxation without overdosage it is advisable to regulate the IV infusion of vecuronium on the basis of appropriate monitoring. Monitoring with mechanomyography (MMG) or electromyography requires costly equipment and is too complex for routine clinical use. Visual observation of the adductor pollicis muscle contracting against zero resistance is not suitable for the reliable assessment of the degree of neuromuscular (NM) block. For clinical purposes satisfactory monitoring can be achieved with the simple device (Myoscan) described. The reliability of the Myoscan was tested in 30 patients by simultaneous monitoring of the force of contraction of the adductor pollicis on one side with the Myoscan and on the contralateral side with the MMG. Retrospective analysis of the MMG indicated that the conduct of anaesthesia would have been virtually the same if it would have been based on MMG monitoring.

Key words

MEASUREMENT TECHNIQUES: neuromuscular blockade, Myoscan; NEUROMUSCULAR RELAXANTS: vecuronium.

From the Department of Anesthesiology, Montefiore Medical Center and Albert Einstein College of Medicine, Bronx, New York.

Address correspondence to: Dr. F.F. Foldes, Montefiore Medical Center, 111 East 20th Street, Bronx, NY 10467.

Supported by a grant from Organon Inc., West Orange, New Jersey.

Because of the intermediate duration of its action it is convenient to administer vecuronium bromide by continuous IV infusion for maintenance of muscular relaxation during relatively long surgical procedures. There is a wide individual variation in vecuronium requirements¹⁻¹⁰ (Table 1). Therefore, to achieve uninterrupted relaxation with continuous infusion of a muscle relaxant (MR), without the use of unnecessarily large doses, neuromuscular (NM) blockade should be continuously monitored. Monitoring can be accomplished by recording the mechanomyogram (MMG), electromyogram (EMG) or by visual observation of the response of the adductor pollicis or some other suitable muscle, to indirect stimulation by single impulses administered at 0.1 Hz or by 2 sec trains of 2 Hz impulses (TOF stimulation).¹¹ Recording of the MMG or EMG requires expensive equipment and is too complex for routine clinical use. Visual observation of a muscle contracting against zero resistance does not allow reliable assessment of the degree of NM block. For clinical purposes satisfactory monitoring can be achieved by a simple, inexpensive device called the "Myoscan" (Figure). To demonstrate this the muscular relaxation achieved with the continuous IV infusion of vecuronium was monitored simultaneously with the Myoscan on one and the MMG on the other upper extremity in 30 patients.

Methods

This study was approved by the Institutional Review Board of Montefiore Medical Center and all ASA physical status Class I and II patients participating gave informed consents. Of the 30 patients, eight were males and 22 were females. Their mean age was 45.8 ± 2.8 (26 to 65) years; mean weight was 72.2 ± 1.5 (60.5 to 92.9) kg. Patients were premedicated with 50 to 100 mg IM diphenhydramine and meperidine each. Anaesthesia was induced with $0.001 \text{ mg} \cdot \text{kg}^{-1}$ fentanyl, $0.10 \text{ mg} \cdot \text{kg}^{-1}$ droperidol, a "sleep dose" (2 to $3 \text{ mg} \cdot \text{kg}^{-1}$) of thiopentone and N_2O $4 \text{ L} \cdot \text{min}^{-1}$ - O_2 $2 \text{ L} \cdot \text{min}^{-1}$. Anaesthesia was maintained with increments of fentanyl plus the above N_2O - O_2 mixture. After induction of anaesthesia 200 to

300 g resting tension was applied to the adductor pollicis muscles and the ulnar nerves at the wrist were stimulated (Constant Current Nerve Stimulator, Model FR, Rusz Instruments, Inc.), through surface electrodes, with TOF supramaximal, square wave impulses of 0.2 ms duration, administered every 10 s. On one side the force of contraction of the adductor pollicis muscle was quantitated by FT10 transducers and continuously recorded on a Grass polygraph. On the contralateral side the contractions of the adductor pollicis muscle were observed visually on the Myoscan.

It has been observed (Nagashima H and Foldes FF, unpublished observations) that after administration of vecuronium or other nondepolarizing MR, when the force of contraction elicited with single supramaximal, 0.1 Hz impulses decreased to 15 to 25 per cent of control only T_1 of TOF impulses elicited a definite response on the contralateral side on the Myoscan. Furthermore, when in the course of recovery of NM transmission the force of contraction increased to about 15, 25 or 35 per cent of control, T_2 , T_3 and T_4 respectively elicited visible responses on the Myoscan. On the basis of this information the trachea was intubated when, after administration of a single $0.1 \text{ mg} \cdot \text{kg}^{-1}$ IV dose of vecuronium, the first of TOF impulses (T_1) elicited a response on the Myoscan. When the second TOF stimulus (T_2) again elicited a visible response, the IV infusion of $0.04 \text{ mg} \cdot \text{ml}^{-1}$ vecuronium solution (10 mg vecuronium dissolved in 250 ml 0.9 per cent NaCl) was started at the rate of $2 \text{ ml} \cdot \text{min}^{-1}$ ($80 \text{ } \mu\text{g} \cdot \text{min}^{-1}$). Subsequently, the rate of infusion was so adjusted that only T_1 elicited visible expansion of the spring of the Myoscan.

When there was no further clinical need for muscular relaxation, the vecuronium infusion was discontinued and spontaneous recovery of the force of contraction of the adductor pollicis was recorded with the MMG on one side for as long as conditions (e.g., need to vacate the operating room) allowed. On the contralateral side the times at which T_2 , T_3 and T_4 first elicited a response on the Myoscan were noted. If at the time when the patient had to be removed from the operating room the responses elicited on the Myoscan by T_1 , T_2 , T_3 and T_4 appeared to be uneven the residual NM block was reversed. This was accomplished with a mixture of $0.08 \text{ mg} \cdot \text{min}^{-1}$ atropine and $0.1 \text{ mg} \cdot \text{min}^{-1}$ pyridostigmine. The force of contraction of the adductor pollicis elicited by TOF stimuli was recorded at 2, 5 and 8 min after the end of injection of the antagonist on one side and observed on the Myoscan on the contralateral side. Recovery was considered to be clinically satisfactory when the responses elicited by T_1 , T_2 , T_3 and T_4 appeared to be equal and similar to those observed before administration of vecuronium. If at 8 min the responses to the TOF stimuli appeared to be unequal

FIGURE The Myoscan consists of an armboard with an appropriate cutout, a metal of plastic ring, and a spring with about 400 to 600 $\text{g} \cdot \text{cm}^{-1}$ compliance. The upper extremity used for the IV infusion is attached to the armboard in either the supine or prone position.

Surface electrodes are placed above the ulnar nerve at the wrist and the ring is attached to the second phalanx of the thumb. The ring is connected with a short thread to the proximal end of the spring. After induction of anaesthesia sufficient pull is exerted on a second thread to the distal end of the spring to make the thumb perpendicular to the hand and to apply 200 to 400 g resting tension to it. This tension is maintained by winding the distal end of the second thread around a metal screw driven into the armboard and securing it with a piece of adhesive tape. The ulnar nerve is stimulated by trains-of-4 (TOF) supramaximal, square wave impulses of 0.2 ms duration, administered at 2 Hz, every 10 s. See "Methods" for evaluation of the status of muscular relaxation and the regulation of the use of muscle relaxants and anticholinesterases with the help of the Myoscan.

and/or smaller than those observed before the administration of vecuronium, the recovery was observed for an additional 4 min. If at that time recovery was still incomplete $0.05 \text{ mg} \cdot \text{kg}^{-1}$ pyridostigmine was administered and, depending on the heart rate 0.003 to 0.006 $\text{mg} \cdot \text{kg}^{-1}$ atropine was also injected.

Results

The MMG indicated that maximal NM block produced by the $0.1 \text{ mg} \cdot \text{kg}^{-1}$ intubating dose of vecuronium was $98.5 \pm$

TABLE I Vecuronium requirements for maintenance of muscular relaxation by continuous intravenous infusion

Authors	Number of patients	Dose ($\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)		Anaesthesia
		Mean $\pm$ SEM	Range	
Agoston <i>et al.</i> ¹	9	0.91 ± 0.16	0.18–1.42	Balanced
d'Hollander <i>et al.</i> ^{2*}				
Age (years) < 40	8	1.13 ± 0.18	—	Balanced
40–60	8	1.09 ± 0.13	—	Balanced
> 60	8	0.72 ± 0.09	—	Balanced
d'Hollander <i>et al.</i> ^{3*}	20	0.55 ± 0.09	0.10–1.12	Balanced
Noelde <i>et al.</i> ⁴	12	1.25	—	Balanced
Mirakhor <i>et al.</i> ⁵	10	1.38 ± 0.11	—	Balanced
d'Hollander <i>et al.</i> ⁶	15	1.13 ± 0.11	—	Balanced
Swen <i>et al.</i> ⁷	6	1.25 ± 0.11	—	Balanced
	6	0.79 ± 0.07	—	Halothane
Østergaard ⁸	15	1.67	—	Balanced
de Vries <i>et al.</i> ⁹	28	1.10	0.80–1.50	Balanced
Hyman <i>et al.</i> [†]	30	1.17 ± 0.10	0.48–2.50	Balanced
Cannon <i>et al.</i> ¹⁰	5	1.04 ± 0.22	0.50–1.75	Balanced
	6	0.34 ± 0.06	0.10–0.50	Enflurane
	6	0.26 ± 0.04	0.10–0.40	Isflurane

*In the studies of d'Hollander *et al.*^{3,5,6} the vecuronium requirements at equilibrium were expressed in $\mu\text{g}\cdot\text{m}^{-2}\cdot 10\text{ min}^{-1}$. These values were converted to $\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ assuming that the body surface area of an average 70 kg subject is 1.7 m².

†Scientific Exhibit at the 1986 Annual Meeting of the ASA, Las Vegas, Nevada, October 17–21.

0.4 per cent and that it developed in 2.8 ± 0.2 min. Based on the observation of the Myoscan the maximal effect (no visible response to stimulation) also developed in 2.8 ± 0.2 min. Intubation time based on the observation of the Myoscan was 2.0 ± 0.1 min. If patients would have been intubated when T₁ on the MMG indicated 80 per cent NM block the intubation time would have been 1.6 ± 0.1 min. The clinical duration of the $0.1\text{ mg}\cdot\text{kg}^{-1}$ vecuronium assessed from the observation of the Myoscan (T₁ elicited a distinct, T₂ a barely visible response) was 41.3 ± 2.0 min. At this time the MMG indicated that the force of contraction of the adductor pollicis returned to 15.3 ± 1.2 per cent of control. Muscular relaxation was satisfactory when only T₁ of TOF stimuli elicited a response. The mean ($\pm$ SEM) duration of infusion was 76.2 ± 14.0 (12.0 to 352.0) min and its rate was 0.90 ± 0.05 (0.38 to 1.50) $\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

After discontinuation of the infusion MMG indicated that the force of contraction recovered spontaneously to 25 per cent of control in 11.9 ± 1.4 min ($n = 25$) and the recovery rate (from 25 per cent to 75 per cent of control) was 14.7 ± 2.0 ($n = 7$). The residual NM block could be reversed by $0.1\text{ mg}\cdot\text{kg}^{-1}$ pyridostigmine. The recovery of NM transmission, as indicated by the T₄/T₁ ratios on the MMG, was more complete and developed more quickly when the T₄/T₁ ratio before the administration of the antagonist was > 0.2 (Table II).

No cardiovascular or other side effects, attributable to vecuronium, were observed in either group.

Discussion

The findings of this study indicate that after the administration of an $0.1\text{ mg}\cdot\text{kg}^{-1}$ initial dose, satisfactory muscular relaxation can be maintained by the continuous IV infusion of about $0.9\text{ mg}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ vecuronium. To achieve rapidly the 85 to 95 per cent steady state NM block of the adductor pollicis necessary for surgical relaxation the infusion of vecuronium should be started as soon as the NM effect of its initial dose starts to wear off. In agreement with the findings of other investigators^{1–10} there

TABLE II The relationship between the T₄/T₁ ratio before reversal and the effect of pyridostigmine

Before reversal	T ₄ /T ₁ ratio Min after administration of antagonist*		
	2	5	8
<0.2 (12)	$0.31 \pm 0.05^{\dagger}$	0.53 ± 0.05	0.65 ± 0.06
>0.2 (15)	0.62 ± 0.05	0.76 ± 0.05	0.82 ± 0.02

* $0.1\text{ mg}\cdot\text{kg}^{-1}$ pyridostigmine and $0.008\text{ mg}\cdot\text{kg}^{-1}$ atropine.

†All values are means $\pm$ SEM of number of observations indicated in parenthesis.

TABLE III Simultaneous monitoring of the continuous infusion of vecuronium with myoscan and MMG

Time of observation	Observations made with the Myoscan	Data recorded on the MMG	
		T_1 (% of Control)	T_d/T_1 Ratio
Before vecuronium	Equal response to 4 stimuli	100.0	0.9 $\pm$ 0.01
Before intubation	Only T_1 elicits response	11.2 $\pm$ 1.6	0
At development of maximal effect	No response	1.5 $\pm$ 0.4	0
After discontinuation of infusion (min)	Responses elicited by		
6.8 $\pm$ 1.1	T_1 and T_2	15.3 $\pm$ 1.2	0
12.1 $\pm$ 1.2	T_1 , T_2 and T_3	25.5 $\pm$ 2.1	0.04 $\pm$ 0.01
15.6 $\pm$ 1.3	T_1 , T_2 , T_3 and T_4	33.5 $\pm$ 2.4	0.10 $\pm$ 0.01
After clinically satisfactory reversal	Apparently equal responses to T_1 , T_2 , T_3 and T_4	>90	0.75 $\pm$ 0.05

was considerable individual variation in the $\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ vecuronium requirements. In this study the dose required varied from 0.38 to 1.5 $\mu\text{g}\cdot\text{kg}^{-1}$. In another group of 16 similarly anaesthetized patients, monitored with MMG the dose of vecuronium was 1.03 ± 0.07 (0.55 to 1.40) $\text{mg}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Unpublished Nagashima H and Foldes FF). Recovery rate of NM transmission after the discontinuation of the infusion of vecuronium (14.7 ± 2.0 min) was similar to that observed in patients in whom muscular relaxation was maintained by the injection of fractional doses (14.3 ± 1.4).¹² Recovery rates were independent of the duration of the infusion of vecuronium.

The observations summarized in Table III indicate that for clinical purposes completely satisfactory monitoring of the IV infusion of vecuronium can be achieved with the Myoscan. The trachea can be intubated when after the administration of the initial dose of vecuronium only T_1 elicits a response: the IV infusion of vecuronium should be started as soon as T_2 again elicits a response and its rate should be so regulated that only T_1 elicits a response for as long as relaxation is necessary. Residual NM block can be easily reversed, with moderate doses of anticholinesterases when T_4 also elicits a response: and reversal can be considered satisfactory when the responses to the TOF stimuli appear to be equal and similar to those observed before administration of the initial dose of vecuronium.

In conclusion, satisfactory muscular relaxation could be maintained with the continuous infusion of 0.38 to 1.50 (0.90 ± 0.05) $\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ vecuronium. Spontaneous recovery after discontinuation of the infusion was not influenced by the duration of infusion and was just as rapid as when vecuronium was administered in divided doses.¹² If necessary residual NM block could be reversed by moderate doses of pyridostigmine. Because of the individual variation in the potency and duration of action of vecuronium NM block should be continuously monitored during the infusion of vecuronium. Satisfactory

monitoring can be accomplished by a simple, inexpensive, easily applicable device, the Myoscan.

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Résumé

On observe des variations individuelles considérables dans la dose de vécuronium requise pour le maintien du relâchement musculaire. Afin de fournir un relâchement ininterrompu sans surdosage il est à conseiller d'ajuster le débit de perfusion de vécuronium se basant sur une surveillance appropriée. La surveillance avec la mécanomyographie (MMG) ou l'électromyographie demande un équipement coûteux et serait trop complexe pour une utilisation clinique de routine. La seule observation de la contraction du muscle adducteur du pouce contre aucune résistance n'est pas appropriée pour une évaluation fiable du degré du bloc neuromusculaire (NM). Pour des fins cliniques une surveillance satisfaisante peut être acquise avec un appareil simple (myoscan) qu'on décrit. La fiabilité du myoscan a été vérifiée chez 30 patients avec une surveillance simultanée de la force de contraction du muscle adducteur du pouce avec le myoscan d'un côté et du côté contralatéral avec le MMG. Une analyse rétrospective du MMG nous a indiqué que la conduite anesthésique aurait été pratiquement la même si on s'était basé sur la surveillance du MMG.